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Estimating cost expansion factors in the Sydney urban and NSW rural road networks for economic evaluation of road projects

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Abstract

Transport modelling and economic evaluation are two key components of a road project assessment. Transport modelling is usually undertaken for a two hour peak period and then annualised to determine the costs and benefits. A key parameter used in the annualisation is the expansion factor. Currently, practitioners use expansion factors derived from traffic volumes in different time of day and day of year. With ever increasing traffic and worsening urban congestion, transport economists and modellers are questioning the accuracy of using volume based expansion factors to annualise the costs and benefits. To overcome the deficiency of volume based expansion, this paper will develop a methodology to derive cost expansion factors in the Sydney urban road network and remaining New South Wales rural road network. We have sampled hourly traffic volumes in 2011/12 at traffic observation stations representing freeways, arterial and local roads in Sydney inner, middle and outer rings and rural regions of NSW. Travel speed, vehicle operating cost, accident rate and greenhouse gas emissions are modelled in peak and off-peak hours for weekdays and weekends to capture the effects of dynamic traffic volume, road capacity and resulting road congestion. Cost expansion factors are estimated and implications to economic evaluation will be explored. Results indicate that cost expansion factors are around 10% lower, suggesting volume based expansion tends to overestimate travel costs. As a result, the paper recommends the use of volume based expansion factors for traffic demand modelling and cost expansion factors for cost-benefit analysis of road improvement proposals.

1. Introduction

Expansion factors are a key parameter used in the economic evaluation of road projects. They are used to extrapolate a periodic count of traffic volume to a representative annual figure.

Traditionally, practitioners use volume expansion factors to annualise the cost and benefits from two hour peak period traffic modelling. The volume expansion factors are usually estimated by periodic traffic volumes. During peak hours when there are higher levels of congestion, a small reduction in demand can lead to large travel cost savings. Sydney's road network is experiencing increasing levels of congestion with an estimated cost close to $7.5 billion by 2015 (BTRE 2007). Urban congestion imposes negative costs such as increasing journey travel times, decreasing efficiency of vehicle operation and contributing to poorer air quality. The use of cost expansion factors takes into account these effects, which can provide greater accuracy in the calculated costs and benefits than volume expansion factors.

The use of cost expansion factors is a relatively new topic of interest and not much analysis has been completed in this area. This paper provides some insights into this topic and outlines a methodology used to estimate the cost expansion factors for the Sydney urban network and NSW rural network. Research suggests there is evidence of peak spreading

over time, with an increase in traffic in the peak shoulders as traffic operates near capacity during peak hours. Data from the Bureau of Transport Statistics Household Travel Survey shows that in 2005/06 the number of travellers using motorised transport exceeded 350,000 in the period 7.30-8.30am and 3.00-5.00pm. In 2010/11, this number was already exceeded before 7.30am to 9.00am and lasted for a longer duration in the PM peak between 3.00-6.00pm (BTS 2012). As a result of peak spreading, it is expected that expansion factors should increase over time. This paper describes the data used, the model, the results for the Sydney urban road network and the rural road network and concludes the paper by recommending the use of cost expansion factors instead of volume expansion factors in economic evaluations of transport projects.

2. Literature Review

Volume expansion factors vary by location due to differing traffic volumes in different time periods and as a result, localised volume expansion factors have been estimated for individual project locations. In most cases, a generic volume expansion factor applicable for wider traffic situations has been used as it is impractical to estimate expansion factors for each project when traffic modelling resources are limited (e.g. Sydney volume expansion factor attempts to capture traffic patterns for the whole of Sydney).

Transport for NSW has estimated volume expansion factors in Sydney using traffic volume data in 2011 across a total of 60 traffic stations comprising of tolled freeway, arterial and local roads (TfNSW 2013). The expansion factor for the two hour peak period to weekday and the two hour peak period to annual is 7.21 and 2,492 respectively, using 2011 traffic volume data. In rural areas, the two hour peak to weekday is 6.13 and the two hour peak to annual is 2,130. For the peak hour to weekday expansion factor, a lower expansion factor indicates that peak traffic represents a higher proportion of daily traffic, while a higher expansion factor indicates traffic is more evenly distributed. The peak hour to annual expansion factors also attempts to capture the effects of weekends, public holiday and seasonality.

There has not been much published work on cost expansion factors. Roads and Maritime Services seemed to be one of the first to discuss the difference between volume and cost expansion factors. A tentative cost expansion factor of 2,100 was estimated using the traffic volume data for one week in 2002 which included travel time, vehicle operating cost and accident cost (Wilson n.d). Since there is limited available research on cost expansion factors, this paper provides the opportunity to further explore the idea.

3. Data

Traffic volume data over the 2011/12 period was obtained from Roads and Maritime Services. This includes the average hourly traffic volume for weekday and weekend for both directions of traffic flow. For Sydney urban locations, 14 stations were selected. This consisted of 5 tolled freeways, 4 arterial roads and 5 local roads with a representative mix of the inner, middle and outer rings[1]. This mix fairly represents traffic conditions in Sydney. For the rural model, 36 locations were selected which represent a mix of arterial and local roads in NSW rural regions being the Hunter, Northern, West, South-West and Southern.

