THE COSTS AND BENEFITS OF INDUCED TRAFFIC ON THE SYDNEY HARBOUR TUNNEL AND GORE HILL FREEWAY

ABSTRACT

Statistical analyses have been performed on the effect of the opening of the Sydney Harbour Tunnel (SHT) and Gore Hill Freeway (GHF) on public transport patronage and vehicular usage. The effect of toll increases has also been analysed. Statistically significant estimates have been obtained for the induced traffic and the effects of toll increases and these estimates have provided data for a calculation of consumer surplus gained from the provision of the SHT and GHF. The estimate for consumer surplus has been compared with measured gains calculated from actual changes in travel times, traffic volumes and vehicular speeds after the SHT and GHF opened, and the two measures of benefits were found to be consistent with each other. When external costs of the induced traffic are taken into account, it is found that the benefits gained by the SHT and GHF are outweighed by the external costs in combination with the maintenance and capital costs. It is found that the costs of loss of public transport patronage and congestion costs of induced traffic are significant and cannot be neglected in economic evaluations of future roadworks.

1. INTRODUCTION

The Sydney Harbour Tunnel (SHT) was completed in August 1992 at a cost of $560 million. This project was an important pioneering example of the private provision of public infrastructure. By circumventing government budgetary and loans restrictions the project proceeded earlier than it would have otherwise. The Gore Hill Freeway (GHF) was also completed in August 1992. This project was funded by government funds and cost $130 million, for 3.1 km of freeway.[1] Because the SHT and GHF were completed at the same time and both roads made the harbour crossing for private vehicles easier and quicker, the two projects are treated together in this paper in their effect on Sydney's transport.

The SHT project was justified financially by the then Department of Main Roads (DMR) on the basis of benefits to be derived from (a) reduced travel costs for those who already drive across the Harbour and (b) for those who will be attracted to drive by the improved road facility; (c) reduced fuel usage from less congestion; (d) reduced accident costs and (d) increased system reliability.([2]) The costs are implicitly assumed to be made up of the tunnel construction, maintenance and operation costs. ([3]) The financial justification of the SHT was subjected to dispute, by the Department of Environment and Planning[4] and Travers Morgan[5] before the decision was made, and by the North Sydney Municipal Council[6] afterwards, but the project proceeded regardless. A review of the project by the Auditor-General in 1994, about 2 years after the SHT commenced operation found that

> ".....it is difficult to identify the economy of the Tunnel project. In essence, the State has gained the benefits of a harbour tunnel, constructed at an

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[1] Roads and Traffic Authority, ANNUAL REPORT, 1993/94, Appendix 1.

[2] Department of Main Roads, THE SYDNEY HARBOUR TUNNEL PROJECT FEASIBILITY STUDY, Sydney, July 1987, p 5.

[3] IBID., p 3

[4] Department of Environment and Planning, PROPOSED SYDNEY HARBOUR TUNNEL: ENVIRONMENTAL IMPACT STATEMENT, Sydney, 1987, P5.

[5] Travers Morgan Pty. Ltd., ECONOMIC EVALUATION OF THE SYDNEY HARBOUR TUNNEL, Sydney, Department of Main Roads, Oct. 1986, p 28,29.

[6] Enersol Consulting Engineers, SYDNEY HARBOUR TUNNEL INQUIRY: REPORT, North Sydney Municipal Council, Sydney, 1989, p 1.

> agreed cost of $554 million,..In exchange, the State has agreed to contribute in dollars of the day and for a period of almost 30 years, a loan of $223 million and forego interest thereon, make non-repayable grants of between $1748 (Net present value $676 million) and $2540 million (NPV $728 million)."[7]

The non-repayable grants are the shortfalls predicted to occur in toll revenue compared with the Ensured Revenue Stream which the government is required to pay the contractor. It is not intended in this paper to analyse further the financial arrangements with regard to the SHT, as this analysis has been thoroughly undertaken by the Auditor-General.

For the GHF the benefits included vehicle operating costs, travel time savings and accident cost savings. The costs were the value of land acquisition, construction and maintenance costs.[8]

The aim of this dissertation will be to assess the extent of induced traffic caused by the availability of the SHT and GHF and the benefits and costs of this induced traffic. This will involve separating out the effect of the SHT and GHF from the other factors affecting traffic volume, such as the degree of economic growth, the level of the toll and seasonal factors. The economic, social and environmental costs and benefits associated with this induced traffic will then be assessed. An "after the fact" cost benefit analysis of major transport projects such as the SHT and GHF is worthwhile because these projects represent large expenditures of public resources

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[7] NSW Auditor-General's Office, PRIVATE PARTICIPATION IN THE PROVISION OF PUBLIC INFRASTRUCTURE: THE ROADS AND TRAFFIC AUTHORITY, Sydney, 1994, p 304.

[8] Department of Main Roads, GORE HILL LINK ENVIRONMENTAL IMPACT STATEMENT Dec 1986, p20.

and a biased or inadequate cost benefit analysis before the project can result in a flawed decision and a huge waste in capital expenditure. Assessments of the errors and omissions in past decision making processes should improve the quality of future selection of capital works projects. An aim of this paper is to assess the effect of the failure to fully consider the effects of induced traffic in the decision making process regarding major roads projects.

A study of the effects of the SHT and GHF is important because the SHT and GHF alleviated a crucial bottleneck in Sydney's road system and allowed pent up demand for private vehicle use to be realised. Because there are only a limited number of harbour crossings, the effects of this realisation of pent up demand should be measurable in a way not usually feasible for other road projects.

The plan for this dissertation is as follows:

· Perform regression analyses to estimate the change in public transport patronage, the change in total cross harbour vehicular traffic, the change in SHB and SHT traffic resulting from the projects and the response of SHB and SHT traffic to toll changes.

· Estimate the benefits of the projects by calculating the consumer surplus from an estimated demand curve for SHB and SHT usage.

· Attempt to corroborate the accuracy of the consumer surplus measurement of benefits from the actual traffic flows and time savings achieved after the projects.

· Calculate the costs of the induced traffic using the estimate of the increase in traffic attributable to the

SHT and GHF to calculate the external costs of the induced traffic coming onto the road.

· Compare the calculated costs and benefits.

· Suggest improvements which could be made in cost benefit analysis techniques and in transport policies which may increase overall welfare.

A summary of the various costs and benefits considered in this paper, and where these matters are discussed, is as follows:

Benefits:	
Consumer Surplus	Sections 5,6,7,8
Costs:	
Loss of Public Transport Patronage	Section 2, 3, 9.2
Congestion	Section 9.2
Pollution	Section 9.2
Noise	Section 9.2
Maintenance	Section 9.3
Capital Costs	Section 9.3
Summation of Costs and Benefits	Section 10

2. STATISTICAL MODEL FOR TRAIN PATRONAGE

The aim of this section is to assess the behaviour of train patronage before and after the opening of the SHT and GHF. It is reasoned that, over the time interval 1990 to 1995, the main influences on the patronage of trains in the Northwest Sector of the Sydney train system have been (a) the level of economic activity, which will here be measured by the Gross Domestic Product (GDP) of the whole of Australia at constant 1989/90 prices, (b) the existence or otherwise of the Sydney Harbour Tunnel and Gore Hill Freeway and (c) the time of the year.

Since economic activity involves, among other things, the movement of people, it appears reasonable to expect that higher economic activity, which is usually associated with higher employment and higher income per person for leisure activities, will be associated with more travel to and from work and to various entertainment venues. Therefore a positive coefficient for GDP is expected in the regression analysis. National GDP rather than the GDP for the state of NSW is used because state GDP statistics are not readily available. If economic conditions differ greatly in the state of NSW from conditions in the rest of Australia, then this will be a source of some inaccuracies in the following analysis. GDP is used, rather than other variables which could possibly affect patronage such as population growth or shifts or car ownership levels, because the GDP figure is more readily available and is found in practice to be a significant explanatory variable. Statistics for car ownership in a particular region of Sydney for monthly intervals, or for regional populations for monthly intervals, are unobtainable. In all of the following regression analyses, GDP is found to be a statistically significant explanatory variable. As will be seen, for train patronage, the t ratio for the coefficient of GDP is 4.988, for total vehicular traffic on the Gladesville Bridge, Sydney Harbour Tunnel (SHT) and the Sydney Harbour Bridge (SHB) this t ratio is 50.84, while for SHT and SHB traffic this t ratio is 7.464. All these values indicate a good explanatory power for GDP in traffic volumes. When a greater number of categories of traffic are considered the t value for the coefficient of GDP is greater. This is to be expected, as when the amount of traffic considered is larger, the more closely one would expect the variations in traffic to coincide with the variations with GDP. The GDP could be expected to have superior explanatory power than regional population variations or car ownership levels since the GDP measures the extent of a larger range of economic behaviour. Also, since the Harbour Bridge is such an important traffic artery for the people of Sydney, and serves such a large proportion of the total trips, it appears reasonable to assume that variations in trips on this harbour crossing will be largely explained by variations in GDP.

Northwest sector train patronage statistics are used because statistics exclusively for the railway line across the SHB are not provided by the SRA. The northwest sector figures include the SHB line patronage but also include other lines and many passengers which do not cross the SHB in their trips. This is a limitation of this measure of patronage but the northwest sector patronage figures are the only measure available of SHB train trips. There will therefore be other influences on northwest sector train patronage apart from the explanatory factors considered, but the dummy variable for the existence of the SHT and GHF should measure the extent of changes occurring only at the time of the opening of the SHT and GHF. No other events with a large effect on train patronage are known to have occurred at this time, and it is assumed that no such events happened. The patronage statistics considered cover the period from July 1990 to June 1995, this being the time for which statistics are available in this form. The northwest sector train patronage statistics include all Sydney Harbour Bridge crossings.

For the existence of the SHT and GHF, it is expected that the reduction in travel time offered by the expanded road capacity will tend to attract people out of public transport and into private vehicles. Therefore a negative coefficient is possible for the dummy variable used for the existence of the SHT and GHF. The level of train fares will not be used as an explanatory variable because over the period considered fare rises have been within the rate of inflation and so the real level of fares has remained approximately constant. A train fare rise did occur on 28 June 1992, about two months before the SHT and GHF commenced operation, but it is assumed that any small effect of this fare rise on train patronage would have run its course before the commencement of operation of the SHT and GHF.

Using time series statistics of rail patronage in the northwestern sector of the Sydney area from the SRA as the dependent variable, a regression analysis is shown in Appendix 1 using as explanatory variables (1) the Gross Domestic Product, (2) seasonal dummy variables, and (3) the existence of the SHT as a dummy variable. The following result was obtained from these patronage statistics for each four weekly period from 1990 to 1995 inclusive, after a generalised least squares analysis to correct for the autocorrelation common in time series statistics: (Patronage figures supplied by SRA **Statistician Adrian Lewis phone 02 9219 1483.)**

$$\hat{Patron}_t = -849470 + 68.264\ GDP_t - 619950.SHT + P_t$$

(s.e.)	(1267000)	(13.69)	(131300)
(t)	(-0.6702)	(4.988)	(-4.722)

R^2 = 0.7646

where $\hat{Patron}_t$ is Sydney area northwest sector railway patronage per four week period P_t; and GDP_t is the Gross Domestic Product at 1989/90 prices. P_t represents the 12 dummy variables for the time of year as shown in Appendix 1. Most of these time-of-year dummy variables are not statistically significant. The 95% confidence interval for the coefficient of SHT, the dummy variable for the existence of the Sydney Harbour Tunnel, is:

NAME	LOWER	COEFFICIENT	UPPER
SHT (4 weeks)	-882510	-619950	-357380
SHT (per day)	-31518	-22141	-12764

This coefficient represents a statistically significant estimate of the loss of patronage for the trains which followed the opening of the SHT. According to this estimate, the loss of patronage is at least 12,764 trips per day, which is about 6.5% of the 197,179 average daily trips for the northwest sector in 1990/91. The Department of Environment and Planning predicted in 1987 that the loss of rail patronage because of the SHT for the morning peak could be 7,536 by the year 2011.[9] If this estimate is doubled to include the afternoon peak then it is within the confidence interval of loss of patronage estimated above, although this loss occurred within months of the SHT and GHF opening.

