The University of New South Wales
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Contradictions Within Traffic Engineering: The Consequences of Induced Demand

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August 2023

Abstract

Induced demand has long been the traffic engineer's nightmare. The temporary relief from congestion is quickly exhausted and travel times return to previous levels, if not higher. There has been little deviation from this trend within many Western countries, highlighting an underlying problem with the field of traffic engineering. Following this pattern, the proposed Beaches Link Tunnel aims to ease congestion for residents of the Northern Beaches by bypassing the Spit Bridge corridor. Through a simulation-based project on Aimsun Next, some of the factors that contribute to this pattern were identified. Using the data sourced from the Beaches Link Environmental Impact Statement, a deeper look into the forecasting process was achieved. As predicted, the model produced outcomes that show worsening traffic conditions: average speed decreased, and delays increased. The findings of the EIS were not too dissimilar, with localised delays occurring after the implementation of the Beaches Link. The effect of the new tunnel was to induce demand along the M1 and the Eastbound approaches of Military Rd. The solution proposed by engineers to this problem was yet another expansion project, namely, the Western Harbour Tunnel - a project which the firm writing the report had a vested interest in proceeding. Distributing traffic throughout the entire network cannot solve the issue - it only sows the seeds for more traffic in the future. However, it is precisely the tools of the traffic engineer that enable this 'endless expansion' mindset. Traffic engineers need to understand the wider social implications of their methods and base assumptions.

Keywords: Induced demand, traffic, infrastructure, methodologies, Beaches Link

Acknowledgements

I could not have undertaken this journey without the support of Thomas Gojak. He has helped the writing of this report in innumerable ways, from advice regarding my ideas for this thesis to assisting in proofreading and editing the grammar. His ever-present kindness and wisdom encouraged me to undertake such a monumental task.

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Abbreviations

Acronym	Definition
CBD	Central Business District
EIS	Environmental Impact Statement
LoS	Level of Service
M1	M1 Motorway, alternate name for Warringah freeway
NSW	New South Wales
OD matrix	Origin-Destination Matrix
PWC	Public Works Committee
SCATS	Sydney Coordinated Adaptive Traffic System
TfNSW	Transport for New South Wales
veh	Vehicles

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1.0 Introduction

Despite promises to solve congestion, the conventional response to add another lane has only further entrenched the dynamics that worsen traffic. The Beaches Link Tunnel was announced in 2017 by the Berejiklian government as a measure for combating "one of the busiest roadways in NSW" (TfNSW 2020). The government claims to achieve this constructing a new tunnel connecting the Warringah freeway and the Burnt Bridge Creek Deviation as seen in figure 1.0.1. However, when looking back at comparable infrastructure projects, a clear pattern emerges. The travel saving brought by capacity expansions are quickly exhausted as traffic regresses to previous levels. This can largely be attributed to the concept of induced demand.

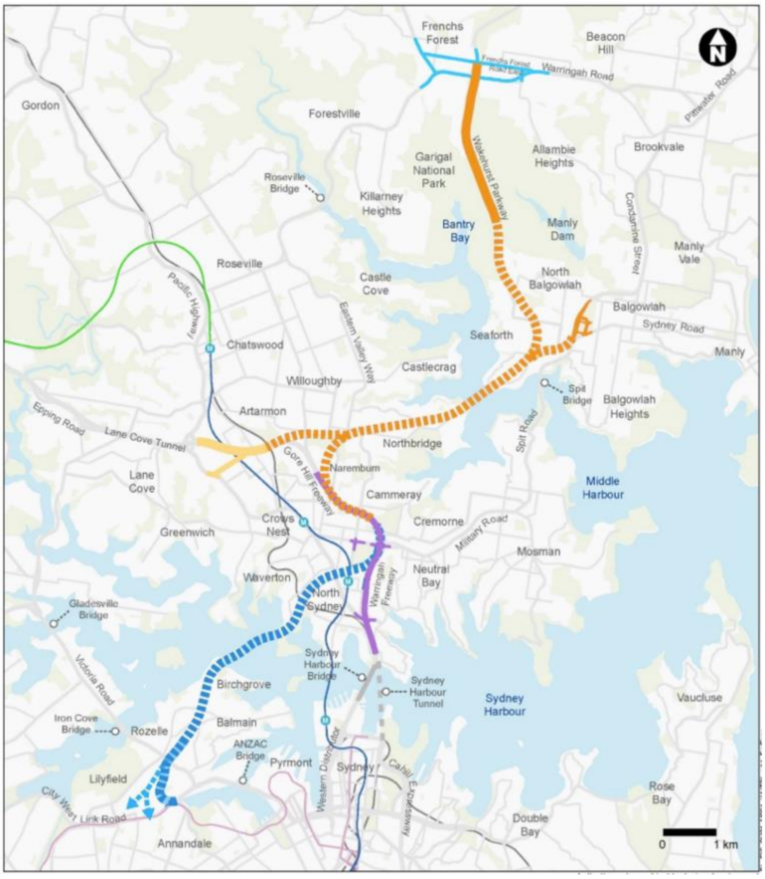

Figure 1.0.1 Proposed Beaches Link tunnel route (TfNSW 2020)

Large infrastructure comes at a great expense to the public. Therefore, these projects deserve a critical lens. As outlined in the report by the PWC, many residents are sceptical of the claims made by project officials. One key concern raised was the problem of induced demand (Mookhey 2022). This thesis aims to highlight the critical flaws and blind spots in the conventional methodologies used by traffic engineers to justify these large infrastructure projects.

A literature review was conducted to understand the scope of the current available research. From this, the gaps between the literature and the application of engineering principles were found and the research objective of this report was established. A simulation-based project that studies this gap was then developed and conducted. The discussion of the results then follows, where the key findings from the research are illuminated. The Beaches Link case study provides some insight into the factors that influence the choices traffic engineers make during the design and forecasting process. Focus will be put on the traffic engineering aspect of this project, particularly on the handling of travel demand. This was achieved by analysing the effects of the proposed tunnel on the current road network using traffic simulation software.

2.0 Literature Review

2.1 Induced Demand

Induced demand has been oft overlooked by engineers when designing road infrastructure. From the earliest scholars of modern traffic engineering (See Appendix A), the addition of capacity in the network has been observed to increase the level of overall traffic. Duranton and Turner (2011) extensively highlight this fact within the US metropolitan context. The proportional increase in Vehicle-Kilometres travelled to lane kilometres was found to be largely due to increased travel from current users of the road. While this paper focused particularly on inter-urban highways, case-studies have been conducted within urban areas with similar results (Bucsky & Juhász 2022). The 55-year dataset for traffic within Budapest further highlights the long-term effects of induced demand. Furthermore, the observation of the inverse effect from reduced lane capacity underlines the mechanisms which dictate demand. This directly highlights a flaw in the methodology of the Beaches Link project, where traffic demand was measured to assess network performance and the viability of the project. As demand is easily alterable in many ways, including reducing capacity, this metric is wholly unsuitable for viability assessment.

While there is consensus regarding the existence of the phenomena, arguments regarding the extent of its effect have been raised. For instance, Van Der Loop et al. (2016) found that the majority of the induced demand was a result of changes from alternative routes and departure times rather than the generation of new trips. This hews more closely to the "triple convergence" model (Downs 2004); which focuses on spatial, time and modal convergence. The small effect of induced demand in this study may be due to the unique modal splits of the study location (Winter et al. 2020), where there is strong incentive for alternative transport modes. The economic arguments for capacity expansions were also lightly explored in the paper. However, other works have pointed out flaws in the methodology of saved time calculations (Marohn 2020, p.67-69; Marohn 2021, p.129-132). The findings of Metz (2008) raises further questions regarding the economic foundations of traffic engineering. In the long-term, travel time is not saved and is instead conserved, supporting the findings of Duranton & Turner (2011).

Significant changes to land use can also be observed from modifications to the transport network (Antoniou et al. 2011). The addition of roadway capacity contributed to densification along the corridor as access was made easier. This follows the findings of Metz (2008), outlining how an increase in lane kilometres can lead to the conservation of travel time as urban development sprawls. While there is considerable depth in the research of induced demand, it is consistently overlooked in the application of engineering principles, resulting in chronically poor demand forecasting.

2.2 Forecasting

Induced traffic has been linked as a factor causing bad demand forecasting. As mentioned previously, this can be partly explained by the change in the land-use induced by freeway expansion (Antoniou et al. 2011). The systemic overestimation of benefits can have major consequences as policy makers are influenced by the results produced by engineers. As cost-benefit analyses require accurate forecasting data, the use of imprecise and unpredictable data regarding the specific elasticity of demand and capacity puts doubt to the accuracy of the results (Næss et al. 2012). Furthermore, sparse ex-post evaluations that ensure the project met the estimates, means little progress has been made in forecasting methodologies. This phenomena has been extensively researched with the accuracy of forecasts remaining stagnant within a 30-year period (Flyvbjerg et al. 2005). The Beaches Link project exemplifies many of the factors that influence the push for large infrastructure projects. Concerns of a conflict of interest was noted (Mookhey 2022, p.22) as private firms were contracted to both advise the planning of the project as well as to then assist in the construction phase. Electoral interests are also present with the project being announced months prior to a by-election (Winestock 2017). The use of flawed methodologies (Næss & Strand 2012) to compare various scenarios (Transport for NSW 2020, p.9-10) further underline the project's ill-considered momentum. However, at the crux of infrastructure projects and urbanism is the "creation, appropriation and circulation of surplus value" (Harvey 1988, p.231). The M-C-M' model (Marx 1867) manifests itself in the Beaches Link. This highlights the perpetual loop, where capital incentives constantly push for the green lighting of large infrastructure projects, irrespective of critical flaws in the methodology used.