4. Model

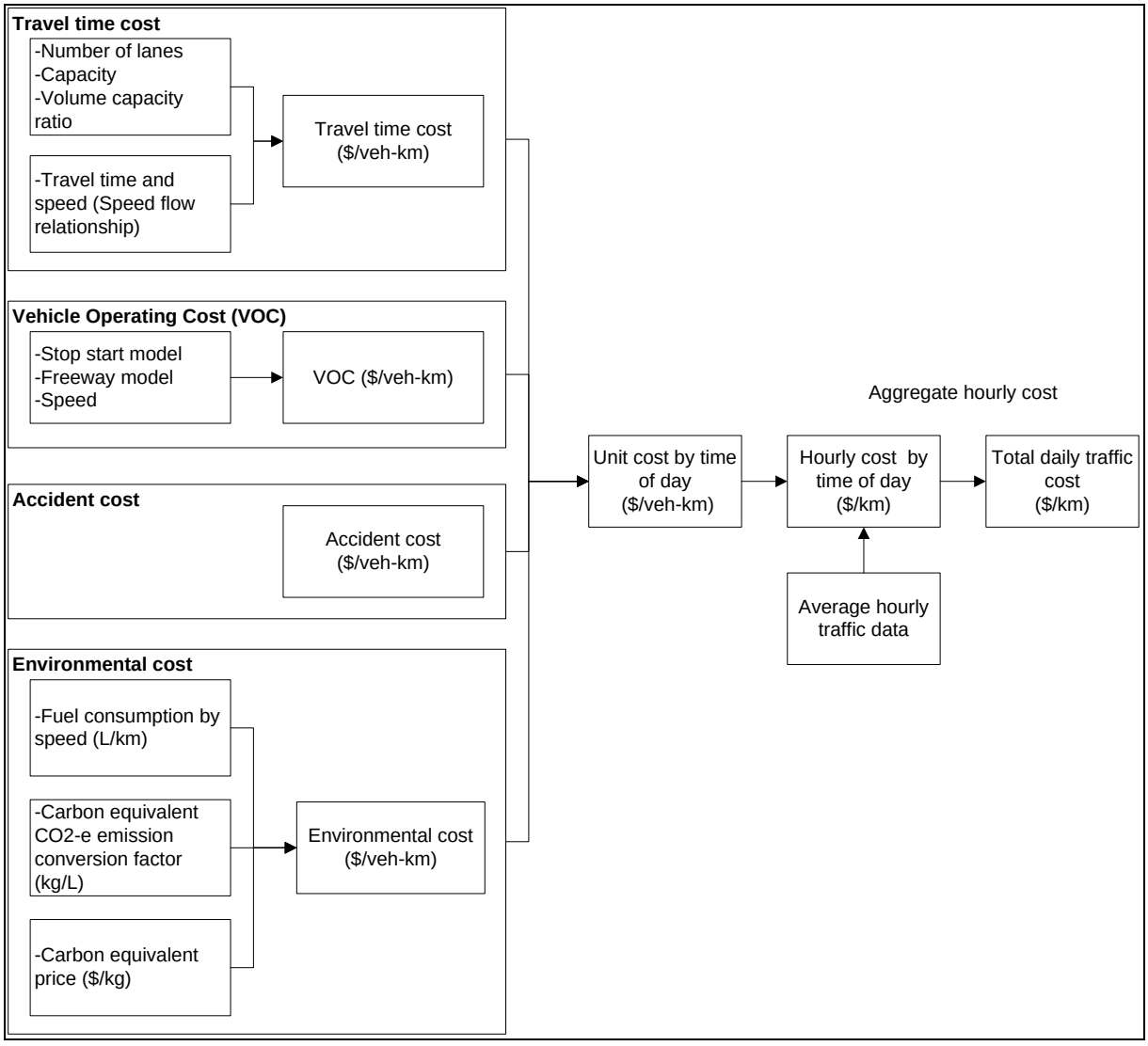
We have developed a model to estimate the total traffic cost for each hour of the day and each direction for each road. This breakdown is required to estimate the cost expansion

[1] The classification of inner, middle and outer rings is adopted from NSW Department of Planning. The inner ring represents areas within 5km of the Sydney CBD; The middle ring represents areas 5-20 km from the Sydney CBD and the outer ring represents areas greater than 20km from the Sydney CBD.

factor. The methodology is illustrated in Figure 1. The total traffic cost is made up of the following components:

- Travel time cost;
- Vehicle Operating Cost (VOC);
- Accident cost; and
- Environmental cost.