As a check, a regression analysis of total Sydney train passenger journeys is carried out in Appendix 4. The following estimate for the coefficient of SHT from this analysis is:

	LOWER	COEFFICIENT	UPPER
per year: (millions)	-42.219	-27.309	-12.399
per day	-115,668	-74,819	-33,970

R^2 = 0.8901

While the two estimates of the decrease in train patronage do not have overlapping confidence intervals,

[9] Department of Environment and Planning, OP. CIT., p 43.

they are of the same order of magnitude. The estimate of patronage reduction based on the Northwest Sector figures is more specific to the problem and is based on a larger number of measures, and so the Northwest Sector patronage reduction estimate is the estimate which will be used for further calculations. While it is not possible to prove that this loss of patronage was caused by the opening of the SHT and GHF, there is no doubt about the sequence of events, i.e. that the loss of train patronage followed the opening of the SHT and GHF.

3. ESTIMATE OF THE EFFECTS OF THE SHT AND GHF ON BUS AND FERRY PATRONAGE

Using information from SRA and Urban Transit Authority (UTA), then State Transit Authority (STA) Annual Reports an attempt is made in Appendix 4 to estimate the changes which occurred in patronage of all of Sydney's government public transport services after the SHT and GHF.

For total public transport patronage the following model was estimated:

$$\widehat{Patron_t} = 174.83 + 0.00080755\ GDP_t - 27.396\ SHT + P_t$$

(s.e.)	(32.61)	(0.00009723)	(9.223)
(t)	(5.361)	(8.306)	(-2.97)

$R^2 = 0.8920$

This gives a statistically significant estimate of the coefficient of SHT, which is change in public transport patronage after the provision of the SHT and GHF as:

LOWER	COEFFICIENT	UPPER

per year: (millions)	-47.496	-27.396	-6.9469
per day	-130,126	-75,057	-19,032

For the change in bus patronage alone the following confidence interval (C.I.) for the coefficient of SHT was estimated, after correction for autocorrelation:

	LOWER	COEFFICIENT	UPPER
per year: (millions)	-5.8218	3.1278	12.077
per day	-15,950	8,569	33,087

$R^2 = 0.7563$

While an increase in bus patronage is suggested by the positive coefficient the C.I. includes zero and so the estimated coefficient is not statistically significant. It is plausible that bus patronage could have been increased with the SHT and GHF as bus trips would have been faster with the expanded road capacity, especially with the GHF. It is not clear how much improvement the SHT would have made to bus travel as transit lanes existed on the approaches of the bridge before the SHT was built, but the transit lanes were extended across the bridge after the SHT was built.

For ferry patronage, the corresponding coefficient, estimated without need for correction for autocorrelation is:

	LOWER	COEFFICIENT	UPPER
per year: (millions)	-5.1894	-3.2055	-1.2216
per day	-14,217	-8,782	-3,347

$R^2 = 0.8513$

This result shows a statistically significant reduction in ferry patronage after the SHT and GHF were built.

The results for the ferry patronage are of uncertain accuracy as the method of counting passenger journeys in the STA apparently changed from the year 1993/94 onwards, and two different figures for patronage are available from STA Annual Reports for the years 1991/92 and 1992/93. The figures for 1993/94 and 1994/95 have been adjusted in this study by the ratio of the two different amounts given for 1991/92 and 1992/93 in an attempt to present passenger journey statistics which are comparable with each other over a time series.

The estimate for bus patronage changes is suggestive of an increase after the SHT and GHF were built, even if the estimate is not significant, and the estimate for ferry patronage suggests a reduction in patronage of a similar amount, even though the figures are of uncertain accuracy. That the changes in bus and ferry patronage roughly cancel each other out is suggested by the total public transport patronage figures which are similar to the changes in train patronage. Since the figures for changes to total public transport patronage also have a C.I. which overlaps the Northwest Sector train patronage change estimate, it is the Northwest Sector train patronage change estimate which will be used as a measure of the loss of public transport passenger journeys which occurred after the opening of the SHT and GHF.

4. STATISTICAL MODEL OF TOTAL VEHICULAR TRAFFIC ON THE GLADESVILLE BRIDGE (GB), SHB AND SHT

To estimate a model of total vehicular traffic which is affected by the SHT and GHF, a regression analysis is performed of the total traffic on the SHB, SHT and the Gladesville Bridge as the dependent variable, against GDP at constant 1989/90 prices as a measure of level of economic activity, the existence of the SHT and GHF as a dummy variable, and against seasonal dummy variables. Again, GDP is used rather than other possible variables and its use has been justified in Section 2. With this model it is hoped to be able to assess whether the trips which have disappeared from public transport could have been taken up by additional private car trips. This analysis of traffic data from the RTA for the SHB, the SHT and the Gladesville Bridge gave the following result, as shown in Appendix 2:

Regression Analysis of Time Series of Total Daily Traffic on the Gladesville Bridge, the Sydney Harbour Bridge and the Sydney Harbour Tunnel (Traffic figures supplied by RTA Statistician Barry Armstrong, phone 02 9662 5569)

$$\hat{T}_t = 45560 + 18.665\, GDP_t + 260260.DUMINGB + P_t$$

(s.e.)	(120400)	(0.3669)	(36640)
(t)	(0.3785)	(50.84)	(7.104)

$R^2 = 0.9927$

where $\hat{T}_t$ is the total traffic in number of vehicles per four week period on the SHB, the GB and on the SHT, GDP_t is the gross domestic product at constant 1989/90 prices, DUMINGB is the dummy variable for the existence of the SHT and P_t is the collection of seasonal dummy variables shown in Appendix 2, which in this case are all statistically significant. The 95% confidence interval for the coefficient of DUMINGB, the dummy variable for the existence of the Sydney Harbour Tunnel, is:

NAME	LOWER	COEFFICIENT	UPPER
DUMINGB(per day)	186220	260260	334300
DUMINGB(per day)	6651	9295	11939

This coefficient represents a statistically significant estimate of the increase in vehicular traffic which followed the opening of the SHT. If one accepts the DMR's estimate of the average vehicle occupancy of 1.4 persons per vehicle, then these numbers of vehicles correspond to the following number of persons:

NAME	LOWER	COEFFICIENT	UPPER
Persons/day	9311	13013	16715

It should be noted that, although the data for the above two regression analyses are independent of each other, the figures for increase in persons in vehicular traffic are of the same order of magnitude as the loss in rail patronage (95% C.I. 12,764 to 31,518), and the confidence intervals largely overlap. This suggests that there is a high probability that the SHT encouraged people to change their mode of transport from public transport to private vehicle. It is assumed here that the increase in traffic is fully measured by the trend in combined Gladesville Bridge, Harbour Bridge and Harbour Tunnel traffic.

5. STATISTICAL MODEL OF HARBOUR BRIDGE AND HARBOUR TUNNEL TOTAL TRAFFIC

The benefits of increased mobility to the people using the vehicles which constitute the induced traffic will be estimated from a demand curve for the SHT derived from a regression analysis of SHB plus SHT traffic (not including Gladesville Bridge traffic this time) against GDP, the level of the toll, seasonal dummy variables and the existence of the SHT as a dummy variable. The toll on the SHB increased from 20 cents to $1.00 on 31 May 1987, from $1.00 to $1.50 on 5 March 1989 and from $1.50 to $2.00 when the SHT opened in August 1992. Figure 5 shows the AADT on the SHB and SHT from 1985 to 1995, with the "Week" column showing the last week of the corresponding year for which the AADT is calculated. This week is chosen to avoid counting anomalies for the year 1992 when the SHT and GHF were opened. From RTA traffic statistics, the results of this regression analysis are as shown in Appendix 3 and are summarised below:

Regression Analysis of Time Series of SHB plus SHT total Traffic.

$$\hat{T}_t = 2584000 + 6.667.\ GDP_t - 244260.TOLLW_t + 731460.DUMEXGB + P_t$$

(s.e.)	(267200)	(0.8894)	(40940)	(31140)
(t)	(9.354)	(7.496)	(-5.966)	(23.49)

$R^2 = 0.9329$

where $\hat{T}_t$ is the total traffic in number of vehicles per four week period on the SHB, and on the SHT, GDP_t is the gross domestic product at constant 1989/90 prices, $TOLLW_t$ is the level of the toll at constant 1989/90 prices, DUMEXGB is again the dummy variable for the existence of the SHT and P_t is the collection of seasonal dummy variables shown in Appendix 3, which are all statistically significant. The 95% confidence interval for the coefficient of DUMEXGB, the dummy variable for the existence of the Sydney Harbour Tunnel, is:

NAME	LOWER	COEFFICIENT	UPPER
DUMEXGB (4 weeks)	669810	731460	793110
DUMEXGB (per day)	23922	26124	28325

This coefficient can be interpreted as the increase which would have occurred in the total SHT plus SHB traffic if the toll had not increased when the SHT opened.

The coefficient for toll, $TOLLW_t$, has a 95% confidence interval of

NAME	LOWER	COEFFICIENT	UPPER
$TOLLW_t$ (4 weeks)	-325330	-244260	-163190
$TOLLW_t$ (per day)	-11619	-8724	-5828

For comparison, the increase in the toll from 20 cents to $1 was predicted by GHD consultants to "restrain growth by little more than 4%" ([10]). According to the estimate here the 80 cents increase would reduce traffic by 9805 x 0.8 = 7844 vehicles per day, which represents 4.35% of the Average Annual Daily Traffic (AADT) of 181,384 in 1987. The estimate here is therefore in agreement with expectations in 1986.

These figures represent the confidence interval of the estimate of the response of SHB plus SHT traffic to a $1.00 increase in the toll. From the above two estimates a demand curve for the SHT can be derived and from the

[10] Gutteridge, Haskins & Davey Pty. Ltd., SYDNEY HARBOUR TUNNEL WORKING PAPERS, Sydney, Department of Main Roads, Oct. 1986 p 34