The four-step model is widely used due to its conceptual simplicity in understanding and ease of modelling in software (ATAP 2016). While the flaws have been extensively outlined, the application of various findings in research has had little progress due to cost and complexity limitations. Cheaper alternatives such as the expansion of the four-step model have been suggested (Antoniou et al. 2011; Zhang et al. 2019). However, more radical approaches such as Activity-based modelling (ABM) and Land Use Traffic Interaction (LUTI) models have also been explored.

ABM attempts to incorporate the "complex constraints" and interrelationships inherent in human decision making (ATAP 2016). By accounting for the reasoning behind decision choices, the model is better able to reflect the choice patterns of real-life, resulting in more accurate forecasting (Arentze et al. 2000). However, this comes at a major disadvantage. The perceived increase in complexity brought on by its microscopic lens, combined with the scarcity of off-the shelf software capable of this type of modelling, explains its underuse in Australia. Following the findings of Antoniou et al. (2011), land-use and transportation are inextricably linked. As land-value increases due to easier accessibility, land-use is increasingly determined by its market value (Harvey 1988, p.187-190), fuelled by “speculation and artificially induced scarcities”. The dynamic LUTI model aims to model this behaviour. By using separate models for land-use and transportation, the interactions of the two fields can be employed for better forecasting (ATAP 2016, p.33).

2.3 Car-Dependency

Car-dependency is a self-perpetuating cycle. As more car infrastructure is built, travelling by car becomes easier, and thus more inevitable. However, this induces more car travel, consequently requiring more car infrastructure. The effect on land-use is also significant. As more people rely on cars to travel, more space is required to store these cars. Valuable land is then converted into parking lots, spreading shops and residences apart. The increasing physical distance between locations precludes the viability of other modes of transport. The hostility of car infrastructure bars pedestrians and cyclists from the streets as cars pose a threat to safety (Speck 2013). Public transport also suffers, as the de-densification of the local area negatively impacts the service quality of transit systems.

On an individual level, health outcomes are seriously affected due to the promotion of a sedentary lifestyle enabled by car use (Ding et al. 2014). CO_2 emissions from internal combustion engines also cause the worsening of local air quality, leading to worse health outcomes, as well as contribute to the degradation of the global environment. Furthermore, car-dependency disproportionately affects lower income residents (Vermesch et al. 2021, Mattioli 2017). The long commutes further exacerbate the gap of health outcomes between high and low-income classes (Kent et al. 2019). Yet, this “zombie automobility” (Jones & McCreary 2022) continues as policy makers and traffic engineers blindly accept the superiority of cars.

Therefore, advocacy for environmental, social, and economic justice, and the battle against traffic congestion have a common adversary. Especially when considering average vehicle occupancy is 1.09-1.2 (Mannering & Washburn 2013, p.4; chrisloader 2017). Large modal shifts can act as a ‘first aid’ response to the current climate crisis (Müller & Reutter 2022). However, little consideration was made for a public transport alternative (Mookhey 2022, p.28). In the proposal for the project, access to the tunnel was the only provision for the public transport network. However, as the Downs-Thompson paradox (Marcucci & Danielis 2000) suggests, buses mixed in with general traffic is not meaningful public transit. If buses get stuck in the same traffic as general private vehicles, then there are very few benefits gained from riding public buses. The project also touts the supposed benefits for cyclists and pedestrians. Active modes of transport play a crucial role in improving health outcomes (Merom et al. 2018, Heinen et al. 2015) as well as in easing congestion. As mentioned previously, car infrastructure is antithetical to the promotion of active modes of transport. One key argument made in the EIS for how the project is in line with "Sydney's cycling future" (TfNSW 2013) is that surface road congestion is reduced (TfNSW 2020). However, the major barrier to the adoption of cycling is safety (Parkin et al. 2007, Noland 1995).

2.4 Summary

It is clear from the research that transport engineers constantly underestimate, whether unintentionally or willingly, the effect of induced demand. This bias consistently encourages law makers to consider large infrastructure projects. The economic incentive within a capitalist system poses a great challenge in preventing this behaviour. However, even excluding this hurdle, the principles of traffic engineering have fundamental flaws. The commonly used four-step model has systematically undervalued demand induced by capacity expansions. Alternative methods, such as the ABM or LUTI model that account for human decision making, have been researched, cost and complexity considerations have prevented widespread adoption. Transport infrastructure is couched within the wider context of the urban environment, affecting more than just decisions regarding travel choice. Given these contradictions within transport engineering, an inter-disciplinary approach is necessary to fully engage in these problems. Further examinations of their claims regarding travel savings in the transport network are warranted.

3.0 Research Objective

From the literature review, it is evident that there is a gap between the research findings and the actions of professional engineers. Traffic engineers have continued to recommend capacity expansions of the road network as a solution to congestion. This underlines how conventional methodologies are critically flawed. A closer inspection of the design process is needed to understand why the motives of the field engineer and the findings of research never seem to converge. The Beaches Link Tunnel can be used as a case study. Following the current accepted process and analysing the various outputs should give an insight into this gap. Comparing the results obtained from a model simulation with the forecasts claimed in the EIS for the Beaches Link may be fruitful in understanding the inner workings of traffic engineering. Additionally, these large infrastructure projects are ostensibly undertaken for the benefit of the surrounding community. Yet, the residents seem to be vigorously opposed to this project. Attention should be paid to this, so further research into their concerns is warranted.

4.0 Methodology

Traffic modelling can be split into two main phases. The first phase involves the development of the base model, where the physical road network is translated into a simplified model. The coding of road geometry, transit lines and traffic signals are crucial in ensuring the model accurately replicate the actual conditions. Translating traffic data into useful trip statistics within the system is also necessary. The second phase is conducted through scenario analyses. The potential impact of a change to the system can be simulated to determine whether the project is viable or not.

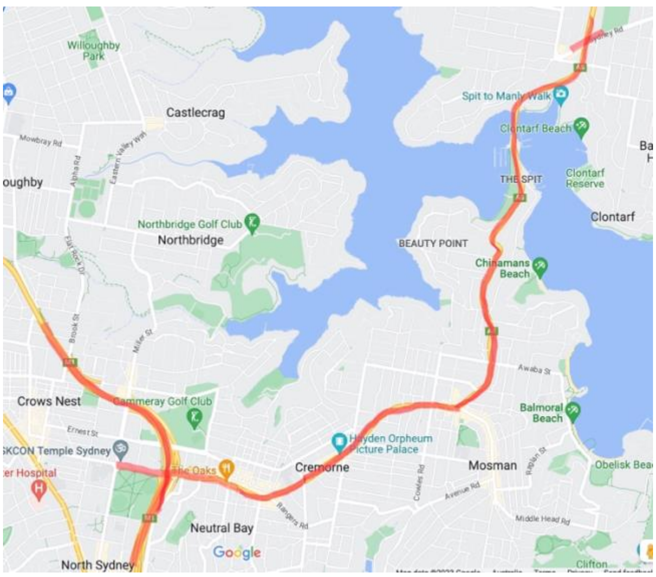

Figure 4.0.1 Google Maps image of North Sydney, study area highlighted (Google 2023)

Focus was put on the Spit Road and Military Road corridor, which acts as the main access point for the Northern Beaches. The connection of this corridor to the Warringah Freeway, which connects Northern Sydney to the CBD (figure 4.0.1), was also of importance. Since traffic congestion is consistently highest during the morning peak hour, focus was on the period between 7 and 9 AM on a typical weekday. Traffic modelling software, Aimsun Next, was used to model this area. Aimsun was chosen as it is widely used within the profession. This is due to its ability to simulate traffic at various scales, from micro simulations of individual intersections to macro analysis of whole transportation networks. This versatility gives engineers a powerful tool that helps to predict the outcomes of their proposed project.

For this project a base model of the current road network was constructed, and simulations were conducted to validate that the model replicated the actual roadways. These simulations have a duration of one hour, reflecting the data gathered for this project. The new Beaches Link tunnel is then added to the model and simulation of the impact of this change can then be ascertained. The simulation process is split into two scenarios, the ‘do minimum’ and ‘do something’ scenarios. The ‘do minimum’ scenario represents the situation where the Beaches Link is not constructed, while the ‘do something’ scenario denotes the situation where the Beaches Link is constructed. In addition, the scenarios were tested at two different time periods, initially in 2027 when the project was expected to be completed, and then 10 years later to assess the impact the changes would have on a wider temporal scale. Traffic engineers can then predict the likely effect of each outcome on the wider road network.