Figure 1: Methodology to estimate traffic cost

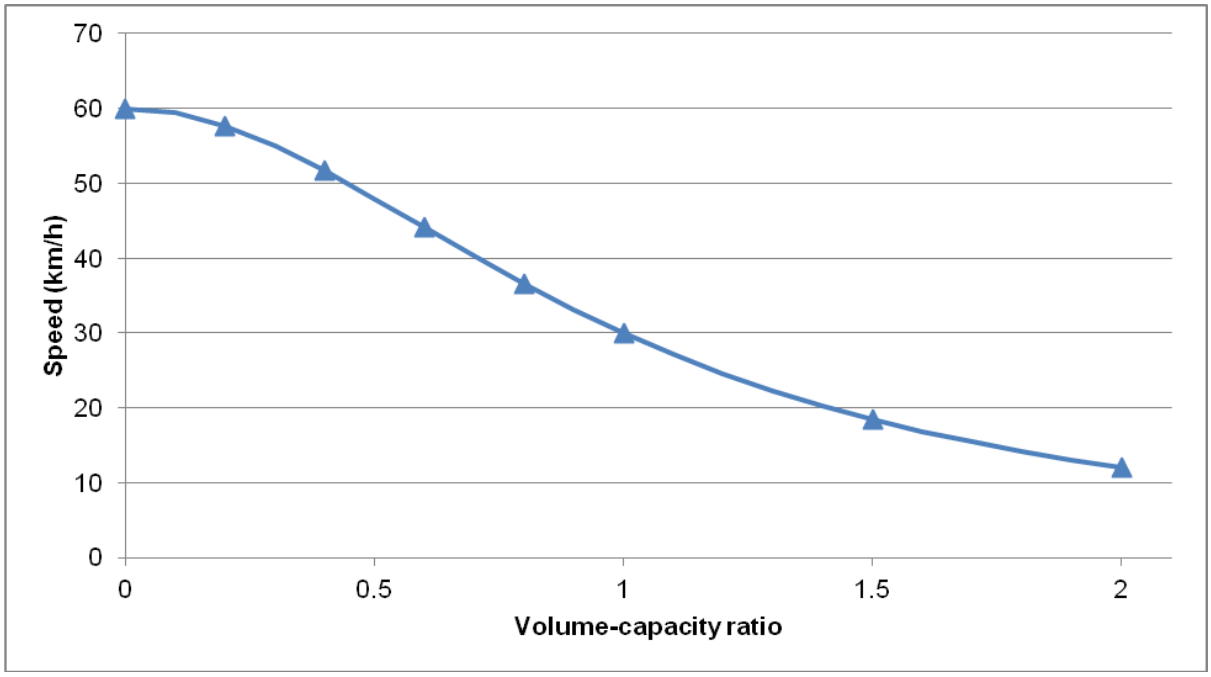


4.1. Travel Time

We estimate the travel time and its time cost for a fixed distance (e.g. 1 km) so that the effect of congestion can be included. For this purpose we have examined the speed flow relationship for each road type. The speed flow curves represent the relationship between traffic flow and travel time and is a function of the free flow speed and volume-capacity ratio of the road. The model adopts the speed flow relationship for different link types, such as local roads, arterial roads, freeways and other link types (Austroads 2011). The link types are reflected by adjusting different delay parameters (such as ramps, traffic signals) and free flow speeds. During periods of light traffic flow, it is expected that speeds are close to the free

flow speed. However, as traffic volume reaches the road capacity and saturation, the speed decreases. Figure 2 shows a typical speed flow curve for arterial roads in NSW with a free flow speed of 60km/h.

Figure 2: NSW RMS speed flow relationship for arterial link of 1km



The volume-capacity ratio for each road location is determined by using the lane capacity by road type (NAASRA 1988). For each road type and location, the travel time and speed (being the inverse) can then be calculated. The travel cost for each hour and for each road is estimated by multiplying the travel time by the value of travel time. The travel time value used in the model also includes goods (freight). The TfNSW Principles and Guidelines for Economic Appraisal of Transport Investment and Initiatives provides a weighted value of travel time ($27.06/veh-hr) of all vehicles (car, LCV and heavy vehicles) by time of day (i.e. peak hour, business peak, off-peak). An alternative method (referred to as Method 2) estimates the travel time cost by using different values for business peak, peak and off-peak, rather than using a weighted average[2]. The different values of travel time for these periods take into account different traffic composition and occupancy rate. The value of travel time for the business peak is greater than the peak period. This is due to a higher proportion of business trips which have a higher value of travel time compared to private trips, as well as a higher proportion of light commercial and heavy vehicles. Generally, business cars account for 22% of traffic in business hours but only 5% in other hours and have a lower occupancy rate of 1.4 compared to 1.6 for private trips. Furthermore, off-peak trips have a greater travel time value than peak trips due to a higher occupancy rate. Thus, Method 2 is intended to test these effects on cost expansion factors.

Travel time cost in the rural model is estimated by incorporating features specific to rural traffic conditions, such as a higher proportion of heavy vehicles. In the rural model, roads were classified as either arterial or local. Both the road capacity and the free flow speed in rural arterials are generally higher than urban arterials. The rural local road capacity is assumed to be the same as urban. Traffic volume distribution in rural areas typically does not exhibit the same profile, as they tend to be higher throughout the day rather than only during the peak period in the urban environment. As a result, the effect of traffic cost by hour is not

[2] In the model for Method 2 we have defined 0800-0900 and 1700-1800 as peak; 0600-0800 and 1800-1900 as peak shoulder; 0900-1700 as business peak and all other hours as off-peak.

as significant for rural areas compared to urban areas. A weighted average hourly value of travel time of $33.36/veh-hr has been calculated, which uses a different traffic composition mix, with a greater proportion of heavy vehicles such as articulated trucks (TfNSW 2013).

4.2. Vehicle Operating Cost

For urban arterial and local roads, the VOC is estimated using the urban stop-start model which predicts the effects of speed on vehicle operating cost. For tolled freeways, the freeway model is used as travel speeds are typically higher than 60km/h. The urban stop-start and freeway model is outlined below (Austroads 2004)[3]:

Urban Stop-Start Model:

$c = A + B / V$

Freeway Model:

$c = C_0 + C_1V + C_2V^2$

Where:

- c represents vehicle operating cost (cents/km).
- V represents journey speed (km/h).
- A, B, C_0, C_1 and C_2 are model coefficients, which have been calculated by Austroads and updated by TfNSW using the private motoring component of CPI Sydney (TfNSW 2013).

Since the average traffic volume does not differentiate vehicle types, a weighted coefficient is calculated using the proportion of traffic composition which includes cars, light commercial vehicles, rigid trucks and articulated trucks. This vehicle composition in traffic was estimated using the ABS 2010 Survey of Motor Vehicle Use (ABS 2010). Therefore, depending on the speed calculated, the VOC unit cost ($/veh-km) is estimated for each location and by each hour.

For the rural model, the freeway model is used to estimate the vehicle operating costs as the rural environment is typically not characterised by interrupted and congested traffic flow and slower speeds.

4.3. Accident Cost

The unit accident cost per kilometre is calculated using the available parameters contained in the TfNSW guidelines (TfNSW 2013). This represents the average crash cost by the road types and is recommended to be used when there is limited information about the type of road accident. Therefore, depending on the road type (i.e. local, arterial and freeway), the relevant accident cost parameter is included as a cost into the model.

4.4. Environmental Cost

Greenhouse gases are produced from fuel burned by motor vehicles and released into the environment through the exhaust. We have estimated the environmental cost by determining a relationship between speed, fuel consumption and greenhouse gas emissions. TfNSW's vehicle operating cost model, known as VEHOP, produces fuel consumption estimates by speed and by vehicle type. The results are consistent with the 'U-shape' which typically shows fuel consumption being greater at lower speeds and then starts to decrease at

[3] Recent Austroads changes to urban journey speed VOC models parameters include time and freight cost. As a result, the equations for the journey speed models refer to Austroads 2004 with indexed coefficients.

increasing speeds and then increases again beyond a certain speed threshold. The weighted fuel consumption of the vehicle types is then calculated by speed using the traffic composition proportions. Using the carbon dioxide equivalent (CO_2-e) conversion factor which states that 2.3kg of CO_2-e emissions are produced from 1L of fuel burned and the CO_2-e price of $52.4/tonne (Austroads 2012), the emission cost by speed can be calculated.