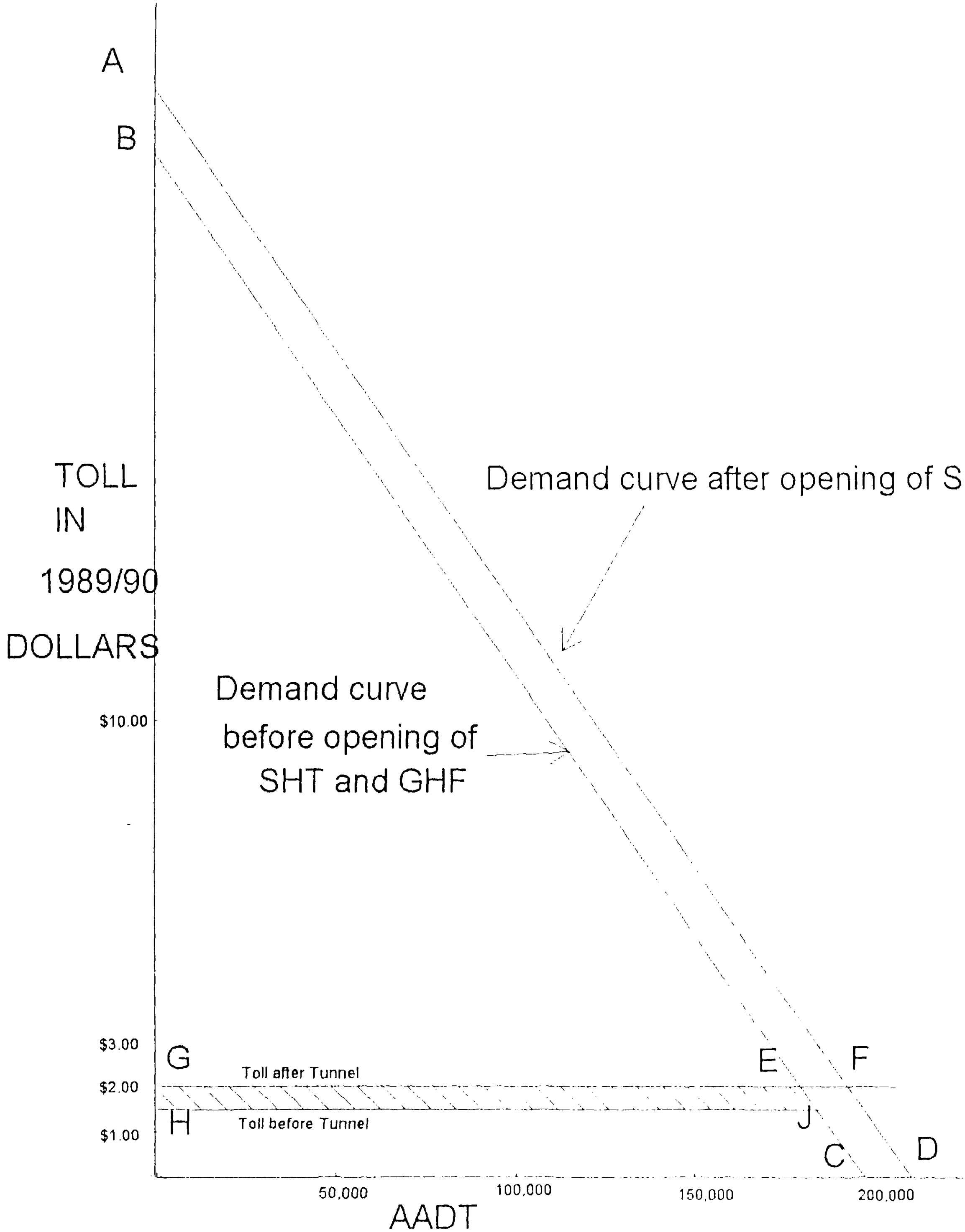

FIGURE 1a

DIAGRAM SHOWING FORM OF DEMAND CURVES FOR SHT AND GHF IF THERE IS NO CAPACITY CONSTRAINT

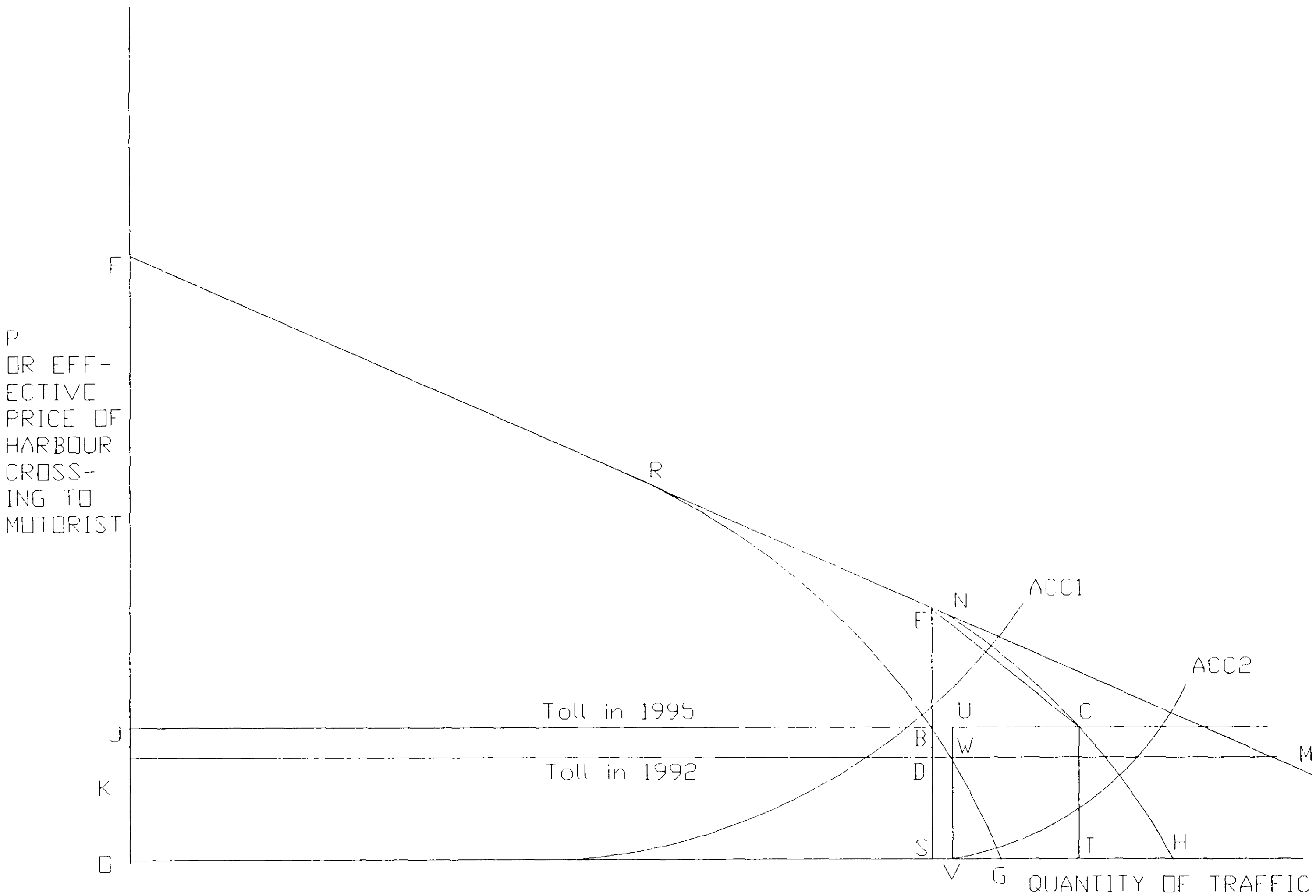

FIGURE 1b

THE DERIVATION OF THE CONSTRAINED DEMAND CURVE FOR USE OF THE SYDNEY HARBOUR BRIDGE OR TUNNEL

(FROM P. FORSYTH PERSONAL FAX 21/2/97)

demand curve an estimate of the consumer surplus for users of the SHT can be calculated. The consumer surplus computed from this demand curve should include all benefits perceived by the users of the SHT, and so this consumer surplus calculation will include time savings, vehicle running cost savings, mobility benefits etc gained by users. Separate calculations of these benefits will therefore only be used to corroborate the consumer surplus calculation.

6. CONSUMER SURPLUS AND THE FORM OF THE DEMAND CURVE

Since the consumer surplus is to be measured by the area under the demand curve and above the toll, the form of the demand curve is important to the magnitude of the consumer surplus. Figure 1a shows one conceivable form of this demand curve, and assumes that the entire demand curve shifts to the right with the opening of the SHT and GHF. This assumption is equivalent to the assumption that the overall demand for harbour crossings over the SHB and SHT has increased with the opening of the SHT and GHF. Using these demand curves the increase in consumer surplus is the area of the large polygon ABEF, less the extraction of some consumer surplus from the increase in the toll, represented on Figure 1a by the area of polygon GHJE. It is implied in these demand curves that there is no capacity constraint, since the responsiveness to toll changes, as represented by the slope of the curves, remains constant for the lengths of the curves.

Another form that the demand curve for the SHB and SHT harbour crossing could take is shown in Figure 1b. It is reasoned here that the demand for harbour crossings is determined by social and economic factors among the people of Sydney, especially the locations of home, work and leisure activities, and the level of economic activity. This demand curve, if unconstrained by the capacity of the harbour crossing, does not change in the short term in response to the expansion of capacity. However the fact that the provision of the SHT has clearly been followed by a sudden increase in use could be interpreted as indicating that the demand curve is constrained by the capacity of the SHB. It will be assumed here that the demand curve to which motorists on the SHB and SHT are responding is in fact the unconstrained demand curve (FM on Figure 1b) less the Average Cost of Congestion curve (ACC1) [11], to make a constrained demand curve FRBG for the situation before the SHT opened. It is reasoned that, at zero traffic the average cost of congestion will be zero while congestion will increase at an increasing rate as traffic increases. Hence the shape of the ACC1 curve.

After the opening of the SHT, the extra capacity will reduce the Average Cost of Congestion for motorists for any particular level of traffic, and so the ACC curve will become ACC2 on Figure 1b. If one subtracts the ACC2 values from the same demand curve FM, the constrained demand curve, FNCH, for after the opening of the SHT is derived. For the levels of traffic under study, there has been an apparent shift of the constrained demand curve to the right, but not the unconstrained demand curve. Before the opening of the SHT and GHF the situation is at point D with traffic KD while after the opening the situation is at C with higher toll and higher traffic JC.

Since the measured traffic volumes will be responding to the toll as well as to the congestion costs imposed by the capacity constraints of the SHT and SHB, it is assumed that the demand curve which is measured by the regression analysis of traffic figures with toll as an explanatory variable is the capacity constrained demand curve. The dummy variable "DUMEXGB", with its coefficient in the regression equation of traffic versus toll, gives the amount by which the constrained demand curve is

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[11] Professor Peter Forsyth, personal fax, 21/2/97.

shifted to the right with the increase in capacity at the opening of the SHT and GHF. The constrained demand curve is then derived from the equation arising from regression analysis of the SHB and SHT traffic statistics in Section 5. For the four weekly traffic figures, using the most likely coefficients, this equation is:

$$\hat{T}_t = 2584000 + 6.667.\ GDP_t - 244260.TOLL_t + 731460.DUMEXGB + P_t$$

For daily traffic figures, assuming constant GDP, taking a yearly average of seasonal factors and representing the total of GDP influence plus the average of seasonal factors plus the constant in the equation by another constant A, and also by replacing the traffic $\hat{T}_t$ with the symbol Q and $TOLL_t$ with the symbol P, the equation becomes:

$$Q = A - 8724.P + 26124.DUMEXGB$$

For the situation before the SHT opened the dummy variable SHT is zero, the average annual daily traffic AADT was 181,196 and the value of the toll was $1.50 nominal or $1.44 in constant 1989/90 dollars. By substituting these values into the above equation the value of A is calculated to be 193,759. Thus the equation of the constrained demand curve before the SHT and GHF opened is:

$$Q = 193,759 - 8724.P$$

After the SHT and GHF open, the value of dummy variable SHT becomes unity and the constrained demand curve after the opening becomes:

Q = 219,883 - 8724.P

This assumes that the slope of the curves remains constant before and after the opening of the SHT and GHF. This assumption is supported by the explanatory power of these variables in the regression analysis, with the coefficient of determination of 0.9329.

As stated the above constrained demand curves are represented in Figure 1b, in an approximate manner, by the steep portions of the lines FRBG for before the opening and FNCH for after the opening.

To assess the degree of capacity constraint on the harbour crossings, the southbound a.m. peak hour traffic on the Harbour Bridge in 1990 was 10500 vehicles. This represents a traffic per lane of 1750, or 92% of the maximum capacity per lane, using the DMR figure of 1900 vehicles per hour as the maximum capacity per lane. At this level of traffic volume, the speed attainable on the SHB would be about 70% of the unconstrained allowable speed or free speed. ([12]). The comparison of peak hour traffic volumes with lane capacities is summarised below. The percentage of free speed corresponding to the traffic volume is theoretically calculated by the BTCE ([13])

1990 Sydney Harbour Bridge

Time	Direction	Traffic	% of Capacity	% of Free Speed
a.m	South	10500	92%	70%
a.m.	North	5150	135%	10%
p.m	South	5400	142%	5%
p.m.	North	9630	84%	85%

1993 Sydney Harbour Bridge

[12] Bureau of Transport and Communications Economics, TRAFFIC CONGESTION AND ROAD USER CHARGES IN AUSTRALIAN CAPITAL CITIES ,OP. CIT. p19

[13] LOC.CIT., p19

Time	Direction	Traffic	% of Capacity	% of Free Speed
a.m	South	8310	72%	90%
a.m.	North	3990	105%	40%
p.m	South	4510	118%	10%
p.m.	North	8190	72%	90%

1993 Sydney Harbour Tunnel

Time	Direction	Traffic	% of Capacity	% of Free Speed
a.m	South	3450	91%	80%
a.m.	North	2820	74%	90%
p.m	South	2560	67%	93%
p.m.	North	3040	80%	87%

It can be seen from the above that there are definite constraints on traffic flow for the traffic travelling in the opposite direction to the main peak flow in both a.m. and p.m., both before and after the provision of the SHT. This supports the contention that the demand curves for harbour crossings are constrained both before and after the opening of the SHT and GHF.

The gain in consumer surplus for the SHT and GHF is the area RNCB in Figure 1b, less the area JKDB. The area JKDB approximates the extra toll paid by base traffic and is here regarded as a transfer payment from motorists to the authorities, with zero net effect on welfare. However, the toll paid by the additional traffic after the opening of the SHT and GHF, equivalent to area BSTC on Figure 1b, is deducted from the calculated consumer surplus and should therefore be added to the benefits of the toll collecting authority. Since the area BSTC is not known, it will be approximated by area UVTC, which can be measured. The measurable figure for area EBC is the estimate that is used for gain in consumer surplus. It can be seen in Figure 1b that the area RBE, and area between arc ENC and chord EC, are therefore excluded erroneously from the consumer surplus gain. The accuracy in this measurement will be assessed by comparison with estimates of the measurable benefits gained by vehicle drivers in terms of time savings, vehicle operating costs etc. The comparison of the consumer surplus calculated using the form of the demand curve assumed above with the measured benefits will also give an indication of the validity of the assumptions regarding the demand curves, and of the choice of the form of demand curve in Figure 1b.