4.1 Data Sources

The main source of data and information used for modelling was sourced from the technical working paper, prepared by the Jacobs Group, attached as an Appendix to the project’s EIS. Information regarding the alignment and lane geometry of the Beaches Link as well as public transport and demand data were all detailed in this report. Traffic data was also sourced from the ‘Traffic Volume Viewer’ website managed by Transport for NSW. This resource compiles various sources of volume counts for the NSW road network. Satellite images from Google Maps were also crucial in the modelling process, providing useful information regarding lane geometry, topography, and street layout of the study area. Google Maps and the 'TripView' application were also used occasionally to find data regarding the scheduling of bus lines. Finally, a site visit of Military Road on the 16^{th} of July 2023 was used to check the physical accuracy of the model as well as for gathering signalling data.

As the original base model was developed and modelling the network in 2016, some inaccuracies may arise due to the sources used in this report. This problem is particularly prevalent in the timetables for the buses, as little data was available online regarding historic scheduling. This problem was confounded by the impermanence of various bus routes, with many lines being altered or removed/added between 2016 and 2023. Similarly, inaccuracies of temporal origin may be present in the signal phase data. As SCATS data was not available, the actual plan for the signals in the area could not be implemented. If a 'green wave' strategy was adopted in this area, it was not reflected in the model.

4.2 Modelling

To start the modelling sequence, a rudimentary road network was coded. This involved laying out the rough paths of the two main roadways studied, the Warringah freeway, a 10-lane highway (see figure B1), and Military Road/Spit Road, which is 3 lanes each way (see figure B2). The signalised intersections were then coded in. Although there were plenty of non-signalised intersections, these connections were not included in the model as many of them would have insignificant effect on traffic movement. Traffic that would otherwise have used these connections were re-routed to the nearest intersection for this simplified model. A list of the intersections and their locations is summarised in table B1.

Lane Geometry

The tools and resources on the Google Maps website were heavily used in adjusting the geometry of roads. Warringah freeway was found to be 3.00m wide, while the Military Rd corridor was 2.7m wide. The M1 had speed limits of 80km/h and Military Rd was consistently 60km/h. It was also noted that the leftmost lane along the Westbound section of Military Rd was a bus lane. Google Maps data was again used to find the elevations of each section of the road. The Neutral Bay and Cremorne area sit on top of a ridge, thus elevations of 80-90m were observed around this area. As Spit Rd approaches the Spit Bridge, elevation quickly drops down back to near sea level. The M1 is also on an uphill slope heading North from the Harbour bridge until the overpass, where elevation once again starts decreasing slightly. As mentioned previously, the site visit on the 16th of July was used to confirm the accuracy of the data from Google Maps.

Centroids

Centroids are used to represent the origins and destinations for trips. Within the model, trips will be generated from one centroid to another centroid. By representing a large area as a centroid, the complex road network and built environment can be simplified, leaving only the major components of the network. This cuts down on computational power as well as manual coding time. As seen in figure 4.2.1, the small circles represent these centroids. A total of 14 centroids were used, with each numbered centroid roughly covering one suburban area. The key for the suburbs can be found in Table B2.

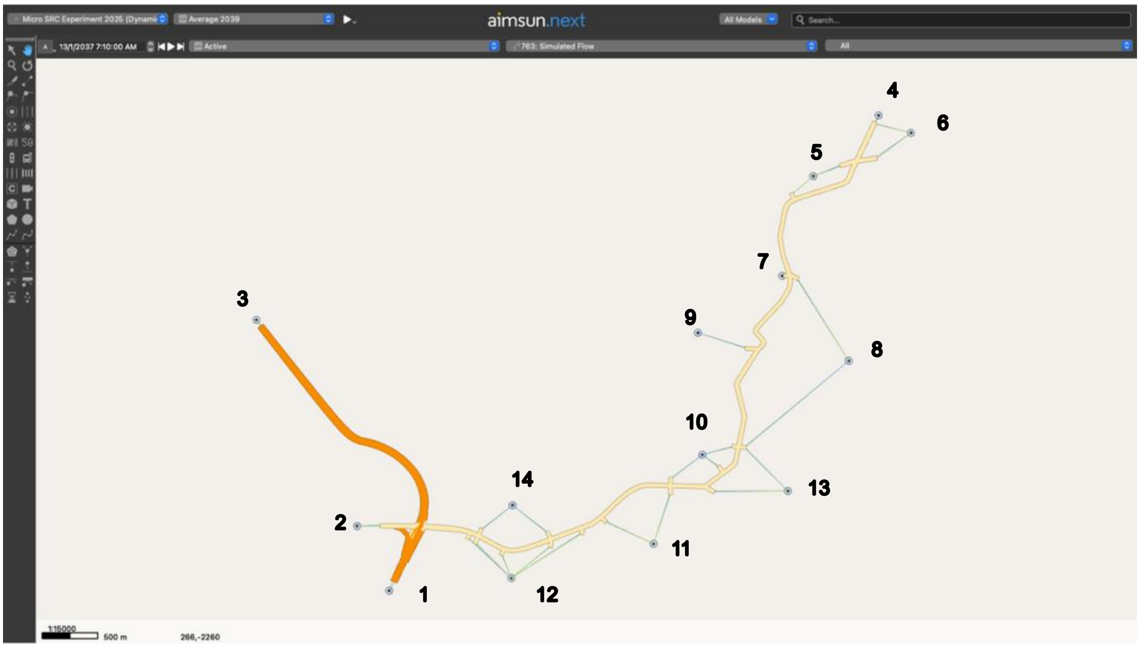

Figure 4.2.1 The Base Model

Transit lines

The inclusion of transit lines is key in the model building process. The large frame and frequent stopping of buses can be a source of congestion as flow is impeded when the bus stops for passengers. However, this effect may be diminished with the use of a dedicated bus lane, as employed for a portion of the Southbound leg of Military Rd. Table B3 summarises the various bus routes that ran along Military Rd. The frequency of these buses was calculated by analysing the timetables for these routes and averaged across the bus lines that shared the same routes and stops within the study area. It was noted that there was a large imbalance in the directionality of the buses, with the overwhelming majority going Southbound.

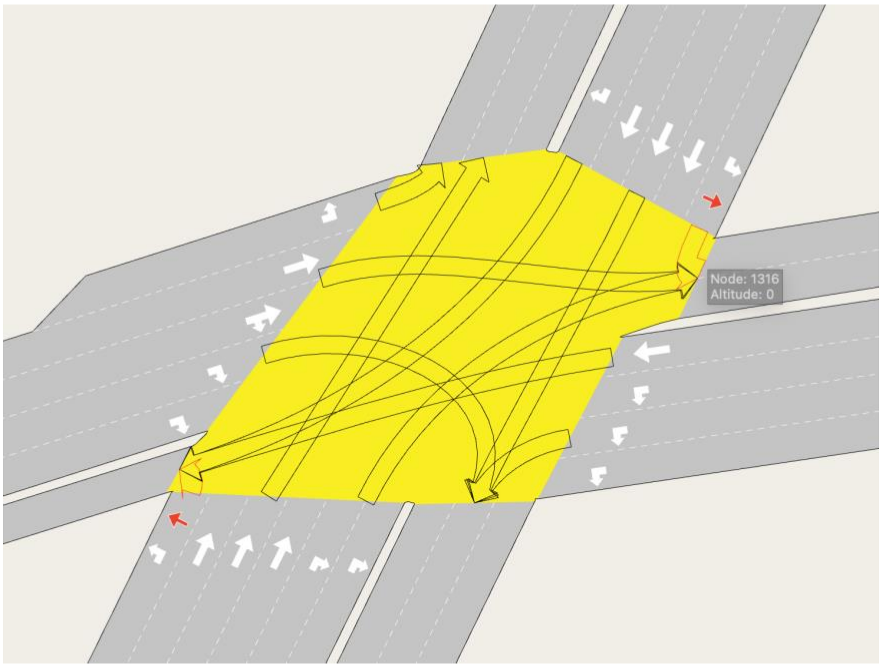

Figure 4.2.2 Manly Rd/Sydney Rd intersection

Signal Phasing

Traffic signals constitute another major component of the model. The lane disciplines were first coded for each intersection, defining the allowed movements for each approaching lane. Figure 4.2.2 shows an example of the various movements that need to be coded for each intersection. As these intersections are signalised, it is important to ensure that vehicles do not queue across the intersection. This may cause gridlock to form in the model, preventing any flow of traffic with no way of fixing this problem. The yellow box option was selected for the intersections where queuing would cause problems. The timing of signals was a key challenge. As mentioned previously, SCATS data was not available. Thus, the observations made during the site visit were used as the basis of signal timings (see figure B3). A fixed cycle was used as no significant changes to timings would have occurred due to the high volumes during peak hour.