For each hour at each location, travel time cost, VOC, accident cost and environmental cost is added to arrive at the unit travel cost per vehicle-kilometre. The unit cost is then multiplied by the average traffic by hour at each location to estimate the total hourly travel cost.

5. Results

5.1. Sydney Urban

5.1.1. Traffic Volume

We first examine the pattern in traffic volume data over 2011/12. Figure 3 shows the average daily traffic volume between freeway, arterial and local roads. On weekdays, we expect a 'peaky' flow with the highest traffic in peak periods and lower traffic in off-peak periods. This is in contrast to weekends, where traffic is more distributed in the middle of the day as seen in Figure 4.

Figure 3: Traffic volume distribution - weekday

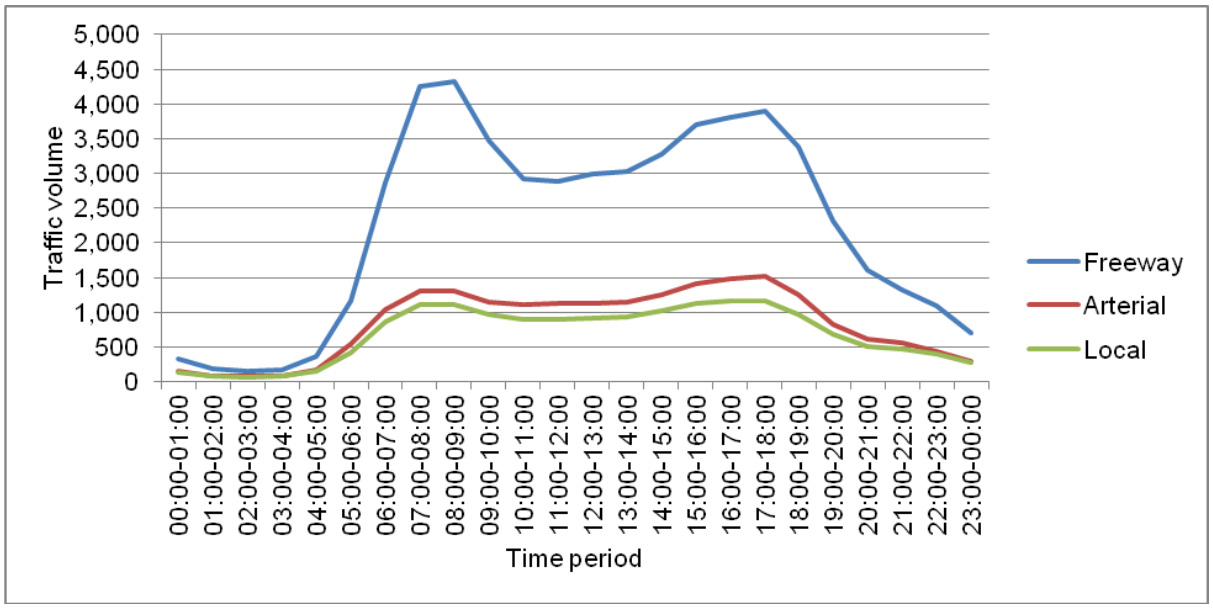
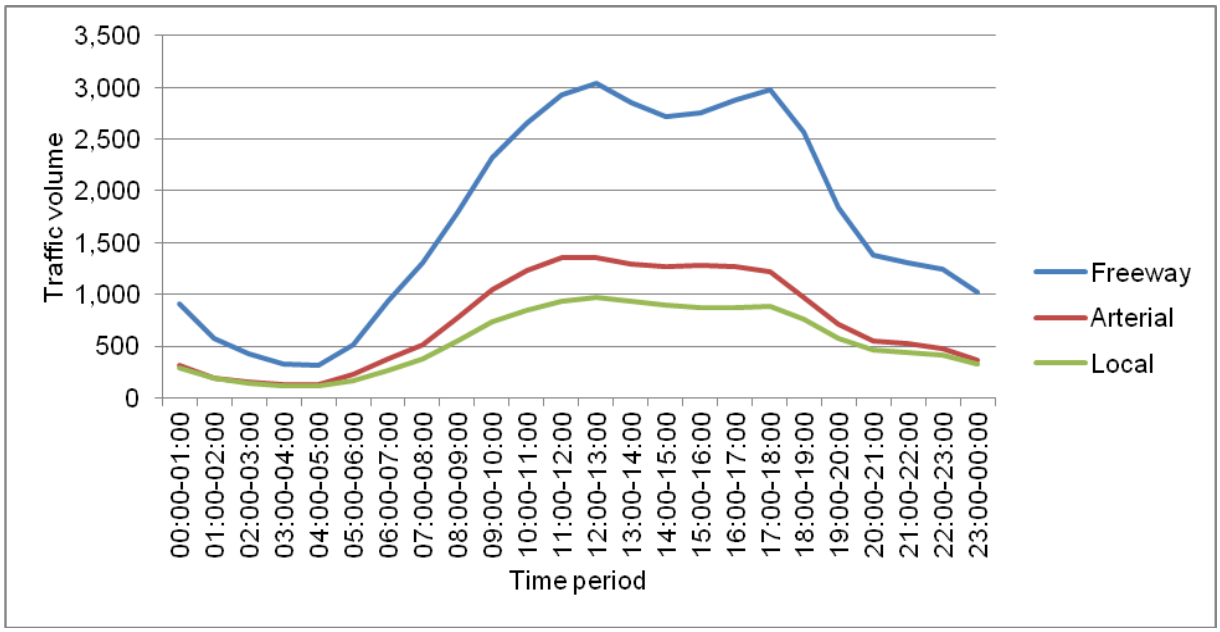
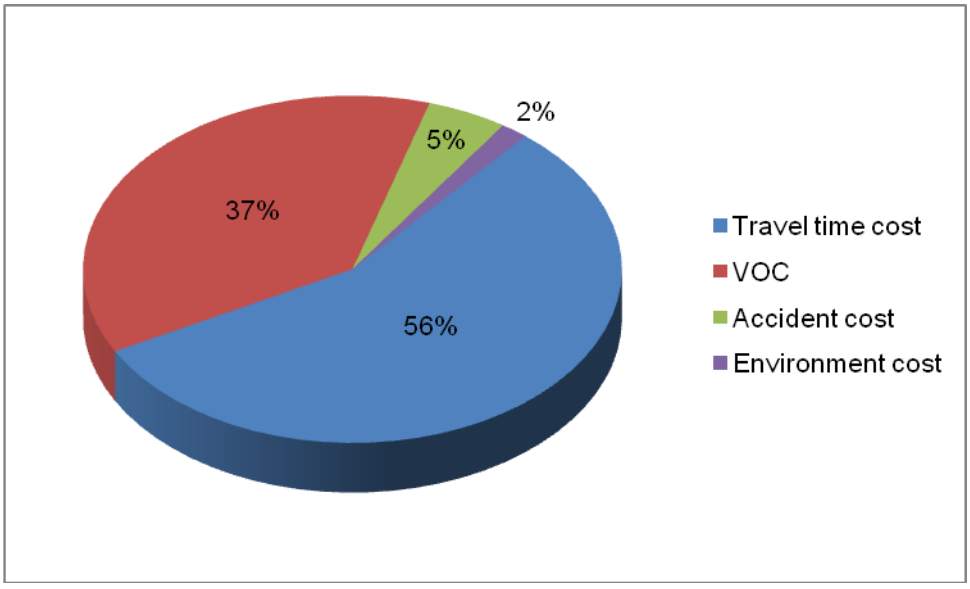