A comparison between the demand curves of Figure 1a, assuming a shift in the entire demand curve and little or no capacity constraint, and the curves of Figure 1b, which assumes that the opening of the SHT and GHF only shifted the capacity constrained portions of the demand curves, shows that a much greater consumer surplus will be calculated from Figure 1a than from Figure 1b. The area of polygon ABEF in Figure 1a is clearly greater than the area RBC of Figure 1b. Because of the above measurements of traffic volume which demonstrate that capacity constraints do exist, and from the above reasoning that the opening of the SHT and GHF are unlikely to have changed the underlying demand for harbour crossings, it is the demand curves of Figure 1b which will be used in this analysis. There will be an opportunity to check the appropriateness of these capacity constrained demand curves when the magnitude of consumer surplus is compared with measured benefits.

7. CALCULATION OF CHANGE IN CONSUMER SURPLUS FOR WEEKDAY TRAFFIC FOLLOWING THE OPENING OF THE SHT AND GHF

According to microeconomic theory, to calculate the change in consumer surplus for crossings of the SHB and SHT following the opening of the SHT and GHF, the area under the income compensated demand curve for the SHT and GHF must be calculated and therefore the demand curve itself must be derived. Since the toll for the harbour crossing only represents typically $10 per week out of

TABLE 1

DEMAND CURVE FOR SYDNEY HARBOUR TUNNEL
CALCULATION OF CHANGE IN CONSUMER SURPLUS

WEEKDAY

At Q=	P=	Slope or a	b in Q=aP+b	d in P=c.Q+d	Toll now	Base Q	Change in cons surp
26470	1.44	-12353	44258.32	3.58279932	1.7598	22519.51	20527
26470	1.44	-9130	39617.2	4.3392333	1.7598	23550.23	30373
26470	1.44	-5906	34974.64	5.92188283	1.7598	24581.26	51155
28921	1.44	-12353	46709.32	3.78121266	1.7598	24970.51	25238
28921	1.44	-9130	42068.2	4.60768894	1.7598	26001.23	37024
28921	1.44	-5906	37425.64	6.33688452	1.7598	27032.26	61864
31372	1.44	-12353	49160.32	3.979626	1.7598	27421.51	30435
31372	1.44	-9130	44519.2	4.87614458	1.7598	28452.23	44333
31372	1.44	-5906	39876.64	6.75188622	1.7598	29483.26	73591

TOTAL

At Q=	P=	Slope or a	b in Q=aP+b	d in P=c.Q+d	Toll now	Base Q	Change in cons surp
23922	1.44	-11619	40653.36	3.49886909	1.7598	20206.24	17570
23922	1.44	-8724	36484.56	4.18209078	1.7598	21132.06	25594
23922	1.44	-5828	32314.32	5.54466712	1.7598	22058.21	41744
26124	1.44	-11619	42855.36	3.68838626	1.7598	22408.24	21608
26124	1.44	-8724	38686.56	4.43449794	1.7598	23334.06	31206
26124	1.44	-5828	34516.32	5.92249828	1.7598	24260.21	50494
28325	1.44	-11619	45056.36	3.87781737	1.7598	24609.24	26061
28325	1.44	-8724	40887.56	4.68679046	1.7598	25535.06	37370
28325	1.44	-5828	36717.32	6.30015786	1.7598	26461.21	60072

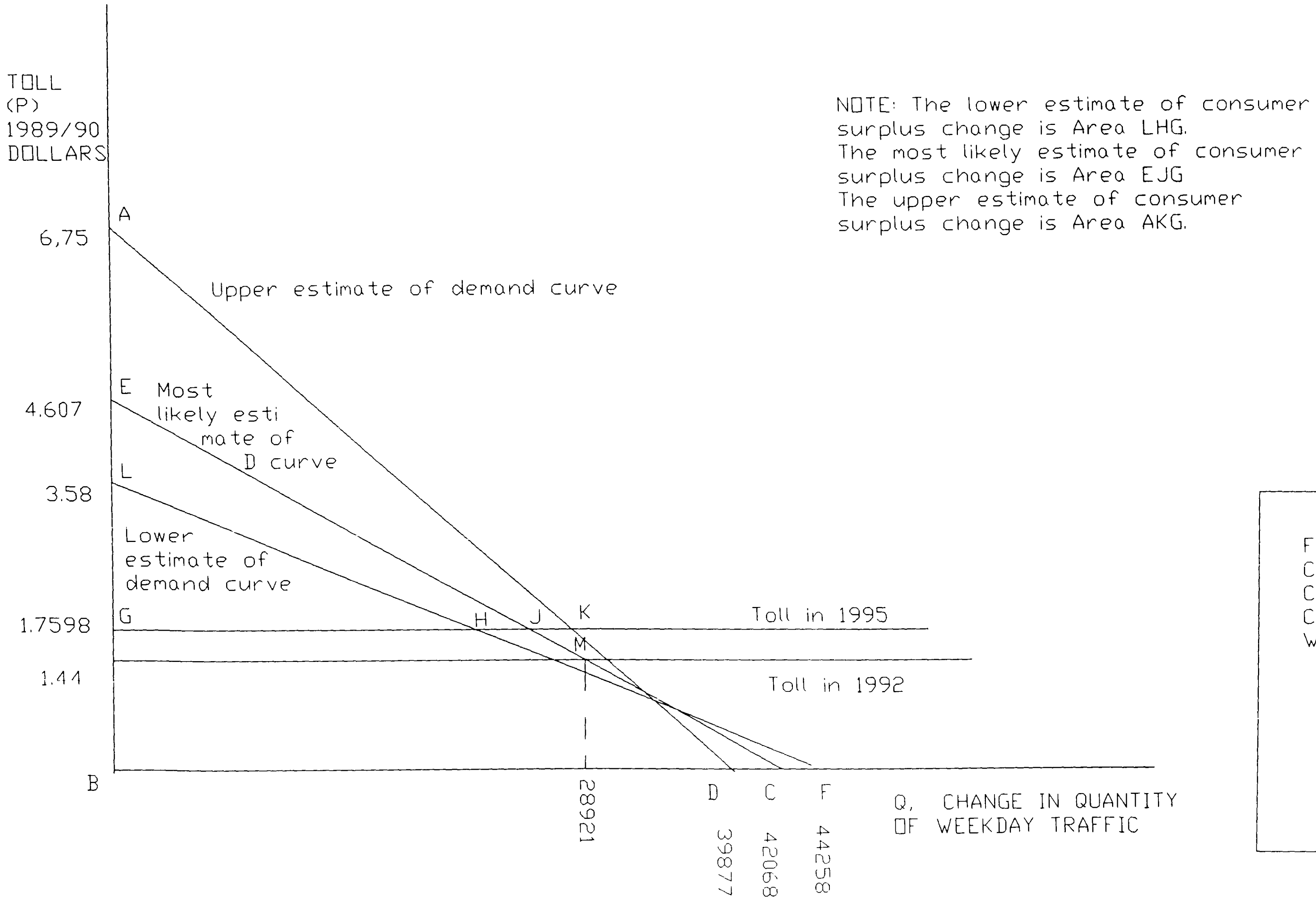


FIGURE 1c
CALCULATION OF CONSUMER SURPLUS CHANGE FOR WEEKDAY TRAFFIC

average weekly earnings of $530.50 for all persons in NSW in August 1992, or 1.9% of income, the demand curve for SHB and SHT use can be taken to be also the income compensated demand curve. The "change in consumer surplus" referred to in this section is the net change in welfare from the opening of the SHT and GHF as measured by changes in the areas under the demand curves.

As explained in Section 6, the change in consumer surplus is assumed to be equal to the triangle EBC in Figure 1b. Figure 1c shows this triangle in more detail, with a shift of origin to the point on the horizontal axis vertically below the point B in Figure 1b. To derive the demand curve, it is necessary to obtain one point through which the curve will pass, and the slope of the curve, which is here assumed to be a straight line. For weekday traffic only, the most likely coefficient for the dummy variable DUMEXGB, which is shown in Appendix 3 to be 578,420 vehicles per 4 weekly period, or 28,921 vehicles per day can be said to be the traffic increase which would have occurred if the toll had not increased but remained at $1.50 nominal, or $1.44 in 1989/90 dollars. This gives a point on the demand curve at quantity demanded of traffic of 28,921 and toll of $1.44. This point is shown as point M on Figure 1c. The slope of the demand curve is given by the coefficient for TOLLW, which is -182,590 vehicles per 4 weekly period, or -9130 vehicles per day per dollar. Thus using standard principles of coordinate geometry, knowing one point on the line and the slope, the demand curve for harbour crossings on the SHB or SHT is:

$$Q = 42068 - 9130.P \text{ or}$$

$$P = 4.607 - Q/9130$$

where Q is the traffic demanded per day and P is the toll at 1989/90 prices. This is line EC on Figure 1c.

Details of the calculation of change in consumer surplus are shown in Table 1, which calculates the change in consumer surplus for weekday and total traffic for the various combinations of induced traffic and responsiveness of traffic to tolls which arise from the confidence intervals of the coefficients of DUMEXGB and TOLL.

From this demand curve, in 1995, with a nominal toll of $2, which is $1.7598 in 1989/90 dollars, the traffic is estimated to be 25,601 vehicles per day, if the other variables such as seasonal factors and GDP are neglected. Thus the consumer surplus, equivalent to the area under the demand curve above the toll level of $1.7598 is Area EJG, which is calculated to be $37,024 per day, in 1989/90 dollars.

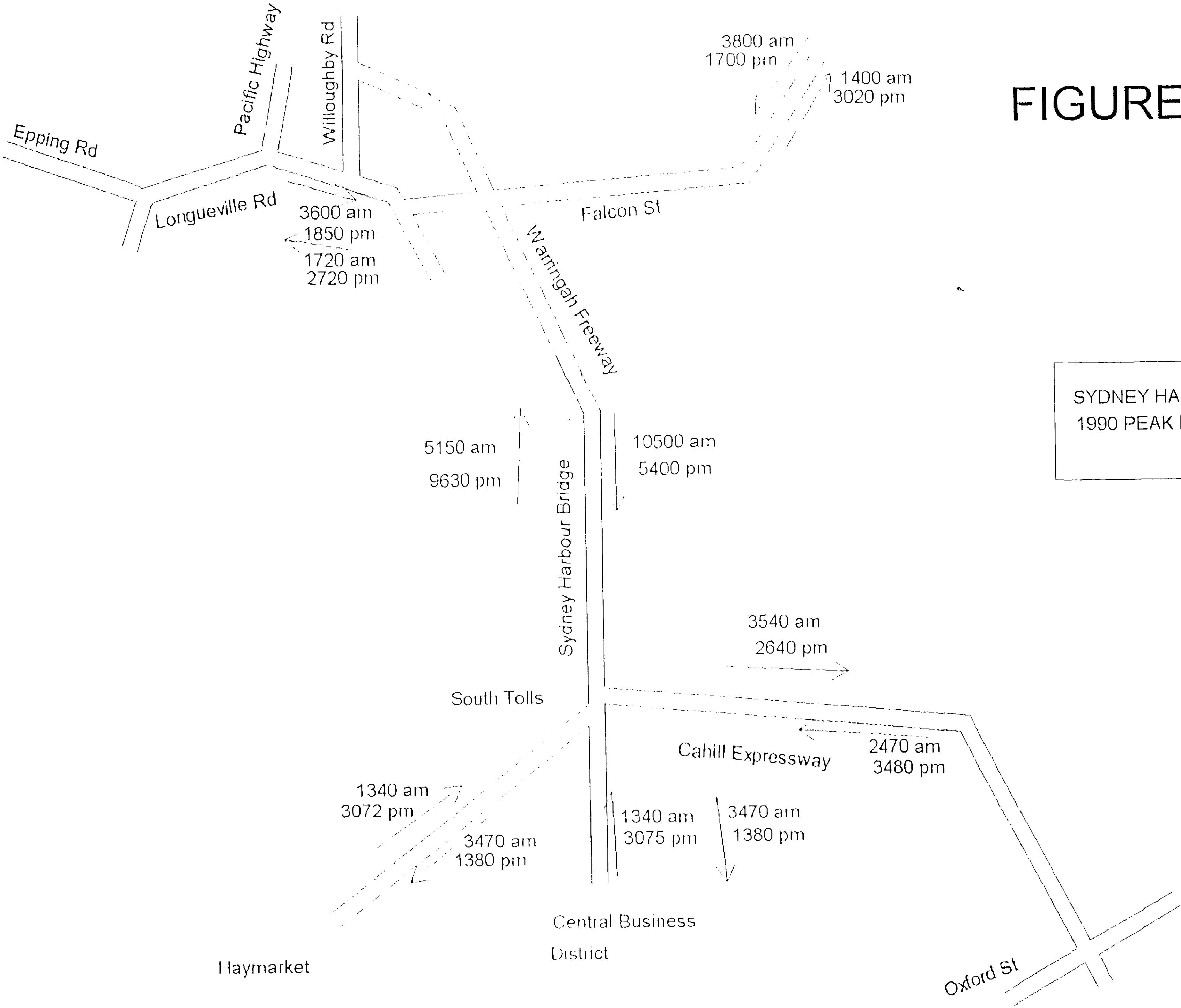
The 95% confidence interval (C.I.) of the consumer surplus is now estimated. At the lower end of the C.I. the demand curve would pass through the point P=$1.44 and Q=26,470, this being the lower end of the C.I. for the coefficient of DUMEXGB. The slope of this lowest consumer surplus demand curve would be -12,353 vehicles per day per dollar of toll. This corresponds to a demand curve of:

$$Q = 44,258 - 12,353.P \text{ or}$$

$$P = 3.58 - Q/12,353$$

This is line LF on Figure 1c, which gives a change in consumer surplus of $20,526 at a nominal toll of $2. This