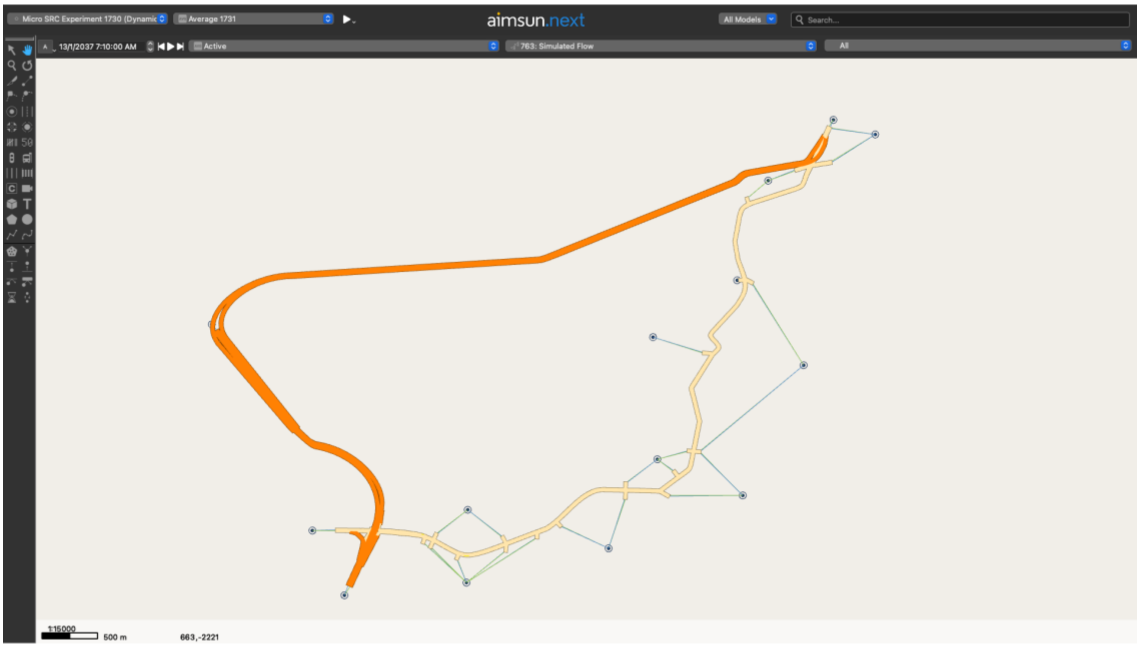

Figure 4.2.3 Beaches Link Model

Beaches Link

A duplicate of the base model was created, then altered, adding in the planned route of the Beaches Link. The alignment follows the indicative route shown in figure 1.1. Figure 4.2.3 shows the new model with the Beaches link tunnel added. This coded tunnel was 7.2km long, only 300m short of the proposed tunnel (TfNSW 2020), indicating that the geography of the base model was fairly accurate. The tunnel is three 3.00m lanes wide. Additional connections to Warringah freeway and Manly Rd were added at each end and can be seen in figures B4 and B5. As topography data was not available, an approximation of the slope was used to simulate the rough shape of the tunnel. This may also be a source of discrepancy between the proposed lengths and simulated lengths.

Table 4.2.1 Traffic Volumes (Jacobs Group 2020)

Road	Direction	Volume (veh)
Spit Rd South of Parriwi Rd	Northbound	1280
	Southbound	2780
Sydney Rd East of Manly Rd	Northbound	460
	Southbound	940
Burnt Bridge Creek West of Condamine St	Northbound	970
	Southbound	1350
Falcon St West of Merlin St	Eastbound	2330
	Westbound	3140
Falcon St East of Miller St	Eastbound	1250
	Westbound	1170

Demand Data

The traffic counts during the morning peak hour from the Jacobs report were used as the basis for the demand data. An Origin-Destination matrix, which dictates traffic demand from centroid to centroid, can then be formed. This involves meticulously translating the data points provided into the centroid format, carefully balancing the counts from each origin and destination pair. The results of this process for the base model can be seen in table B4 and table B5. Heavy vehicle counts were calculated as a percentage of car traffic and the figure of 8% was the average proportion from the Jacobs paper.

OD matrices for the 'do minimum' and 'do something' scenarios also need to be calculated. This was achieved by extrapolating from the data in table 4.2.2, using the expected percentage increases in traffic. The OD matrices for the various scenarios have been summarised in tables B6 to B15.

Table 4.2.2 Expected increase in total traffic demand (Jacobs Group 2020)

	Warringah	**Balgowlah**
2016 model	96,700	16,800
2027 'do minimum'	104,500	17,400
2027 'do something'	105,900	19,900
2037 'do minimum'	112,400	19,200
2037 'do something'	115,500	21,800
Increase '27 do min.	8.07%	3.57%
Increase '27 do some.	9.51%	18.45%
Increase '37 do min.	16.24%	14.29%
Increase '37 do some.	18.92%	28.76%

4.3 Simulation Testing

Dynamic scenario simulations were then conducted. This one-hour simulation has a 30-minute warm up period, where some traffic is generated so that the network does not start completely empty. Some small adjustments were made to the dynamic assignment of paths, as some nodes were not fully utilised. Origin percentages were therefore changed to ensure that each node would generate a realistic amount of traffic. As traffic behaves in a stochastic nature, numerous replications need to be conducted, where an average of the statistics can be gathered for analysis. Random 'seed' values are used for a variety of parameters that slightly alter the output of a simulation. 10 replications using the seeds provided in the traffic modelling guidelines (see table B14) were performed. With each run taking roughly 40-50 seconds, a batch run for a scenario took almost 10 minutes. In total, 5 different sets of simulations were run with the various seeds.

5.0 Results

Figure 5.0.1. Simulation: Traffic on Military Rd

Upon visual examination of the model during simulations, congestion along the main corridor was clear. Figure 5.0.1 highlights that there was a bottleneck just before the Military Rd-Spit Rd Y-intersection. This corresponds to the location where the left lane becomes a bus lane, effectively cutting capacity by 33%. This trend did not change in any scenario and would result in long queues forming past the Spit Bridge on occasion. Another exacerbating factor was the traffic signals. The large number of stops within this section of roadway meant that cars could not flow smoothly at a relatively constant speed. This observation was in line with the arguments set forth in the Jacobs paper, noting that the Beaches Link could cut the number of stops. The claims are backed up by the data (see table C1), showing that the number of stops were cut dramatically after adding the Beaches Link. However, upon closer inspection, the time that cars were stopped had increased, having only increased by 12.9 seconds per kilometre without the intervention and 36.2 with the Beaches Link (table C2). This may partly be explained by the new bottleneck occurring at the Warringah Freeway off-ramp as seen in figure 5.0.2. Even with a one-lane expansion, congestion was extreme, causing delays along the rightmost lanes as well.

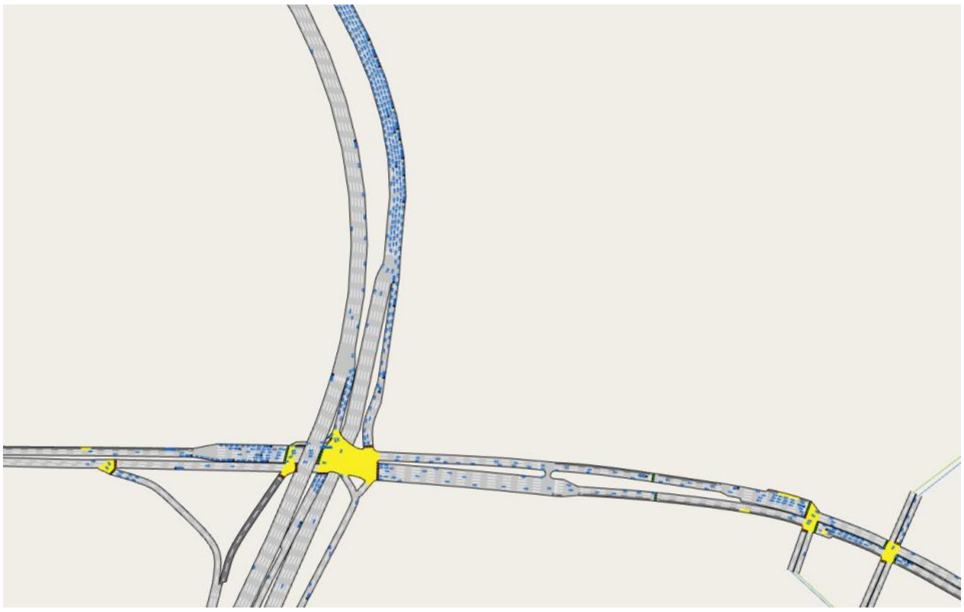

Figure 5.0.2. Simulation: New pile-up on M1 off-ramp after Beaches Link

Delay

The results for delay were summarised in table 5.0.1. While there is an across-the-board increase in delay due to the expected increase in traffic, the effects were not equal between the two scenarios. In the ‘do minimum’ scenario, an increase of 5.9% and 15.1% for the years 2027 and 2037 was registered respectively, falling in between the expected increases noted in table 4.2.2. However, the changes in delay for the ‘do something’ scenario (20.8% and 34.5%) were significantly higher than the expected increases.