Figure 4: Traffic volume distribution - weekend



A breakdown of the components of the total traffic cost is represented in Figure 5. Travel time cost accounts for more than half of the total cost, followed by vehicle operating cost making up more than a third of the total cost.

Figure 5: Breakdown of traffic cost



5.1.2. Expansion Factor Results

Table 1 presents the results from the modelling of cost expansion factors, by each road type and a weighted average. The expansion factors are calculated as the total weekday cost divided by the peak two hour cost, where the peak two hour is the highest hourly traffic cost in the AM and the PM peak period. The peak two hour to annual expansion factor is calculated in a similar way, with the annual cost first estimated as a function of the weekday and weekend daily costs. The volume expansion factors are also estimated from the same data set to compare with the cost expansion factors.

Table 1: Sydney urban cost and volume expansion factors

	Freeway		Arterial		Local		Weighted Average	
	Cost	**Volume**	**Cost**	**Volume**	**Cost**	**Volume**	**Cost**	**Volume**
Peak 2 hours to weekday	6.04	6.59	6.67	7.11	6.39	7.22	6.26	6.81
Peak 2 hours to annual	2,007	2,231	2,327	2,503	2,124	2,469	2,099	2,329

When using the value of travel time by different hour of the day (i.e. business peak, peak hour, off-peak), as opposed to a weighted average value of time, the expansion factor results are higher and closer to the volume expansion factors, highlighted in Table 2. The business peak value of $32.02/veh-hr is used from 9am to 5pm compared to a peak value of $20.33/veh-hr and off-peak of $29.73/veh-hr. The higher value of travel time for business hours is predominantly due to a higher proportion of business vehicles, whilst the higher value in off-peak is due to higher car occupancy during off-peak hours.

Table 2: Sydney urban cost and volume expansion factors, Method 2 (using different hourly travel time cost)

	Freeway		Arterial		Local		Weighted Average	
	Cost	**Volume**	**Cost**	**Volume**	**Cost**	**Volume**	**Cost**	**Volume**
Peak 2 hours to weekday	6.36	6.59	6.73	7.11	6.39	7.22	6.44	6.81
Peak 2 hours to annual	2,129	2,231	2,366	2,503	2,141	2,469	2,177	2,329

5.1.3. Comparison of traffic cost and volume distribution

Figures 6, 7, and 8 compare the distribution of traffic cost and traffic volume on weekdays for freeway, arterial and local roads. Traffic cost is higher during the peak periods on all road types, which indicates that the traffic in peak hours incur a higher unit travel cost.