FIGURE 2

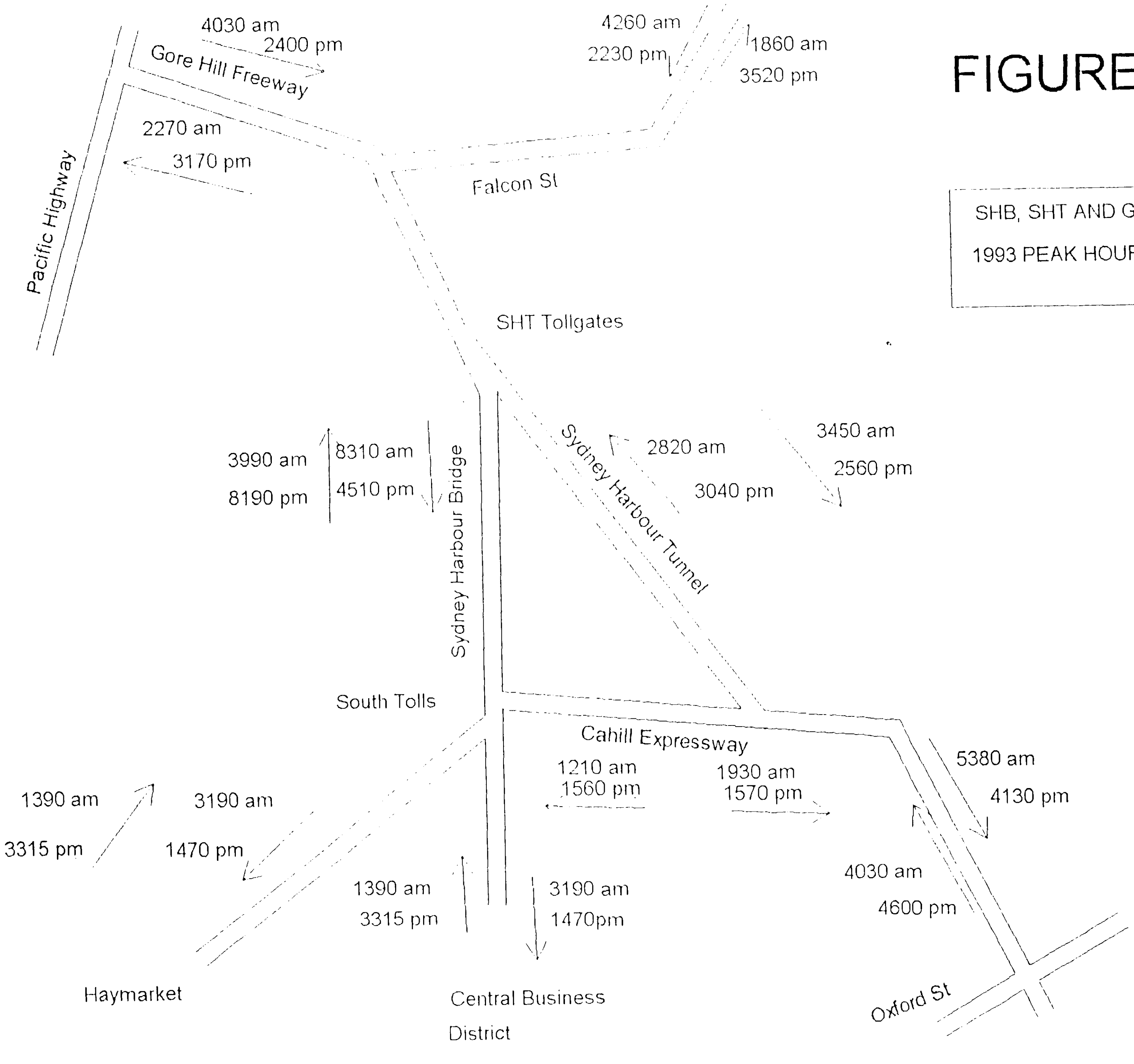


SYDNEY HARBOUR BRIDGE
1990 PEAK HOUR TRAFFIC

FIGURE 3

SHB, SHT AND GHF

1993 PEAK HOUR TRAFFIC



consumer surplus change corresponds to Area LHG on Figure 1c.

For the higher end of the C.I. of consumer surplus, the demand curve would pass through the point P=$1.44 and Q=31,372, this being the higher end of the C.I. for the coefficient of DUMEXGB. The slope of this highest consumer surplus demand curve would be -5,906 vehicles per day per dollar of toll. This corresponds to a demand curve of:

$$Q = 39{,}877 - 5{,}906.P \text{ or}$$
$$P = 6.75 - Q/5{,}906$$

This is line AD on Figure 1c, which gives a change in consumer surplus of $73,591 at a nominal toll of $2. This consumer surplus change corresponds to Area AKG on Figure 1c.

Table 1 gives details of these calculations by deriving the demand curves for the confidence interval values of induced traffic (in the "Q" column) and responsiveness to tolls (in the "a" column). Then, in the "Cons. surp." column, the area between the demand curve and the level of the toll in 1995 is calculated and given in the "Toll now" column. The "Base Q" column gives the value of Q for the toll of $1.7598, this being the base of the triangle whose area gives the change in consumer surplus. The "b in Q=aP+b" column calculates the constant in the demand curve of that form while the "d in P=c.Q+d" column gives the constant in the demand curve expressed in the more usual form with the Price on the left hand side of the equal sign.

In summary, therefore, the change in consumer surplus on an average weekday following the opening of the SHT and GHF is calculated in Table 1 to be:

Lower Estimate	Most Likely Estimate	Upper Estimate
$20,527	$37,024	$73,591

8. CHECK OF THE ACCURACY OF THE CONSUMER SURPLUS MEASURE OF BENEFITS

8.1 CALCULATION OF TIME SAVINGS

For the purposes of the calculation, the number of cars to benefit from these time savings are as measured in the hourly flow figures for 1993 ([14]) and 1990 ([15]). Here it is estimated that peak conditions last for 2 hours in the am and pm peaks. This is longer than the one and a half hours of peak conditions estimated by Cameron McNamara ([16]). It is assumed that only vehicles travelling at peak times will benefit from these time savings. The number of vehicles in the peak hour to travel on the SHB or the SHT and approaches, according to the RTA Traffic Volume Data is shown in Figure 2 for 1990 and Figure 3 for 1993. A number of assumptions have been made to estimate these peak hour traffic volumes as the data is incomplete. The main assumptions are:

(i) Traffic to and from Haymarket and the Central Business District is divided equally after the difference between SHB and Cahill Expressway traffic is calculated.

(ii) All north and south traffic on the Cahill Expressway and the SHT, in 1993 and on the Cahill Expressway in 1990, is assumed to go to and come from Oxford St.

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[14] RTA TRAFFIC VOLUME DATA FOR SYDNEY REGION 1993
[15] RTA TRAFFIC VOLUME DATA FOR SYDNEY REGION 1990
[16] Cameron McNamara Consultants, OP. CIT., Nov 1986 p 33

TABLE 2: HARBOUR BRIDGE TRAVEL TIMES

1990

SOUTHBOUND

	AM PEAK							PM PEAK						
	DIST	Av T	1	2	3	4	5	DIST	Av T	1	2	3	4	5
PACIFIC HWAY														
	0.58	1.25	1.27	1.25	1.17	1.23	1.32		0.74	0.75	0.8	0.65	0.85	0.65
OSBORNE ST														
	0.51	1.21	1.57	0.72	0.67	0.82	2.27		0.9	1.02	0.9	0.62	1.32	0.65
CAMPBELL ST														
	1.35	1.27	5.58	3.25	3.22	4.95	5.88		2.7	4.18	2.12	2.48	2.1	2.6
HERBERT ST														
	0.16	0.38	0.3	0.23	0.32	0.67	0.38		0.38	0.33	0.48	0.47	0.27	0.33
CHRISTIE ST														
	1.04	2.13	1.95	1.88	2.02	2.42	2.38		4.23	2.73	6.57	3.33	6.38	2.15
BROOK ST OFF-R														
	0.09	1.12	2.05	0.63	0.83	1.18	0.88		0.94	0.52	1.38	1.57	0.85	0.4
BROOK ST ON-R														
	0.77	1.01	1	0.82	1.78	0.75	0.68		0.81	0.83	0.88	0.75	0.9	0.67
MILLER ST O'BR														
	0.75	2.36	2.7	2.55	3.15	2.68	0.73		1.01	0.77	1.93	0.73	0.95	0.68
FALCON ST O'B														
	1.13	4.4	8.22	4	3.88	4.27	1.63		3.71	4.53	2.72	4.85	4.97	1.48
MOUNT ST O'B														
	0.5	1.45	1.5	1.35	1.32	2.17	0.9		2.7	1.58	3.42	4.03	2.73	1.72
LAVENDER ST														
	2.16	5.02	5.78	4.08	4.75	5.92	4.58		4.68	3.97	3.6	3.48	3.9	8.43
SOUTHERN TOLLS														
S/T PAC HWAY-STH TLL	9.04	21.6	31.9	20.8	23.1	27.1	21.6	0	22.8	21.2	24.8	23	25.2	19.8
S/T FALCON-STH TLL	3.79	10.9	15.5	9.43	9.95	12.4	7.11	0	11.1	10.1	9.74	12.4	11.6	11.6
S/T MOUNT-STH TLL	2.66	6.47	7.28	5.43	6.07	8.09	5.48	0	7.38	5.55	7.02	7.51	6.63	10.2
S/T LAV. ST-STH TLL	2.16	5.02	5.78	4.08	4.75	5.92	4.58		4.68	3.97	3.6	3.48	3.9	8.43
SOUTHERN TOLLS														
	1.22	1.48	1	1.22	1.48	1.58	2.1	1.22	1.57	1.45	4.53	2.5	0.93	1.42
RP TO PYRMONT														
SOUTHERN TOLLS														
	0.88	0.99	0.95	0.73	1.43	0.97	0.88		0.84	0.82	0.83	0.95	0.83	0.78
TUNNEL N-														
	1.02	1.63	1.22	3.95	0.92	1.05	1.02		1.2	1.78	0.83	1.33	1.1	0.95
SIR JOHN YOUNG														
	0.5	0.78	0.72	0.52	0.67	1.52	0.47		0.81	0.58	0.43	0.77	1.68	0.57
WILLIAM ST OP														
	0.4	0.67	0.9	0.97	0.48	0.22	0.77		1.34	0.78	1	2.4	1.15	1.38
LIVERPOOL ST														
	0.3	1.29	0.92	1.08	1.38	0.7	2.35		1.5	1.57	0.57	1.53	1.58	2.25
OXFORD ST														
S/T SOUTH TLL-OXF.ST	3.1	5.36	4.71	7.25	4.88	4.46	5.49	0	5.69	5.53	3.66	6.98	6.34	5.93