Table 5.0.1 Delay results for cars

Scenario	Value (sec/km)	Standard Deviation
2016 Base	105.3	2.73
2027 ‘do minimum’	111.48	3.5
2037 ‘do minimum’	121.2	3.58
2027 ‘do something’	127.22	2.95
2037 ‘do something’	141.66	4.57

Density & Flow

Tables C3 and C4 contain the results obtained for density and flow respectively. It can be observed that there was a large drop in density for the ‘do something’ scenario in 2027. However, this improvement is short-lived, as density rises back up to 26.5 vehicles per kilometre in 2037, implying that the reprieve will only last roughly 13 years when the effects are linearly extrapolated. Similarly, flow also drops when the Beaches Link is added. This expansion has added to the total lane kilometres available, thus affecting density. Flow was increased as well due to the increase in the absolute space available for vehicles to occupy.

Speed & Queues

The data regarding speed suggest a major problem. Even with the addition of a high-speed motorway, average speeds were lower (table 5.0.2) in the ‘do something’ scenario. Similar results were found when using harmonic speed instead in table C5. Mean queues followed the same trend, worsening conditions within the system. While there was an initial relative improvement compared to the ‘do nothing’ scenario in 2027 (table C6), queues were worse by 2037.

Table 5.0.2 Average speeds for cars

Scenario	Value (km/h)	Standard Deviation
2016 Base	39.62	0.51
2027 ‘do minimum’	39.58	0.4
2037 ‘do minimum’	37.73	0.47
2027 ‘do something’	33.43	0.91
2037 ‘do something’	31.58	0.45

6.0 Discussion

6.1 Data Analysis

As seen in the gathered data, the benefits from the Beaches Link may not be as large as touted when going off the results of this experiment. However, as shown in table 4.2.2, the technical report already acknowledges that some demand will be induced. The report also acknowledges “some residual delays” in the surrounding precincts, it justifies this increase by averaging it onto the broader network level (Jacobs Group 2020, p.252). While it may improve connectivity of the system on a wider scale, the problem is much more local. Congestion is already being generated by 'local' users South of Spit Bridge. The Beaches Link may alleviate some stress on the system, but it does not address the underlying issue. The changing of scales only works to hide the true effects. With queues and delays increasing and speeds decreasing, little benefit can be seen in this project.

As mentioned in relation to figure 5.0.2, the Beaches Link had re-routed some of the traffic around the Southbound section of Military Rd, but then caused traffic at the off-ramp of the M1. This traffic is then dumped onto Military Rd, causing traffic on the Eastbound leg. While this workaround effectively acts as an increase in capacity by utilising the less used parts of the network, it comes at the expense of existing users. This only concentrates the traffic into a smaller area and spreads the impact to a wider user base. The expansion of capacity only serves to kick the can down the road. The net increase in travel demand cannot be solved within this system, as the road network is a zero-sum game. The physical limitations of space cannot keep up with the exponential increases that come about with any system expansions.

Similar effects may have been encountered in the Jacobs report as average speed decreased and the number of stops increased within the Warringah freeway area (Jacobs Group 2020, p.265). The report then states that this effect is "primarily due to the transfer of traffic demand from existing surface roads to the Beaches Link Tunnel, which would increase demand on the Sydney Harbour Tunnel" (Jacobs Group 2020, p.266). However, this argument misses the point that a large portion of the traffic that travels through the Military Rd corridor was already travelling towards the Sydney CBD. The effect of spatial convergence has thus induced demand onto the M1. Furthermore, by bypassing the arterial road with a motorway, a form of time convergence also occurs. As the traffic signals on the surface roads create 'platoons' of cars, a similar effect to ramp metering is achieved. The flow of vehicles onto the M1 is then managed. Therefore, the introduction of the Beaches Link would effectively concentrate the introduction of vehicles, causing more traffic. The can is kicked further down the road, transferring the traffic from one congested part of the network to another. As the report suggests an expansion of the network in the form of the Western Harbour Tunnel, the traffic problem is further dispersed into the wider network.

Considering that Jacobs was shortlisted as a preferred contractor to build the Western Harbour Tunnel (Rabe 2021), the conclusions of their technical paper ought to be read in light of the profits they stood to make if their proposal had been executed. Having started as a project to fix the traffic problem around the Northern Beaches, they have now 'kicked the can' all the way to the city.

6.2 Aimsun

Currently, the outcomes are path-dependent on the methodologies used. The tools used by traffic engineers have shaped the approaches employed against the problems encountered. The simplification of the real network tends to exaggerate and highlight the major problems within the system. The pileups encountered in figure 5.0.2 may not be fully reflective of real-world conditions. However, the visualisation of traffic in Aimsun does push engineers to quickly adjust the model so that the symptoms are temporarily alleviated. This underlines one issue with simulation-based analyses. While adjusting the number of lanes is easy to do in the model, the real-world implementation of this comes at great expense. The scrubbing of any local context only works to further enable simple repairs.

As noted earlier, the start-stop nature of Military Rd was cited as a key reason for the Beaches Link. Spit Junction, the area surrounding the intersection of Military Rd and Spit Rd, is a commercial area with high pedestrian activity. Currently, Spit Rd splits this area in two, creating a need for many connection points to facilitate the functioning of the precinct. While it may then be enticing to construct a bypass, the tunnel will only worsen traffic as previously noted. The animation of traffic from a top-down view certainly does not help in this regard. Modelling of Sydney's transit network is gamified, compelling engineers to embrace the various tools at their disposal within the Aimsun ecosystem. The reliance on modelling software can lead to a tendency for upholding the status quo. Combined with the sectoral unwillingness to invest and adopt newer strategies, little change will be brought about, and the same pitfalls will continue to plague Sydney's transport system.

6.3 Bias

The underlying issue here, is car dependency. This tunnel only further exacerbates this problem. The bypass overwhelmingly favours those who live farther out from the city. Alterations to the transport network will have flow-on effects on land-use. Most notably, it will enable suburbs to sprawl even further as travel is made easier. While forecasts predict a 32% increase in population for the area by 2036 (TfNSW 2020, p. E-1), it is unclear whether this growth is influenced by the addition of the Beaches Link. The self-perpetuating nature of growth in this context should cast doubt on the predicted outcomes of the model. Furthermore, by implementing a tolling scheme, the desired effects of reducing congestion on surface roads will be dampened. Tolling can be seen as a regressive tax on society, disproportionately disadvantaging lower-income groups. While it is important to ensure that large infrastructure projects are financially sustainable, toll roads should not be the solution.

Trains, Trams & Trolleybuses

A better alternative may be the introduction of a Northern Beaches train line. As seen in table B3, a large fleet of buses currently service the whole Northern Beaches area. A train line would serve the same role as a new road tunnel, yet it can provide a much larger increase to capacity while also directly addressing the underlying issue of car congestion. Re-implementing the old tram lines that were torn up (Brierley Newton 2018) in similar fashion to the General Motors Streetcar Conspiracy within the United States (Marx 2022, p.21), may supplement trains, providing transport within small to medium distances. Public transport will also affect demand levels and land-use. However, the ceiling on capacity and space restraints are much higher than car infrastructure, owing to its high efficiency in transporting people, hence it is very unlikely that induced demand problems would appear within the transport network. The effect may be dampened however, if adequate measures are not put in place to restrict car infrastructure as well. Following the idea of modal convergence, the introduction of a train line, if poorly planned, can indirectly act as an expansion of the road network.

This policy should be implemented in conjunction with changes to surface roads. Changes to land-use will also need to be considered when redesigning the roads. The introduction of a train station may induce increased commerce, as travel is made easier. Increased pedestrian activity from this change may further highlight the need to address the safety hazard cars pose to other road users. Thus, various policies, such as lane reductions may also help in improving safety and attractiveness for business. The Dutch concept of ‘ontvlechten’ follows a similar concept where there is a concerted effort in separating transport infrastructure. Practices, such as filtered permeability provide the physical barrier necessary for impeding and consequently reducing the flow of private vehicles (*The Bike Lanes You Can’t See - Ontvlechten* 2020, Kuik et al. 2013). Without these measures, the full benefits of transit cannot be realised and there will be little change to the status quo.

Metrics

The metrics used by traffic engineers portray an underlying bias. Measurements, such as Level of Service, are taken from the perspective of the driver (Marohn 2021, p.50-52). Grading streets based on flow once again scrubs any local context from the equation, while also ignoring the opinions of other road users. This metric can be useful in automobile exclusive sections, but they are routinely used in mixed-use environments. Intersections along Military Rd were analysed using LoS to justify the construction of the Beaches Link (Jacobs Group 2020). Total delay also has a similar problem. There is an underlying assumption within this metric, that delay has a compounding form which is detrimental to the system. However, this cannot be well translated onto collective means of transport as delay is closer to having a concurrent relationship. The biases present within the field of traffic engineering have helped to create the problems of today and impede the path towards the solution.