Figure 6: Traffic cost and volume distribution for freeway, weekday

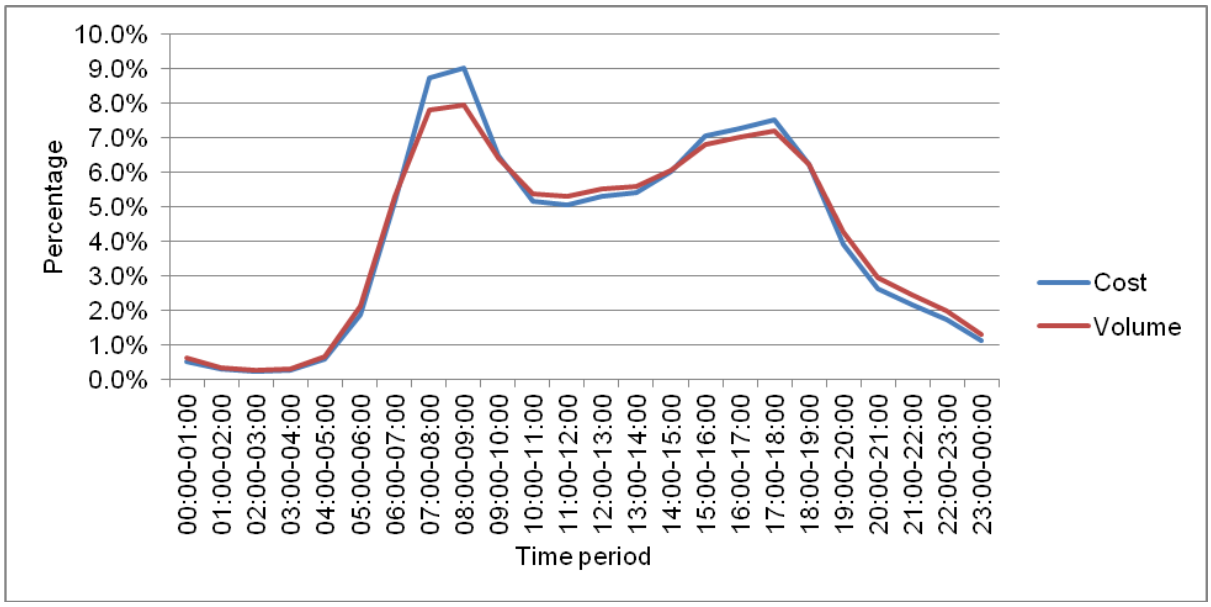


Figure 7: Traffic cost and volume distribution for arterial roads, weekday

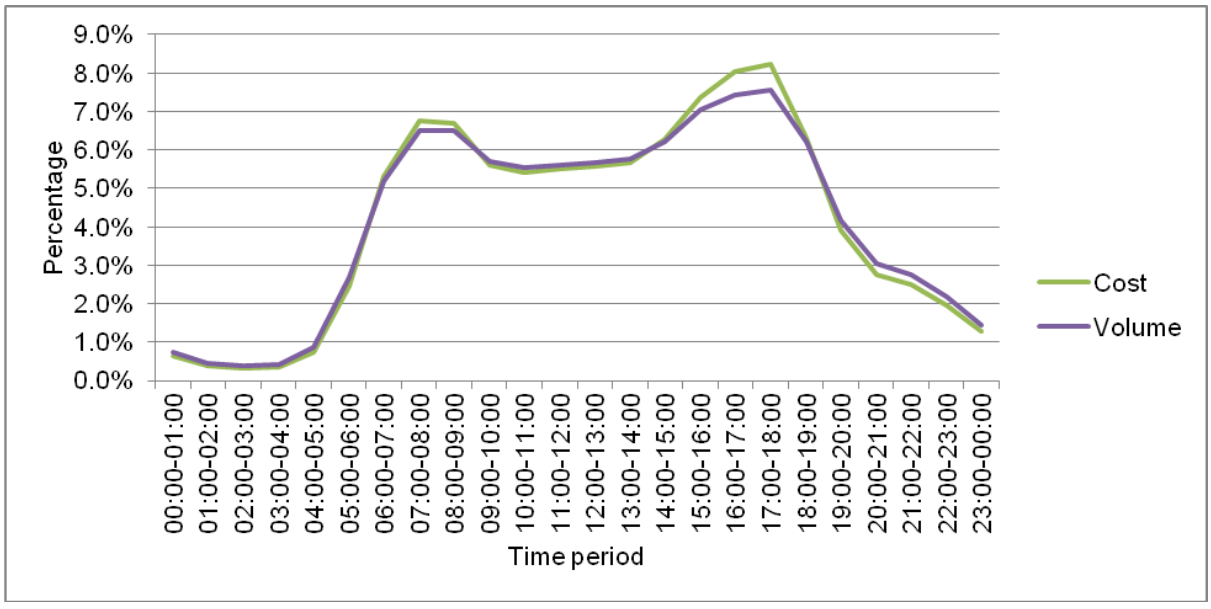
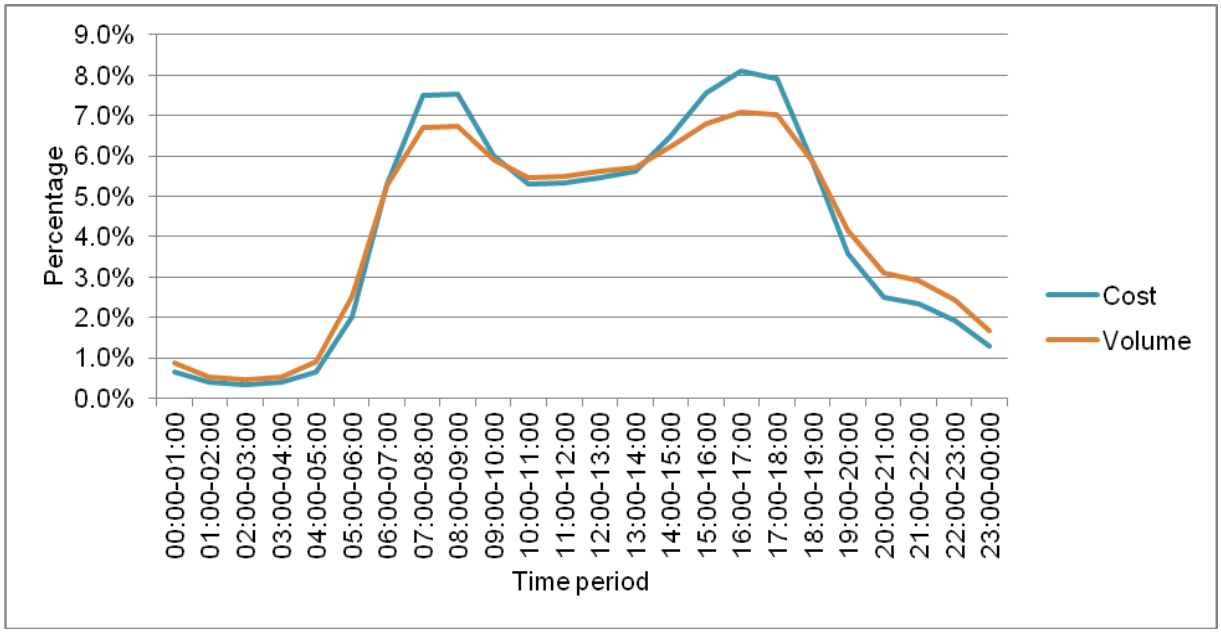


Figure 8: Traffic cost and volume distribution for local roads, weekday



The two hour peak represents a slightly greater proportion of traffic cost compared to traffic volume across the freeway, arterial and local roads, as shown in Table 3. The larger difference is evident in freeways, with the two hour peak representing 17% of the total daily traffic cost compared to 15% of the daily traffic volume.