TABLE 3: SHB AND SHT TRAVEL TIMES

1995 SOUTHBOUND	AM PEAK DIST	Av T	1	2	3	4	5	PM PEAK DIST	Av T	1	2	3	4	5
LONGUEVILLE RD														
	0.4	0.68	0.65	0.63	0.67	0.77	0.7	0.4	0.64	0.4	0.48	1.25	0.52	0.55
PACIFIC HWAY														
	2.74	4.64	5.07	4.45	4.48	4.73	4.47	2.74	1.81	1.82	1.78	1.83	1.82	1.8
WILLOUGHBY RD O														
	0.9	0.91	0.98	0.97	0.87	0.87	0.88	0.9	0.63	0.6	0.62	0.65	0.67	0.6
WEST ST O'B														
	0.24	0.23	0.23	0.22	0.23	0.22	0.23	0.24	0.17	0.18	0.17	0.17	0.17	0.17
MILLER ST O'B														
	0.5	0.67	0.3	0.4	1.55	0.7	0.42	0.5	0.37	0.42	0.33	0.4	0.37	0.33
ERNEST ST O'BR														
	0.25	0.38	0.2	0.18	1.08	0.22	0.23	0.25	0.18	0.18	0.18	0.18	0.18	0.18
FALCON ST O'B														
	1.15	1.8	1.55	1.57	1.93	1.87	2.08	1.15	1.05	1.08	1.08	1	1.03	1.03
MOUNT ST O'B														
	0.3	0.21	0.23	0.2	0.2	0.2	0.18	0.37	0.4	0.4	0.4	0.4	0.42	0.37
HIGH ST O'B														
	0.57	1.64	0.72	0.75	2.87	0.87	2.9							
NTH TOLLS														
								0.2	0.2	0.22	0.2	0.17	0.23	0.2
LAVENDER ST														
	1.66	2.54	2.67	2.58	2.33	2.62	2.52	2.1	3.77	2.62	2.45	2.43	5.68	5.67
SOUTHERN TOLLS														
S/T LONG. RD-SOUTH TLL	8.71	13.7	12.6	12	16.2	13.1	14.6	8.85	9.22	7.92	7.69	8.48	11.1	10.9
S/T FALCON-SOUTH TLL	3.68	6.19	5.17	5.1	7.33	5.56	7.68	3.82	5.42	4.32	4.13	4	7.36	7.27
S/T MOUNT ST-SOUTH TLL	2.53	4.39	3.62	3.53	5.4	3.69	5.6	2.67	4.37	3.24	3.05	3	6.33	6.24
S/T LAV. ST-SOUTH TLL	1.66	2.54	2.67	2.58	2.33	2.62	2.52	2.1	3.77	2.62	2.45	2.43	5.68	5.67
SOUTHERN TOLLS														
	1.2	1.05	1.53	0.9	0.9	0.93	1	1.2	1.06	1.07	1.07	1.02	1.03	1.12
HAYMARKET														
SOUTHERN TOLLS														
	0.85	0.83	0.78	0.8	0.88	0.88	0.78		0.88	0.88	0.87	0.87	0.92	0.87
TUNNEL N-														
	1.1	2.67	2.55	2.78	2.57	2.67	2.78		3.35	2.18	3.93	3.95	2.15	4.52
SIR JOHN YOUNG														
	0.5	0.72	0.62	0.83	0.65	0.63	0.85		2.31	0.72	3.3	0.7	1.38	5.47
WILLIAM ST OP														
	0.4	1.23	0.93	2.18	1.03	0.95	1.05		1.17	0.4	0.72	1.95	2.07	0.73
LIVERPOOL ST														
	0.3	1.15	1.32	1.82	0.83	0.95	0.82		1.12	0.75	0.55	1.88	1.88	0.55
OXFORD ST														
S/T SOUTH TLL-OXF.ST	3.15	6.6	6.2	8.41	5.96	6.08	6.28	0	8.83	4.93	9.37	9.35	8.4	12.1
SHT TOLLGATES														
	2.7	2.57	2.68	2.58	2.57	2.52	2.52		2.18	2.17	2.22	2.22	2.17	2.13
DOMAIN TUNNEL N														
	1.1	2.66	2.58	2.5	2.8	2.93	2.47		1.87	1.22	1.18	2.07	2.32	2.55
SIR JOHN YOUNG														
	0.5	1.21	1.13	1.02	1.05	1.55	1.32		1.17	1.17	1.15	1.18	1.17	1.2
WILLIAM ST OP														
	0.4	1.91	2.08	1.6	1.62	2.5	1.75		1.96	1.92	1.7	2.28	2.23	1.67
LIVERPOOL ST														
	0.3	1.91	1.72	1.78	2.42	1.92	1.72		1.79	1.67	1.9	1.45	2.3	1.63
OXFORD ST														
S/T SHT TOLLGATE-OXF. ST VIA SHT	5	10.3	10.2	9.48	10.5	11.4	9.78	0	8.97	8.15	8.15	9.2	10.2	9.18
S/T FALC.ST-SHT TOLLGT	1.24	3.09	3.02	3.12	3.15	3.17	3.02	1.25	1.1	0.95	0.87	1.4	0.88	1.38

(iii) North and south traffic entering and leaving SHB and SHT approaches at Falcon St is assumed to be the same as traffic measured south of the Spit Bridge.

(iv) All north and south traffic to and from the Pacific Highway is assumed to cross either the SHB or SHT.

(v) Because hourly traffic flow figures for 1995 are not yet available, 1993 figures have been used instead, and so it is assumed that peak traffic flows have not changed significantly between 1993 and 1995.

Tables 2 to 5 show the peak hour travel times between various locations on the harbour crossings and approaches in 1990 and 1995. Travel time figures are from the RTA. ([17]). Table 6 shows details of the calculation of total travel times spent in peak hours and of the total time estimated to have been saved by peak time traffic because of the provision of the SHT and GHF.

In the DMR Environmental Impact Statement it is reasoned that the variability of travel time is a cost to motorists. This variability cost is estimated by the DMR to be the cost of a time equal to half the difference between the maximum travel time and the average travel time ([18]), and this measure of variability is added to the predicted time savings in the estimate of benefits.

The average time savings and time variability savings per car due to the provision of the SHT and GHF between 1990 and 1995 have been calculated, as shown on Table 7, to be as follows (in minutes):

---

[17] Central Region RTA, SELECTED TRAVEL TIME DATA, March 1990 and November 1995

[18] DMR SHT ENVIRONMENTAL IMPACT STATEMENT, OP. CIT., p16

	Time Savings per vehicle	Time + Variability Savings per vehicle
Southbound am peak	3.024	4.62
Southbound pm peak	4.579	4.758
Northbound am peak	9.216	9.827
Northbound pm peak	3.392	4.102

These figures give smaller time savings than the DMR predictions, which, after averaging, were:

	Time Savings per vehicle	Time + Variability Savings per vehicle
Southbound am peak	8.9	11.4
Southbound pm peak	8.9	11.4
Northbound am peak	8.9	11.4
Northbound pm peak	8.9	11.4

(DMR p 18)

However the measured time savings are comparable to the value of 5.9 minutes calculated for the DEP study ([19])

8.2 BENEFITS FOR INDUCED TRAFFIC

The problem of time savings attributable to induced, or generated traffic, is dealt with by the DMR in their economic justification by giving an average value of benefits to each induced vehicle equal to half the benefits which would be gained by a vehicle which was travelling across the harbour both before and after the SHT and GHF "in confirmity [sic] with economic theory".

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[19] DEP, OP. CIT., p 54

TABLE 4: HARBOUR BRIDGE TRAVEL TIMES

1990

NORTHBOUND

	AM PEAK							PM PEAK						
	DIST	Av T	1	2	3	4	5	DIST	Av T	1	2	3	4	5
OXFORD ST														
	0.55	2.84	5.15	2.28	1.07	0.95	2.43	0.55	1.79	0.82	2.05	2.15	2.07	1.87
WILLIAM ST OP														
	0.38	0.58	0.47	0.45	0.63	0.52	0.95	0.38	0.56	0.55	0.48	0.47	0.45	0.83
SIR JOHN YOUNG														
	0.2	0.96	1.43	0.2	1.28	0.23	1.15	0.2	0.26	0.25	0.25	0.18	0.27	0.37
CAHILL EXP														
	1.02	7.78	4.69	9.57	10.6	9.13	7.42	1.02	2.13	3.52	3.47	1.22	1	1.45
TUNNEL N-														
	1.32	8.78	9.43	10.3	7.75	9.38	6.4	1.32	3.69	4.7	2.6	3.17	4.37	3.62
SOUTHERN TOLLS														
S/T OXF.ST-SOUTH TLL	3.47	20.9	21.2	22.8	21.4	20.2	18.4	3.47	8.43	9.84	8.85	7.19	8.16	8.14
RP FR CITY STH														
	1.19	15.1	19.5	14.1	13.1	13.7	15.1	1.19	2.84	2.3	3.52	2.68	4.32	1.4
SOUTHERN TOLLS														
S/T CITY STH-SOUTH TLL	1.19	15.1	19.5	14.1	13.1	13.7	15.1	1.19	2.84	2.3	3.52	2.68	4.32	1.4
SOUTHERN TOLLS														
	2	2.31	1.88	1.93	2.92	2.4	2.43	2	2.92	2.1	5.25	2.67	2.55	2.05
LAVENDER ST														
	0.5	0.43	0.4	0.42	0.42	0.43	0.47	0.45	0.45	0.42	0.43	0.52	0.45	0.42
MOUNT ST O'B														
	1.13	0.93	0.94	0.95	0.9	0.93	0.92	1.13	0.93	0.95	0.92	1	0.92	0.88
FALCON ST O'B														
	0.75	0.58	0.57	0.6	0.57	0.6	0.58	0.75	0.62	0.67	0.62	0.6	0.65	0.57
MILLER ST O'BR														
	0.3	0.24	0.22	0.23	0.22	0.3	0.23	0.3	0.23	0.17	0.2	0.32	0.27	0.2
WEST ST O'B														
	0.5	0.39	0.35	0.37	0.37	0.52	0.37	0.5	0.38	0.28	0.35	0.53	0.43	0.32
BROOK ST OFF-R														
	1.04	4.1	3.9	3.33	3.75	6.13	3.38	1.04	5.61	8.18	2.9	6.78	5.61	4.57
PACIFIC HWAY														
	0.16	0.52	0.52	0.7	0.53	0.33	0.5	0.16	0.73	0.83	0.22	1.15	0.78	0.68
HERBERT ST														
	1.35	1.6	1.53	1.67	1.42	1.65	1.75	1.35	2.18	2.6	1.9	2.12	2.28	1.98
CAMPBELL ST														
	0.51	0.84	1.03	0.57	0.53	0.95	1.1	0.51	1.05	1.58	0.83	0.55	1.67	0.62
OSBORNE ST														
	0.58	0.69	0.67	0.68	0.73	0.72	0.67	0.58	1.47	1.08	1.67	1.3	1.78	1.52
LONGUEVILLE RD														
S/T SOUTH TLL- LONGUE	10	27.7	31.5	25.6	25.5	28.6	27.5	9.96	19.4	21.2	18.8	20.2	21.7	15.2
S/T SOUTH TLL- FALCON	3.63	3.67	3.22	3.3	4.24	3.76	3.82	3.58	4.3	3.47	6.6	4.19	3.92	3.35
S/T SOUTH TLL- MOUNT	2.5	2.74	2.28	2.35	3.34	2.83	2.9	2.45	3.37	2.52	5.68	3.19	3	2.47
S/T SOUTH TLL-LAV. ST	2	2.31	1.88	1.93	2.92	2.4	2.43	2	2.92	2.1	5.25	2.67	2.55	2.05