7.0 Conclusion

Throughout this thesis, the concept of induced demand and its impact on the transport network has been central. A model of the Northern Beaches area was initially created within the traffic simulation software, Aimsun Next. Simulation runs were conducted, comparing the effect the Beaches Link Tunnel had on traffic levels. The study was repeated for a later period to measure its longitudinal effects. Induced demand could be evident within the model, shown in the various results presented. Delays increased, particularly along the Eastbound section of Military Rd, as vehicles from the Northern Beaches bypassed Spit Rd and looped around to enter the system from the other direction. This influx of traffic also caused problems on the M1, as the off-ramp did not have sufficient capacity.

Spatial and time convergence had worsened the flow along the Warringah Freeway. However, the presence of induced demand was not a surprise, with the Jacobs report itself predicting a disproportionate increase in traffic demand themselves. The results from the simulations carried out from this report may not be conclusive. There were many areas where refinements of the details could have been made. Nevertheless, the results did mirror the findings of the Jacobs paper, and the cancelling of the project (O'Sullivan 2023) suggests that there were problems about its fundamental promises.

The ignorance displayed by the engineers that worked on the EIS is clear. Yet it comes as no surprise when considering the historical context of traffic engineering. Engineers may be caught up in the sheer momentum of car culture, knowing no alternative as public transit falters within suburban sprawl and hostile drivers scare potential cyclists. Traffic engineers have been blind to the social consequences of their actions, de-densifying neighbourhoods, and decimating communities. However, the role of capital should not be ignored, as the profit motive is ever-present within a capitalist system. More specifically, if a private corporation can employ the academic authority of traffic engineering to justify their own profit-driven proposal - a proposal that will only worsen traffic conditions - this should seriously call into question the methodological soundness of the discipline itself.

If all you have is a hammer, then everything begins to look like a nail. The tools available to engineers enable the perpetuation of capacity expansions and the subsequent increase in traffic demand. Analysis into the applicability and current widespread use of car-centric metrics may be a productive avenue of research. If meaningful change is to occur, then an inter-disciplinary approach that takes stock of the social and geographic context is necessary.

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Appendix A

Excerpt from The Power Broker outlining the earliest understanding of "traffic generation" (induced demand)

> …a few planners had even begun to understand that, without a balanced system, roads not only would not alleviate transportation congestion but would aggravate it. Watching Moses open the Triborough Bridge to ease congestion on the Queensborough Bridge, open the Bronx-Whitestone Bridge to ease congestion on the Triborough Bridge and then watching traffic counts on all three bridges mount until all three were as congested as one had been before, planners could hardly avoid the conclusion that "traffic generation" was no longer a theory but a proven fact: the more highways were built to alleviate congestion, the more automobiles would pour onto them and congest them and thus force the building of more highways-which would generate more traffic and become congested in their turn in an inexorably widening spiral that contained the most awesome implications for the future of New York and of all urban areas.

(Caro 1975)

Appendix B

The modelling process

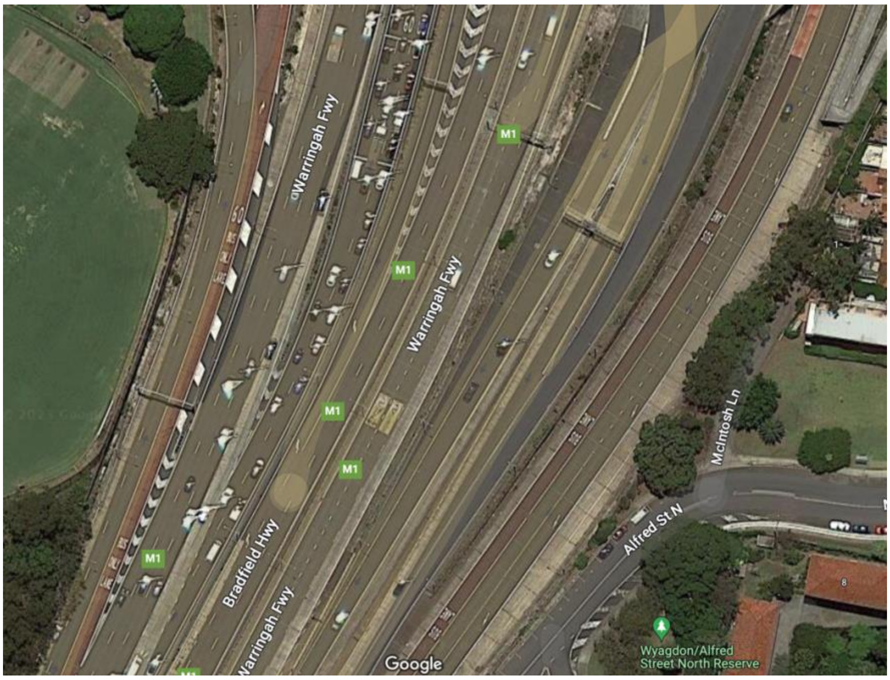

Figure B1. Satellite image of Warringah freeway (Warringah Freeway n.d.)

Figure B2. Satellite image of Ben Boyd Rd/Military Rd intersection (Ben Boyd Rd n.d.)

Table B1. List of intersections

Main Road	Intersection	Co-ordinates	Description
	Warringah Freeway overpass (Falcon St)	-33.8297S 151.2139E	Overpass
Military Rd	East of Park Ave	-33.8924S 151.2171E	Pedestrian crossing
	Watson St	-33.8301S 151.2184E	T-intersection
	Ben Boyd Rd	-33.8305S 151.2195E	4-way intersection
	n/a	-33.8310S 151.2210E	Pedestrian crossing
	Wycombe Rd	-33.8315S 151.2224E	T-intersection
	Murdoch St Winnie St	-33.8303S 151.2265E	4-way intersection
	n/a	-33.8286S 151.2292E	Pedestrian crossing
	Spofforth St	-33.82812S 151.2303E	T-intersection
	Belmont Rd	-33.8270S 151.2318	T-intersection
	n/a	-33.8243S 151.2370E	Pedestrian crossing
	Cowles Rd	-33.8244S 151.2384E	4-way intersection
	Spit Rd	-33.8245S 151.2409E	Angled T-intersection
Spit Rd	Ourimbah Rd	-33.8233S 151.2427E	T-intersection
	Awaba St	-33.8215S 151.2439E	4-way intersection
	n/a	-33.8182S 151.2439E	Pedestrian crossing
	n/a	-33.8166S 151.2433E	Pedestrian crossing
	Medusa St	-33.8130S 151.2442E	T-intersection. LTOR off ramp along Northbound Spit Rd to Medusa St
	Spit West car park & Parriwi Rd	-33.80686S 151.2467E	Four-way intersection, slight angle to Parriwi Rd
	n/a	-33.8026S 151.2462E	Spit Bridge boat crossing

Manly Rd	Battle Blvd	-33.8004S 151.2469E	T-intersection. Access only from Northbound section of Manly Rd. Non-signalised.
	Sydney Rd	-33.7961S 151.25284E	4-way intersection, slight angle in Sydney Rd approaches. LTOR ramp along Northbound Manly Rd to Sydney St.

Table B2. Centroid Key

Centroid Number	Centroid Name
1	Sydney
2	North Sydney
3	Ryde
4	Northern Beaches
5	Seaforth
6	Balgowlah/Manly
7	Spit Car Park
8	Balmoral
9	Beauty Point
10	Middle Harbour
11	Cremorne
12	Neutral Bay
13	Mosman
14	Cammeray

Table B3. Transit Lines (TfNSW 2019)

Line	Direction	Frequency (minutes)
B1	N	5
B1	S	5
150X, 151,188	S	4
165X, 166X, 175X, 177X, 178X, 180X, 183X, 185X, 188X, 189X, 190X	S	3
168, 173	N	7
168, 173, 248	S	6
169, 169X	S	8
170, 171, 178, 180	S	6
170X, 171X	S	8
227, 228, 230	S	6
229	S	60
244, 245, 246, 247	S	3
249	S	15