Table 3: Two hour peak traffic cost and volume distribution, weekday

	Freeway		Arterial		Local	
	Cost	**Volume**	**Cost**	**Volume**	**Cost**	**Volume**
Peak 2 hours (1AM+1PM)	17%	15%	15%	14%	16%	14%

Table 4 shows the proportion of two hour peak cost and volume using Method 2. The difference in the proportion of traffic cost is only 1% higher than traffic volume for freeways, arterial and local roads, highlighting that using a different value of travel time by hour (Method 2) provides similar results between cost and volume expansion factors.

Table 4: Two hour peak traffic cost and volume distribution, weekday – Method 2

	Freeway		Arterial		Local	
	Cost	**Volume**	**Cost**	**Volume**	**Cost**	**Volume**
Peak 2 hours (1AM+1PM)	16%	15%	15%	14%	16%	14%

5.2. NSW Rural

The traffic volume distribution for rural environments is different to urban with distribution of traffic throughout the day. The exception is for the Hunter region which exhibits a 'peaky' traffic flow similar to the urban environment. The other regions show the bulk of traffic distributed during the day, rather than in the peak period only. As a result, the peak two hour period is calculated as the maximal two hourly costs throughout the day. Each region exhibits different traffic flows. The Hunter region has high traffic volume on arterial roads compared to local roads whilst other regions exhibit higher traffic volumes on local roads. Only arterial roads for the Western region could be obtained due to data limitations. The average traffic volume distribution is shown in Figures 9 and 10.

Figure 9: Average traffic volume on rural arterial roads, weekday

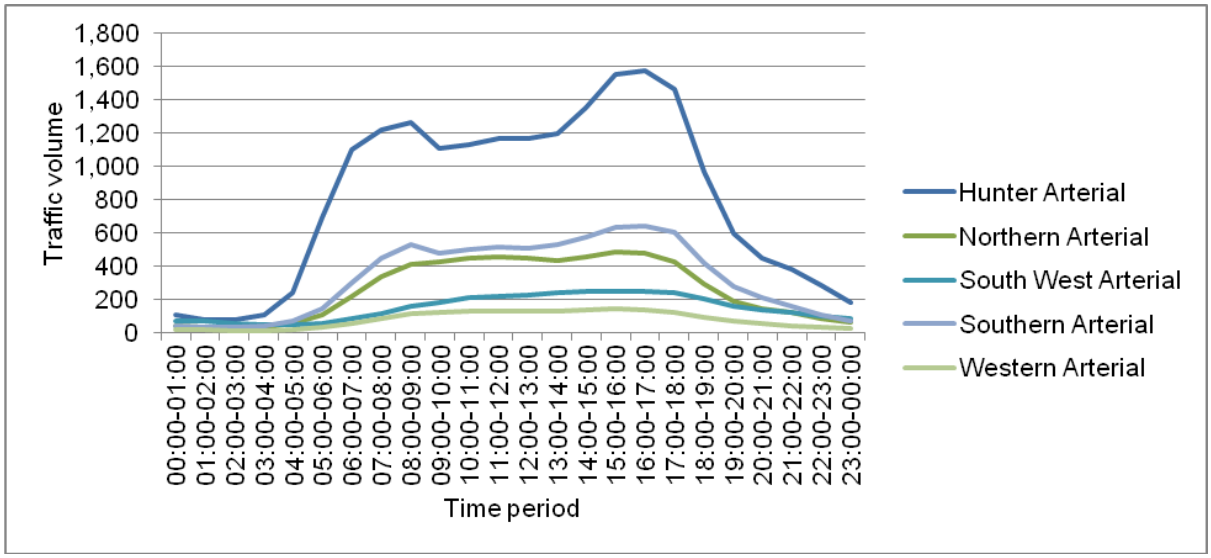
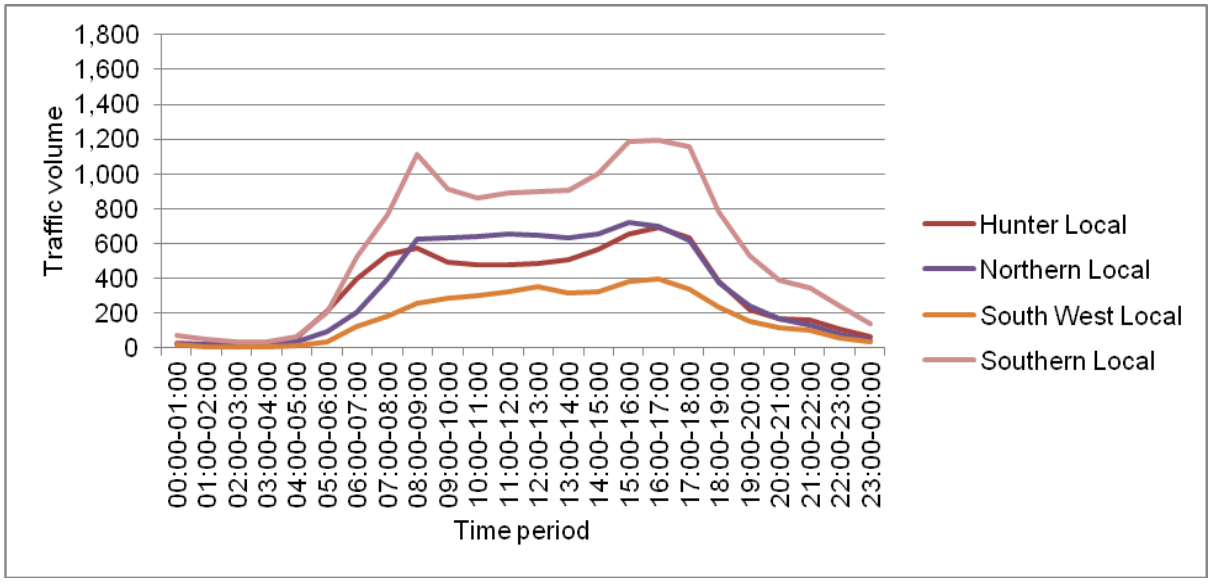