TABLE 5: SHB AND SHT TRAVEL TIMES

1995 NORTHBOUND	AM PEAK DIST	Av T	1	2	3	4	5	PM PEAK DIST	Av T	1	2	3	4	5
OXFORD ST														
	0.55	2.43	3.68	1.98	2.33	1.98	2.15	0.55	2.46	2.95	2.15	2.17	2.65	2.4
WILLIAM ST														
	0.38	0.74	0.88	0.68	0.62	0.87	0.63	0.38	0.55	0.67	0.47	0.63	0.52	0.48
SIR JOHN YOUNG														
	0.13	0.25	0.27	0.28	0.27	0.23	0.2	0.13	0.26	0.23	0.22	0.33	0.25	0.27
CAHILL EXPRWY														
	1	1.03	1.03	1	1.07	1.03	1	1	0.99	1.03	0.97	1.03	0.97	0.93
DOMAIN TUNNEL N														
	1.26	1.96	2.23	1.6	2.27	2.12	1.58	1.26	1.76	1.53	1.52	2.07	1.58	2.1
SOUTHERN TOLLS														
S/T OXF.ST-SOUTH TLL	3.32	6.41	8.09	5.54	6.56	6.23	5.56	3.32	6.02	6.41	5.33	6.23	5.97	6.18
HAYMARKET														
	0.25	0.66	1.53	0.73	0.47	0.25	0.3	0.25	0.25	0.22	0.23	0.28	0.27	0.23
ERSKINE ST RAMP														
	0.88	6.94	8.5	8.63	6.05	5.75	5.77	0.88	1.05	1.47	0.85	0.85	1.3	0.8
SOUTHERN TOLLS														
S/T SOUTH TLL-HYMKT	1.13	7.6	10	9.36	6.52	6	6.07	1.13	1.3	1.69	1.08	1.13	1.57	1.03
SOUTHERN TOLLS														
	2	2.27	2.27	2.13	2.27	2.38	2.28	2	1.91	1.83	1.88	1.95	1.98	1.92
LAVENDER ST														
S/T SOUTH TLL-LAV ST	2	2.27	2.27	2.13	2.27	2.38	2.28	2	1.91	1.83	1.88	1.95	1.98	1.92
SOUTHERN TOLLS														
	2	2.27	2.27	2.13	2.27	2.38	2.28	2	1.91	1.83	1.88	1.95	1.98	1.92
LAVENDER ST														
	0.22	0.19	0.18	0.18	0.22	0.18	0.2	0.22	0.18	0.18	0.18	0.18	0.15	0.2
HIGH ST O'B														
	0.3	0.22	0.2	0.22	0.22	0.22	0.23	0.3	0.22	0.22	0.22	0.2	0.23	0.22
MOUNT ST O'B														
	1.15	1.26	1.13	1.55	1.15	1.22	1.15	1.15	1.54	1.54	1.54	1.57	1.58	1.47
FALCON ST O'B														
	0.25	0.17	0.17	0.17	0.17	0.17	0.17	0.25	0.19	0.2	0.22	0.17	0.17	0.18
ERNEST ST O'B														
	0.5	0.44	0.42	0.45	0.45	0.48	0.4	0.5	0.42	0.45	0.18	0.43	0.38	0.37
MILLER ST O'BR														
	0.24	0.17	0.17	0.17	0.18	0.17	0.18	0.24	0.19	0.23	0.18	0.17	0.17	0.2
WEST ST O'B														
	0.9	0.53	0.5	0.55	0.53	0.52	0.53	0.9	0.62	0.68	0.58	0.58	0.62	0.62
WILLOUGHBY RD O														
	2.74	1.67	1.88	1.87	1.88	1.82	1.92	2.74	2.05	2.18	2.18	1.85	2.18	1.67
PACIFIC HWAY OB														
S/T SOUTH TLL-PAC HWY	8.3	7.12	6.92	7.29	7.07	7.16	7.06	8.3	7.32	7.51	7.16	7.1	7.46	7.05
S/T SOUTH TLL-FALC ST	3.67	3.94	3.78	4.08	3.86	4	3.86	3.67	3.85	3.77	3.82	3.9	3.94	3.81
S/T SOUTH TLL-MOUNT ST	2.52	2.68	2.65	2.53	2.71	2.78	2.71	2.52	2.31	2.23	2.28	2.33	2.36	2.34
OXFORD ST														
	0.55	2.98	4.33	2.45	2.45	2.5	3.17		1.84	1.47	2.67	1.25	1.25	2.58
WILLIAM ST														
	0.38	1.33	1.42	1.45	1.42	1.18	1.18		0.54	0.43	0.47	0.63	0.47	0.7
SIR JOHN YOUNG														
	0.13	0.42	0.37	0.6	0.63	0.23	0.25		0.3	0.6	0.2	0.2	0.25	0.27
CAHILL EXPRWY														
	1	0.9	0.63	0.77	0.88	0.62	1.6		0.85	0.82	0.9	0.82	0.88	0.85
DOMAIN TUNNEL N														
	2.7	2.17	2.02	2.12	2.35	2.37	2		2.08	2.02	2.02	2.18	2	2.17
S/T OXF. ST-SHT TOLL VIA SHT	4.76	7.8	8.77	7.39	7.73	6.9	8.2	0	5.61	5.34	6.26	5.08	4.85	6.57
SHT TOLLGATES														
	1.24	1.34	1.58	0.95	1.47	1.77	0.93		1.39	0.97	1	1.08	2.7	1.22
FALCON ST														
	0.25	0.17	0.17	0.17	0.17	0.17	0.17	0.25	0.19	0.2	0.22	0.17	0.17	0.18
ERNEST ST O'B														
	0.5	0.44	0.42	0.45	0.45	0.48	0.4	0.5	0.42	0.45	0.18	0.43	0.38	0.37
MILLER ST O'BR														
	0.24	0.17	0.17	0.17	0.18	0.17	0.18	0.24	0.19	0.23	0.18	0.17	0.17	0.2
WEST ST O'B														
	0.9	0.53	0.5	0.55	0.53	0.52	0.53	0.9	0.62	0.68	0.58	0.58	0.62	0.62
WILLOUGHBY RD O														
	2.74	1.87	1.88	1.87	1.88	1.82	1.92	2.74	2.05	2.18	2.18	1.85	2.18	1.87
PACIFIC HWAY OB														
S/T SHT TOLL-PAC HWY	5.87	4.52	4.72	4.16	4.68	4.93	4.13	4.63	4.86	4.71	4.34	4.28	6.22	4.46
S/T SHT TOLL-FALC.ST	1.24	1.34	1.58	0.95	1.47	1.77	0.93	1.24	1.39	0.97	1	1.08	2.7	1.22

([20]) The question of the value of benefits to induced traffic was dealt with by Foster and Beesley in 1963 ([21]). I will attempt to paraphrase the argument of Foster and Beesley in the following manner: some individuals will find the time savings offered just enough to attract them to use the new facility, others would have been attracted to the facility by lesser time savings, still others would have been induced to change their mode or route of travel to use the new facility by only a very slight time saving. Thus a demand curve of time taken on the facility (as a measure of price which the consumer is prepared to pay) versus traffic demand at that level of service on the facility can be envisaged.

This demand curve takes the form shown in Figure 4, where FG represents the downward sloping demand curve, OA is time spent on the old facility and OB is the lesser time spent on the new facility. The time saving of AB increases the traffic level by HJ, which represents the induced traffic. Those members of the induced traffic group close to point H are the ones who were ready to use the new facility for a very slight time saving and the members close to point J are the ones for whom the time saving has only just made it worth their while. The benefits derived for the induced traffic group are given by the area of the triangle CDE. For those individuals comprising the base traffic, the increase in benefits is given by the rectangle ABCD. Since the area of triangle CDE is half the area of a rectangle of sides CD and DE, it can be seen that the benefits per vehicle for induced traffic are a half the benefits per vehicle of base traffic. This analysis assumes that the demand curve FG is linear, and that the value of time is the same for the induced traffic as for the base traffic. Foster and Beesley therefore also value the benefits to induced

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[20] DMR SHT ENVIRONMENTAL IMPACT STATEMENT, OP. CIT., P 19

[21] C.D. Foster & M.E. Beesley, "Estimating the Social Benefits of Constructing an Underground Railway in London", JOURNAL OF THE ROYAL STATISTICAL SOCIETY, 1963, Part I, p 77

traffic at half the rate per vehicle compared to base traffic, as will the calculations performed here.

8.3 THE VALUE OF TRAVELLING TIME SAVED

Naturally, the value of travel time savings depends on the average value of each hour to the motorists. This value of time has been the subject of considerable study and controversy. The average value of time for motorists used in the initial DMR cost benefit analysis for the SHT was $6.00 per hour, increasing to $7.70 per hour after 1999, in 1986 dollars([22]). These values of time savings were larger than the values used to justify the GHF because of assumed higher bus occupancy rates in the SHT EIS([23]). The Department of Environment and Planning (DEP) environmental impact statement of 1987 agreed with the DMR value per hour of time savings figure before 1999 but found that the value of time after the year 2000 should be $6.90 and that therefore the DMR had overestimated time savings for the period 2000 to 2021([24]), differing from the DMR's value mainly because of a different prediction in traffic composition rather than using different time values per person. The Travers Morgan Study of July 1986 used values of time of $4.55 and $7.10 ([25]) for peak and off peak times respectively, smaller than the corresponding DMR values of $5.10 and $8.70([26]). Both the DEP ([27]) and Travers Morgan ([28]) studies found that the SHT is not economically justified.

The DEP engaged Professor J. Black and Mr G. Kim to model and predict cross harbour traffic trends. Black and Kim devised a model for the traffic which gave predicted time

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[22] DMR SHT ENVIRONMENTAL IMPACT STATEMENT, OP. CIT., p7
[23] DEP, OP. CIT,. p 50
[24] DEP, OP. CIT., p 51
[25] Travers Morgan, ECONOMIC EVALUATION OF THE SYDNEY HARBOUR TUNNEL July 1986 p20
[26] DMR SHT ENVIRONMENTAL IMPACT STATEMENT, OP. CIT., p 7
[27] DEP, OP. CIT., p 5
[28] Travers Morgan, ECONOMIC EVALUATION OF THE SYDNEY HARBOUR TUNNEL OP. CIT., p 30

TABLE 6

CALCULATION OF AVERAGE PEAK HOUR TIME SAVINGS AFTER COMPLETION OF
THE GORE HILL FREEWAY AND THE SYDNEY HARBOUR TUNNEL

1990

SOUTHBOUND	AM PEAK DIST	Av T	VARIA-BILITY	Time + Variab.	Av. Speed	Traff-ic	Prop-ortion	Av T. X Prop.	Time + Var. X Prop.	Speed X Prop.	Dist. X Prop.	PM PEAK DIST	Av T	VARIA-BILITY	Time + Variab.	Av. Speed	Traff-ic	Prop-ortion	Av T. X Prop.	Time + Var. X Prop.	Speed X Prop.	Dist. X Prop.
S/T PAC HWAY-STH TLL	9.04	21.6	5.16	26.76	25.11	3600	0.206	4.441	5.50	5.16	1.86	9.04	22.8	1.21	24.01	23.79	1850	0.196	4.478	4.72	4.67	1.78
S/T FALCON-STH TLL	3.79	10.87	2.316	13.185	20.92	6900	0.394	4.283	5.20	8.24	1.49	3.79	11.09	0.835	11.73	20.50	3550	0.377	4.179	4.42	7.73	1.43
S/T MOUNT-STH TLL	2.66	6.47	0.81	7.28	24.67		0.000	0.000	0.00	0.00	0.00	2.66	7.38	1.385	8.765	21.63		0.000	0.000	0.00	0.00	0.00
S/T LAV. ST-STH TLL	2.16	5.02	0.45	5.47	25.82		0.000	0.000	0.00	0.00	0.00	2.16	4.68	1.875	6.555	27.69		0.000	0.000	0.00	0.00	0.00
S/T SOUTH TLL-PYRMT	1.22	1.48	0.31	1.79	49.46	3470	0.198	0.293	0.35	9.80	0.24	1.22	1.57	1.48	3.05	46.62	1380	0.146	0.230	0.45	6.83	0.18
S/T SOUTH TLL-OXF.ST	3.1	5.36	0.945	6.305	34.70	3540	0.202	1.084	1.27	7.02	0.63	3.1	5.69	0.645	6.335	32.69	2640	0.280	1.595	1.78	9.16	0.87
S/T LAV.ST-OXF.ST	5.26	10.38	0.475	10.855	30.40		0.000	0.000	0.00	0.00	0.00	5.26	10.37	1.995	12.37	30.43		0.000	0.000	0.00	0.00	0.00
						17510	1	10.1	12.33	30.22	4.22						9420	1	10.48	11.36	28.39	4.25
TRAFFIC									10500											5400		