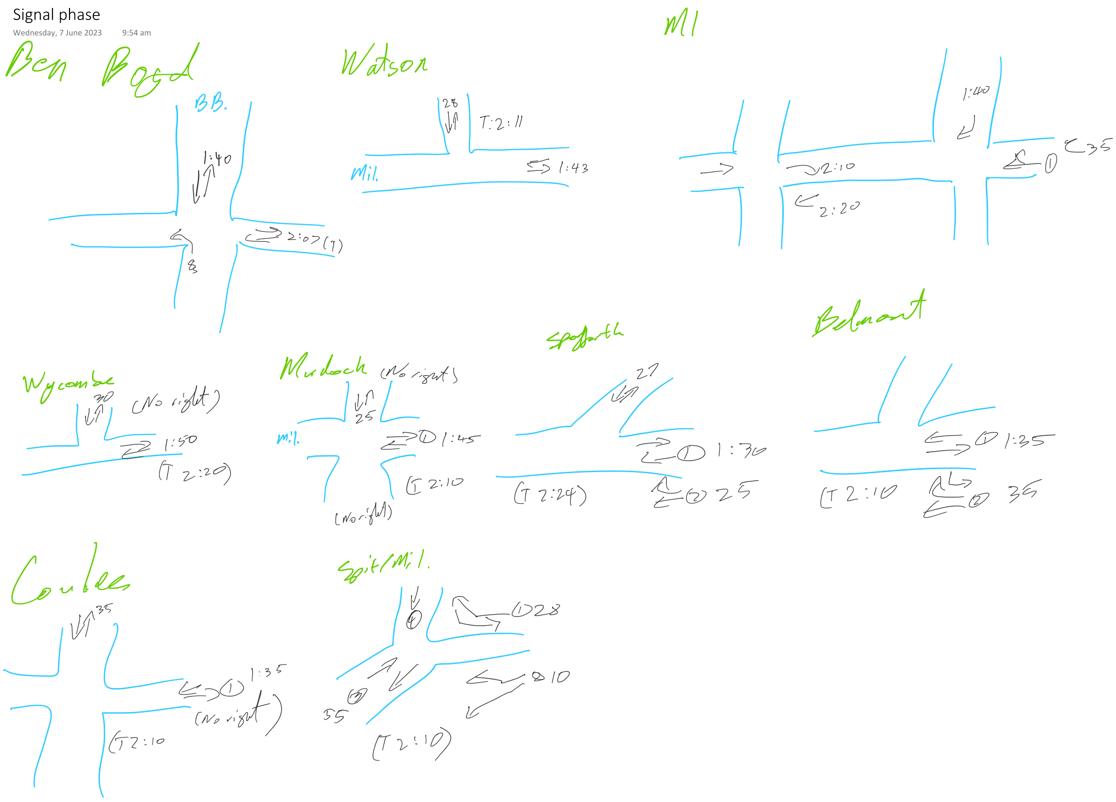

Figure B3. Site visit traffic signal timings

Figure B4. Warringah freeway connection of Beaches Link

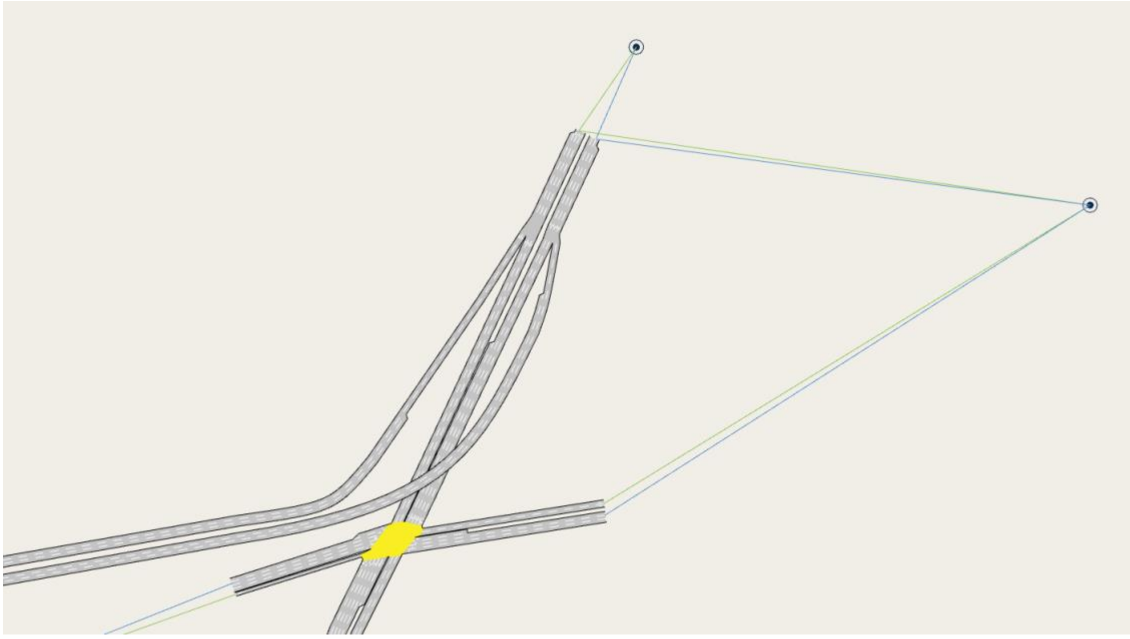

Figure B5. Manly Rd connection of Beaches Link

Table B4. OD Matrix, 2016 base (cars)

O\D	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Total**
1		300	800	105	15	30	5	125	65	115	130	140	125	125	2080
2	400		270	120	20	20	5	40	30	50	55	80	75	85	1250
3	1100	15		30	13	25	2	100	50	100	100	120	110	120	1885
4	285	255	70		100	100	10	85	60	75	80	60	80	90	1350
5	150	50	45	150		80	2	70	50	75	70	110	83	100	1035
6	250	200	50		120		10	50	40	60	40	50	40	30	940
7	10	5	5	10	4	5		1	1	1	1	1	1	1	46
8	110	50	70	65	55	60	1		15	25	20	30	35	40	576
9	100	30	40	70	5	15	3	10		15	25	20	15	30	378
10	120	55	80	90	12	20	2	15	25		50	40	20	30	559
11	140	50	75	90	12	20	1	20	5	50		40	25	40	568
12	140	50	100	80	12	20	2	10	10	25	30		40	45	564
13	140	60	90	90	14	35	1	15	15	50	30	70		40	650
14	115	50	100	70	13	30	2	15	5	45	55	50	25		575
Total	3060	1170	1795	970	395	460	46	556	371	686	686	811	674	776	

Table B5. OD Matrix, 2016 base (trucks)

O\D	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
1		24	64	8	1	2	0	10	5	9	10	11	10	10	166
2	32		22	10	2	2	0	3	2	4	4	6	6	7	100
3	88	1		2	1	2	0	8	4	8	8	10	9	10	151
4	23	20	6		8	8	1	7	5	6	6	5	6	7	108
5	12	4	4	12		6	0	6	4	6	6	9	7	8	83
6	20	16	4	0	10		1	4	3	5	3	4	3	2	75
7	1	0	0	1	0	0		0	0	0	0	0	0	0	4
8	9	4	6	5	4	5	0		1	2	2	2	3	3	46
9	8	2	3	6	0	1	0	1		1	2	2	1	2	30
10	10	4	6	7	1	2	0	1	2		4	3	2	2	45
11	11	4	6	7	1	2	0	2	0	4		3	2	3	45
12	11	4	8	6	1	2	0	1	1	2	2		3	4	45
13	11	5	7	7	1	3	0	1	1	4	2	6		3	52
14	9	4	8	6	1	2	0	1	0	4	4	4	2		46
Total	245	94	144	78	32	37	4	44	30	55	55	65	54	62	

Table B6. OD matrix, 2027 do minimum (cars)

O\D	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
1		345	900	115	19	33	5	123	60	113	127	137	125	123	2225
2	440		307	140	24	24	5	43	30	50	55	80	75	85	1358
3	1150	32		50	17	28	2	104	50	102	102	122	112	122	1993
4	299	270	78		101	105	10	88	61	75	82	63	82	96	1410
5	154	58	49	155		83	2	69	48	74	73	107	83	101	1056
6	260	213	57		121		10	49	38	63	37	53	39	30	970
7	10	5	5	10	5	5		1	1	1	1	1	1	1	47
8	116	63	74	60	50	60	1		16	27	23	33	36	42	601
9	105	38	49	67	5	15	3	12		17	28	24	18	34	415
10	129	66	91	85	13	19	2	17	22		55	46	22	33	600
11	148	57	84	86	12	20	1	22	6	55		50	25	41	607
12	147	56	112	88	13	20	2	13	12	28	33		41	49	614
13	149	68	104	87	15	35	1	17	20	54	35	73		46	704
14	117	63	103	67	13	33	2	18	3	50	56	51	20		596
Total	3224	1334	2013	1010	408	480	46	576	367	709	707	840	679	803	

Table B7. OD matrix, 2027 do minimum (trucks)

O\D	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Total**
1		28	72	9	2	3	0	10	5	9	10	11	10	10	178
2	35		25	11	2	2	0	3	2	4	4	6	6	7	109
3	92	3		4	1	2	0	8	4	8	8	10	9	10	159
4	24	22	6		8	8	1	7	5	6	7	5	7	8	113
5	12	5	4	12		7	0	6	4	6	6	9	7	8	84
6	21	17	5	0	10		1	4	3	5	3	4	3	2	78
7	1	0	0	1	0	0		0	0	0	0	0	0	0	4
8	9	5	6	5	4	5	0		1	2	2	3	3	3	48
9	8	3	4	5	0	1	0	1		1	2	2	1	3	33
10	10	5	7	7	1	2	0	1	2		4	4	2	3	48
11	12	5	7	7	1	2	0	2	0	4		4	2	3	49
12	12	4	9	7	1	2	0	1	1	2	3		3	4	49
13	12	5	8	7	1	3	0	1	2	4	3	6		4	56
14	9	5	8	5	1	3	0	1	0	4	4	4	2		48
Total	258	107	161	81	33	38	4	46	29	57	57	67	54	64	

Table B8. OD matrix, 2037 do minimum (cars)