Figure 10: Average traffic volume on rural local roads, weekday



The calculated expansion factors for rural regions are shown in Table 5. Compared to the urban regions, the difference in cost and volume expansion factor is not as evident in the rural regions as the proportion of daily traffic cost is similar to the proportion of daily traffic volume. A possible reason for this is due to the majority of the traffic volume being spread more evenly throughout the day in rural regions. The exception to this is the Hunter region which shows the proportion of traffic cost clearly higher than the proportion of traffic volume during 3-6pm, especially for the local roads. The proportion of traffic cost during the two hour peak period for arterial roads (excluding Hunter region) is 16%, which is the same for the proportion of volume. The result is clearer for local roads with a higher proportion of traffic cost being 20% compared to the proportion of traffic volume at 17%. In addition, the results show that the expansion factor for rural regions is generally lower than urban areas.

Table 5: Rural cost and volume expansion factors by region

	Hunter				**Northern**			
	Arterial		Local		Arterial		Local	
	Cost	Volume	Cost	Volume	Cost	Volume	Cost	Volume
Peak 2 hours to weekday	5.73	6.22	5.20	5.91	6.39	6.46	4.89	5.86
Peak 2 hours to annual	1,950	2,129	1,721	1,995	2,274	2,298	1,536	1,965
	South-West				**Southern**			
	Arterial		Local		Arterial		Local	
	Cost	Volume	Cost	Volume	Cost	Volume	Cost	Volume
Peak 2 hours to weekday	7.10	7.11	5.23	5.58	6.02	6.12	5.08	5.99
Peak 2 hours to annual	2,502	2,507	1,829	1,960	2,222	2,253	1,677	2,032
	Western							
	Arterial		Local					
	Cost	Volume	Cost	Volume				
Peak 2 hours to weekday	6.53	6.54	n/a	n/a				
Peak 2 hours to annual	1,638	2,322	n/a	n/a				

6. Implications to Economic Evaluations

The use of cost expansion factors takes into account dynamic traffic volume throughout the day and better represents periods where there are high levels of congestion which results in higher travel time, vehicle operating costs and emissions. The results show that the cost expansion factor for the two hour AM peak is about 10% lower than the volume expansion factor. This suggests that the traditional use of volume expansion factors by transport economists and modellers can result in an overestimation of trip costs. Thus, it is recommended that cost expansion factors be used as they provide greater accuracy in estimating costs. Impacts on the Benefit-Cost Ratio (BCR) and Net Present Value (NPV) by adopting cost expansion factors should be investigated on case-by-case basis. As the BCR and NPV are based on incremental costs with and without the project, the cost expansion factors may lead to either a lower or a higher BCR. Since the largest difference between cost and volume expansion factors occurs in the urban areas, this will have the most significant impact on the evaluation of urban road projects, in comparison to rural projects.

7. Conclusion

This paper develops a model to estimate cost expansion factors for the Sydney urban and NSW rural regions. Average daily traffic volumes were sourced for a sample of freeway, arterial and local roads in urban and rural areas. The traffic cost is estimated and is composed of travel time cost, vehicle operating cost, accident and environmental cost which

we have estimated as a function of speed. The results of our modelling suggest that cost expansion factors are around 10% lower than volume expansion factors in urban roads. The main reason for this is that the two hour peak cost represents a greater proportion of the daily cost compared to the same period using traffic volume. However when differing values of travel time throughout the day (i.e. business peak, peak, off-peak) and car occupancy are considered, the difference is less pronounced and the cost expansion factors are similar to the volume expansion factors. For rural regions, the cost expansion factors are generally lower than urban regions and the difference in cost expansion factors are not as evident in the rural regions as the proportion of daily traffic cost is similar to the proportion of daily traffic volume.

Further improvements in the model could potentially include calculating expansion factors based on different categorisations such as the inner, middle and outer rings of Sydney.

References

ABS (2010) ABS Survey of Motor Vehicle Use 2010 cat no. 9208.0

Austroads (2011) Speed-flow Relationships: Implications of project appraisal, Austroads AP-R393-11

Austroads (2012) Guide to project evaluation, part 4, project evaluation data, updated RUE unit values, Austorads AGPE04-12

Austroads (2004) Economic evaluation of road investment proposal, unit values for road user costs at June 2002

BTRE (2007) Estimating urban traffic and congestion cost trends in Australian cities. Working paper 71. Bureau of Infrastructure, Transport and Regional Economics

BTS (2012) 2010/11 Household Travel Survey, NSW Bureau of Transport Statistics

NAASRA (1988) Guide to Traffic Engineering Practice Part 2 Roadway Capacity, National Association of Australian State Road Authorities

TfNSW (2013) Principles and Guidelines for Economic Appraisal of Transport Investment and Initiatives, Transport for NSW

Wilson, Matthew (n.d) Expansion Factors for Economic Analysis of Urban Road Projects, Roads & Traffic Authority