O\D	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Total**
1		435	914	151	30	70	5	125	65	115	130	140	125	125	2430
2	560		350	160	40	58	5	40	30	50	55	80	75	85	1588
3	1190	70		70	30	60	2	100	50	100	100	120	110	120	2122
4	370	321	85		110	120	10	90	63	90	96	74	91	106	1626
5	155	59	53	155		84	2	75	53	85	80	120	90	120	1131
6	255	218	56		128		10	60	43	89	69	81	71	51	1131
7	10	5	5	11	5	6		2	2	2	2	2	2	2	56
8	100	69	78	59	43	50	2		18	25	20	42	36	44	586
9	92	35	44	62	7	15	4	14		19	29	29	22	37	409
10	119	69	98	85	9	15	3	19	30		56	41	21	33	598
11	136	61	97	88	10	15	2	22	7	50		41	29	41	599
12	138	63	113	78	12	16	3	18	10	25	31		44	46	597
13	128	89	104	85	13	30	2	20	15	50	33	71		42	682
14	100	71	121	69	10	24	2	23	5	45	57	52	30		609
Total	3353	1565	2118	1073	447	563	52	608	391	745	758	893	746	852	

Table B9. OD matrix, 2037 do minimum (trucks)

O\D	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Total**
1		35	73	12	2	6	0	10	5	9	10	11	10	10	194
2	45		28	13	3	5	0	3	2	4	4	6	6	7	127
3	95	6		6	2	5	0	8	4	8	8	10	9	10	170
4	30	26	7		9	10	1	7	5	7	8	6	7	8	130
5	12	5	4	12		7	0	6	4	7	6	10	7	10	90
6	20	17	4	0	10		1	5	3	7	6	6	6	4	90
7	1	0	0	1	0	0		0	0	0	0	0	0	0	4
8	8	6	6	5	3	4	0		1	2	2	3	3	4	47
9	7	3	4	5	1	1	0	1		2	2	2	2	3	33
10	10	6	8	7	1	1	0	2	2		4	3	2	3	48
11	11	5	8	7	1	1	0	2	1	4		3	2	3	48
12	11	5	9	6	1	1	0	1	1	2	2		4	4	48
13	10	7	8	7	1	2	0	2	1	4	3	6		3	55
14	8	6	10	6	1	2	0	2	0	4	5	4	2		49
Total	268	125	169	86	36	45	4	49	31	60	61	71	60	68	

Table B10. OD matrix, 2027 do something (cars)

O\D	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Total**
1		340	837	135	16	39	5	127	67	116	131	140	126	125	2204
2	460		280	140	24	28	5	44	32	51	57	84	79	91	1375
3	1132	30		44	16	42	2	112	62	112	105	121	111	121	2010
4	365	292	100		107	129	13	102	77	92	105	83	105	115	1685
5	160	55	55	168		83	3	71	52	77	73	112	86	100	1095
6	260	217	70		125		15	72	62	81	68	78	60	54	1162
7	10	7	5	12	5	6		2	1	1	2	2	1	1	55
8	114	66	89	75	58	77	1		26	35	26	33	41	50	691
9	117	52	56	79	12	28	3	13		27	31	42	32	43	535
10	127	72	92	96	17	23	3	28	38		70	58	36	41	701
11	146	67	89	98	16	22	2	34	13	78		53	39	57	714
12	143	59	113	86	19	24	2	27	26	48	43		52	70	712
13	142	76	111	109	21	37	1	36	27	69	46	84		68	827
14	116	69	129	88	22	32	3	29	21	59	63	67	43		741
Total	3292	1402	2026	1130	458	570	58	697	504	846	820	957	811	936	

Table B11. OD matrix, 2027 do something (trucks)

O\D	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Total**
1		27	67	11	1	3	0	10	5	9	10	11	10	10	176
2	37		22	11	2	2	0	4	3	4	5	7	6	7	110
3	91	2		4	1	3	0	9	5	9	8	10	9	10	161
4	29	23	8		9	10	1	8	6	7	8	7	8	9	135
5	13	4	4	13		7	0	6	4	6	6	9	7	8	88
6	21	17	6	0	10		1	6	5	6	5	6	5	4	93
7	1	1	0	1	0	0		0	0	0	0	0	0	0	4
8	9	5	7	6	5	6	0		2	3	2	3	3	4	55
9	9	4	4	6	1	2	0	1		2	2	3	3	3	43
10	10	6	7	8	1	2	0	2	3		6	5	3	3	56
11	12	5	7	8	1	2	0	3	1	6		4	3	5	57
12	11	5	9	7	2	2	0	2	2	4	3		4	6	57
13	11	6	9	9	2	3	0	3	2	6	4	7		5	66
14	9	6	10	7	2	3	0	2	2	5	5	5	3		59
Total	263	112	162	90	37	46	5	56	40	68	66	77	65	75	

Table B12. OD matrix, 2037 do something (cars)

O\D	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Total**
1		375	850	175	20	50	6	127	65	120	135	145	130	130	2328
2	440		350	160	25	37	7	47	36	56	64	89	88	99	1498
3	1150	45		40	13	29	2	122	67	127	114	142	138	145	2134
4	507	298	102		105	148	13	107	79	95	107	89	109	118	1877
5	165	73	63	170		93	4	76	56	83	72	117	94	119	1185
6	290	253	102		125		12	69	63	88	59	67	64	68	1260
7	11	7	5	12	5	5		2	1	2	2	1	2	1	56
8	126	77	104	78	60	71	1		22	33	29	39	40	54	734
9	117	59	76	82	15	28	4	17		21	33	42	23	40	557
10	139	87	111	112	27	31	3	25	32		69	53	29	45	763
11	142	94	105	117	27	32	2	36	14	63		51	37	52	772
12	158	96	138	102	15	33	2	24	22	37	53		62	56	798
13	152	95	120	112	18	43	1	29	28	62	47	83		59	849
14	124	73	130	90	16	40	3	32	19	60	66	64	35		752
Total	3521	1632	2256	1250	471	640	60	713	504	847	850	982	851	986	

Table B13. OD matrix, 2037 do something (trucks)

O\D	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Total**
1		30	68	14	2	4	0	10	5	10	11	12	10	10	186
2	35		28	13	2	3	1	4	3	4	5	7	7	8	120
3	92	4		3	1	2	0	10	5	10	9	11	11	12	171
4	41	24	8		8	12	1	9	6	8	9	7	9	9	150
5	13	6	5	14		7	0	6	4	7	6	9	8	10	95
6	23	20	8	0	10		1	6	5	7	5	5	5	5	101
7	1	1	0	1	0	0		0	0	0	0	0	0	0	4
8	10	6	8	6	5	6	0		2	3	2	3	3	4	59
9	9	5	6	7	1	2	0	1		2	3	3	2	3	45
10	11	7	9	9	2	2	0	2	3		6	4	2	4	61
11	11	8	8	9	2	3	0	3	1	5		4	3	4	62
12	13	8	11	8	1	3	0	2	2	3	4		5	4	64
13	12	8	10	9	1	3	0	2	2	5	4	7		5	68
14	10	6	10	7	1	3	0	3	2	5	5	5	3		60
Total	282	131	180	100	38	51	5	57	40	68	68	79	68	79	

Table B14. Seed Values

Run	Seed Value
1	560
2	28
3	7771
4	86524
5	2849
6	5321
7	137
8	98812
9	601027
10	559

Appendix C

Summary of Results

Table C1. Number of stops

Scenario	Value (#/veh/km)	Standard Deviation
2016 Base	0.07	n/a
2027 ‘do minimum’	0.07	n/a
2037 ‘do minimum’	0.08	n/a
2027 ‘do something’	0.4	n/a
2037 ‘do something’	0.4	n/a

Table C2. Stop Time

Scenario	Value (sec/km)	Standard Deviation
2016 Base	84.19	2.49
2027 ‘do minimum’	89.5	3.12
2037 ‘do minimum’	97.08	3.59
2027 ‘do something’	105.98	2.73
2037 ‘do something’	120.42	4.95

Table C3. Density

Scenario	Value (veh/km)	Standard Deviation
2016 Base	27.96	0.58
2027 ‘do minimum’	30.68	0.44
2037 ‘do minimum’	33.26	0.63
2027 ‘do something’	20.93	0.61
2037 ‘do something’	26.5	0.82

Table C4. Flow

Scenario	Value (veh/h)	Standard Deviation
2016 Base	10174.3	119.24
2027 ‘do minimum’	10438.5	112.17
2037 ‘do minimum’	10937.9	90.27
2027 ‘do something’	11840.5	112.12
2037 ‘do something’	12028.1	160.2

Table C5. Harmonic speed (cars)

Scenario	Value (km/h)	Standard Deviation
2016 Base	23.08	0.41
2027 ‘do minimum’	22.23	0.49
2037 ‘do minimum’	21	0.44
2027 ‘do something’	20.29	0.33
2037 ‘do something’	18.78	0.44

Table C6. Mean queue

Scenario	Value (veh)	Standard Deviation
2016 Base	1558.97	46.18
2027 'do minimum'	1788.71	32.22
2037 'do minimum'	1936.57	54
2027 'do something'	1733.18	72.04
2037 'do something'	2406.83	115.89