1995

SOUTHBOUND	AM PEAK DIST	Av T	VARIA-BILITY	Time + Variab.	Av. Speed	Traff-ic	Prop-ortion	Av T. X Prop.	Time + Var. X Prop.	Speed X Prop.	Dist. X Prop.	PM PEAK DIST	Av T	VARIA-BILITY	Time + Variab.	Av. Speed	Traff-ic	Prop-ortion	Av T. X Prop.	Time + Var. X Prop.	Speed X Prop.	Dist. X Prop.
S/T LONG. RD-SOUTH TLL	8.71	13.7	1.255	14.955	38.15	4030	0.198	2.716	2.96	7.56	1.73	8.85	9.22	0.935	10.16	57.59	2400	0.189	1.746	1.92	10.91	1.68
S/T FALCON-SOUTH TLL	3.68	6.19	0.745	6.935	35.67	4280	0.211	1.303	1.46	7.51	0.77	3.62	5.42	0.97	6.39	42.29	2110	0.167	0.903	1.06	7.04	0.64
S/T MOUNT ST-SOUTH TLL	2.53	4.39	0.605	4.995	34.58		0.000	0.000	0.00	0.00	0.00	2.67	4.37	0.98	5.35	36.66		0.000	0.000	0.00	0.00	0.00
S/T LAV. ST-SOUTH TLL	1.66	2.54	0.065	2.605	39.21		0.000	0.000	0.00	0.00	0.00	2.1	3.77	0.955	4.725	33.42		0.000	0.000	0.00	0.00	0.00
S/T SOUTH TLL-HYMKT	1.2	1.05	0.24	1.29	68.57	3190	0.157	0.165	0.20	10.76	0.19	1.2	1.06	0.03	1.09	67.92	1470	0.116	0.123	0.13	7.88	0.14
S/T SOUTH TLL-OXF.ST	3.15	6.6	0.905	7.505	28.64	1930	0.095	0.627	0.71	2.72	0.30	3.15	8.83	1.655	10.49	21.40	1570	0.124	1.094	1.30	2.65	0.39
S/T SHT TOLLGATE-OXF.	5	10.26	0.58	10.84	29.24	3450	0.170	1.741	1.84	4.96	0.85	5	8.97	0.61	9.58	33.44	2560	0.202	1.812	1.94	6.76	1.01
ST. VIA SHT							0.000															
S/T FALC. ST-SHT TOLLGATE	1.25	3.09	0.04	3.13	24.27	3450	0.170	0.524	0.53	4.12	0.21	1.25	1.1	0.15	1.25	68.18	2560	0.202	0.222	0.25	13.78	0.25
						20330	1	7.076	7.7101	37.63	4.0493						12670	1	5.901	6.602	49.019	4.105
TRAFFIC									11760											7070		

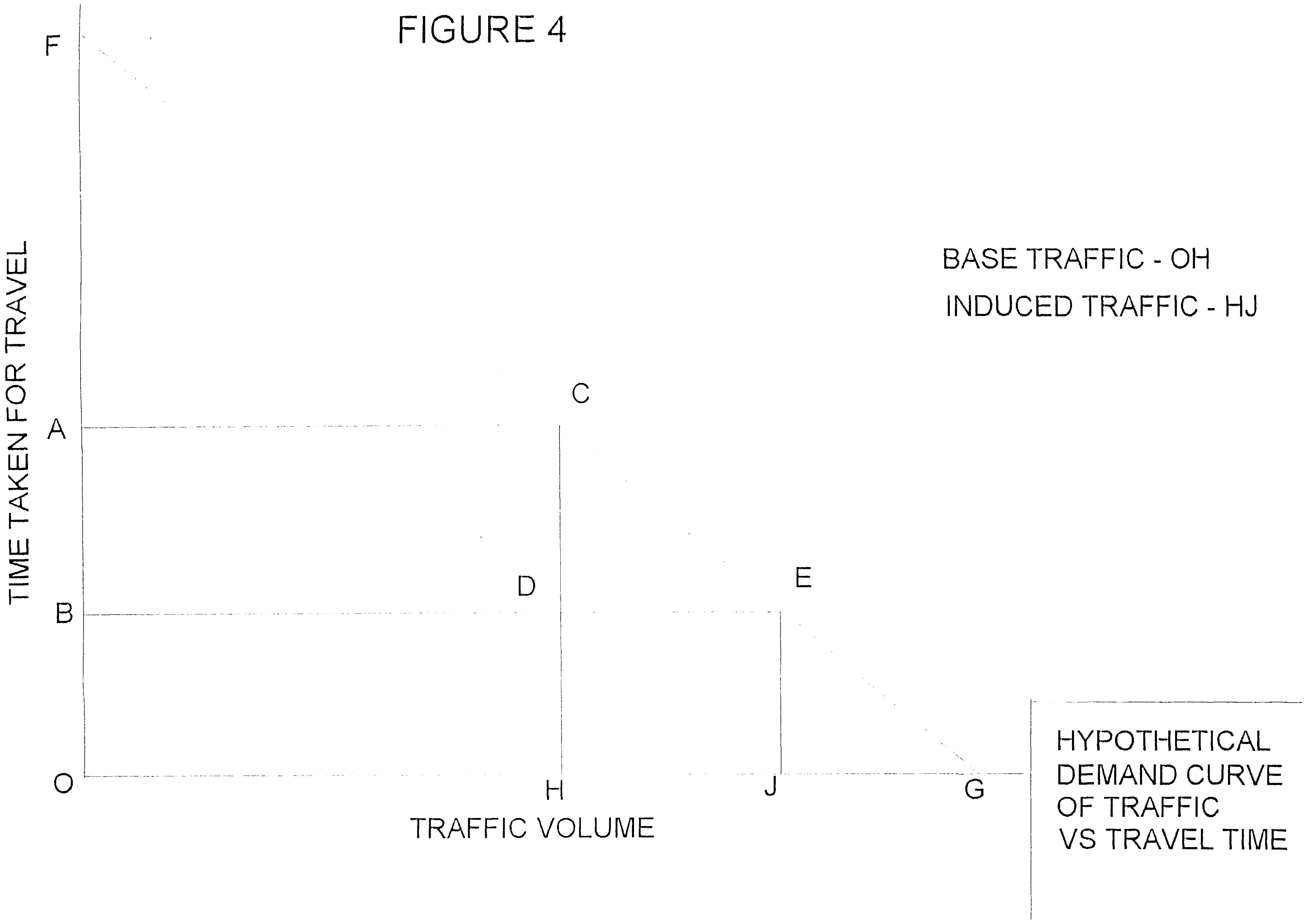
1990

NORTHBOUND	AM PEAK DIST	Av T	VARIA-BILITY	Time + Variab.	Av. Speed	Traff-ic	Prop-ortion	Av T. X Prop.	Time + Variab. X Prop.	Speed X Prop.	Dist. X Prop.	PM PEAK DIST	Av T	VARIA-BILITY	Time + Variab.	Av. Speed	Traff-ic	Prop-ortion	Av T. X Prop.	Time + Variab. X Prop.	Speed X Prop.	Dist. X Prop.
S/T OXF.ST-SOUTH TLL	3.47	20.94	0.92	21.86	9.94	2470	0.276	5.773	6.03	2.74	0.96	3.47	8.43	0.705	9.135	24.70	3480	0.215	1.813	1.96	5.31	0.75
S/T CITY STH-SOUTH TLL	1.19	15.1	2.19	17.29	4.73	1340	0.15	2.258	2.59	0.71	0.18	1.19	2.84	0.74	3.58	25.14	3075	0.19	0.540	0.68	4.78	0.23
S/T SOUTH TLL- LONGUE	10.01	27.73	1.878	29.608	21.66	1720	0.192	5.323	5.68	4.16	1.92	9.96	19.41	1.15	20.56	30.79	2720	0.168	3.262	3.46	5.17	1.67
S/T SOUTH TLL- FALCON	3.63	3.67	0.285	3.955	59.35	3430	0.383	1.405	1.51	22.72	1.39	3.58	4.3	1.15	5.45	49.95	6910	0.427	1.836	2.33	21.33	1.53
S/T SOUTH TLL- MOUNT	2.5	2.74	0.3	3.04	54.74		0	0.000	0.00	0.00	0.00	2.45	3.37	1.155	4.525	43.62		0	0.000	0.00	0.00	0.00
S/T SOUTH TLL-LAV. ST	2	2.31	0.305	2.615	51.95		0	0.000	0.00	0.00	0.00	2	2.92	1.165	4.085	41.10		0	0.000	0.00	0.00	0.00
S/T OXF.ST-LAV.ST	5.47	23.25	0.73	23.98	14.12		0	0.000	0.00	0.00	0.00	5.47	11.35	1.375	12.73	28.92		0	0.000	0.00	0.00	0.00
S/T LAV.ST-LONGUE ST.	8.01	25.42	2.093	27.513	18.91		0	0.000	0.00	0.00	0.00	7.96	16.49	1.335	17.83	28.96		0	0.000	0.00	0.00	0.00
						8960	1	14.76	15.81	30.324	4.4457						16185	1	7.45	8.426	36.588	4.174
TRAFFIC									5150											9630		

1995

NORTHBOUND	AM PEAK DIST	Av T	VARIA-BILITY	Time + Variab.	Av. Speed	Traff-ic	Prop-ortion	Av T. X Prop.	Time + Variab. X Prop.	Speed X Prop.	Dist. X Prop.	PM PEAK DIST	Av T	VARIA-BILITY	Time + Variab.	Av. Speed	Traff-ic	Prop-ortion	Av T. X Prop.	Time + Variab. X Prop.	Speed X Prop.	Dist. X Prop.
S/T OXF.ST-SOUTH TLL	3.32	6.41	0.84	7.25	31.08	1210	0.112	0.717	0.81	3.48	0.37	3.32	6.02	0.195	6.215	33.09	1560	0.085	0.514	0.53	2.82	0.28
S/T HYMKT-SOUTH TLL	1.13	7.6	1.215	8.815	8.92	1390	0.128	0.976	1.13	1.15	0.15	1.13	1.3	0.195	1.495	52.15	3315	0.181	0.236	0.27	9.46	0.20
S/T SOUTH TLL-PAC HWY	8.3	7.12	0.085	7.205	69.94	860	0.079	0.566	0.57	5.56	0.66	8.3	7.32	0.095	7.415	68.03	2310	0.126	0.925	0.94	8.59	1.05
S/T SOUTH TLL-FALC ST	3.67	3.94	0.07	4.01	55.89	1720	0.159	0.626	0.64	8.88	0.58	3.67	3.85	0.045	3.895	57.19	5020	0.275	1.057	1.07	15.70	1.01
S/T SOUTH TLL-MOUNT ST	2.52	2.68	0.05	2.73	56.42		0	0.000	0.00	0.00	0.00	2.52	2.31	0.025	2.335	65.45		0	0.000	0.00	0.00	0.00
S/T SOUTH TLL-LAV ST	2	2.27	0.055	2.325	52.86		0	0.000	0.00	0.00	0.00	2	1.91	0.035	1.945	62.83		0	0.000	0.00	0.00	0.00
S/T OXF. ST-SHT TOLL	4.76	7.8	0.486	8.285	36.62	2820	0.261	2.033	2.16	9.54	1.24	4.76	5.61	0.48	6.09	50.91	3040	0.166	0.933	1.01	8.46	0.79
VIA SHT							0											0				
S/T SHT TOLL-PAC HWY	5.87	4.52	0.205	4.725	77.92	940	0.087	0.393	0.41	6.77	0.51	4.63	4.86	0.68	5.54	57.16	860	0.047	0.229	0.26	2.69	0.22
S/T SHT TOLL-FALC. ST	1.24	1.34	0.215	1.555	55.52	1880	0.174	0.233	0.27	9.65	0.22	1.24	1.39	0.655	2.045	53.53	2180	0.119	0.166	0.24	6.38	0.15
						10820	1	5.544	5.993	45.024	3.7256						18285	1	4.058	4.324	54.109	3.701
TRAFFIC									6810											11230		

FIGURE 4


F
TIME TAKEN FOR TRAVEL
A
B
O
C
D
E
H
J
G
TRAFFIC VOLUME
BASE TRAFFIC - OH
INDUCED TRAFFIC - HJ
HYPOTHETICAL DEMAND CURVE OF TRAFFIC VS TRAVEL TIME

savings of 5.9 minutes for 1992 which were smaller than the DMR predictions ([29]). The DMR conceded that its methods for calculating travel time savings were not very rigorous ([30]) and, from a revised model of its own, reduced the predicted time savings to 10.3 minutes. ([31]) However, this reduced time savings to a point where the SHT was no longer economically justified. The DMR then used larger figures for the average value of time savings from David Hensher, who has argued in papers published subsequently, that the VTTS then in use were out of date, being merely updates of figures whose context may have lost some relevance, especially for non-work travel. [32] The larger VTTS figures suggested by David Hensher were crucial in giving benefit cost ratios of greater than one and thus in the economic justification of the SHT project [33]. The figures for VTTS used here, and the vehicle occupancy rates, are from a paper written in 1990 by D.A Hensher et al [34]. As shown in Table 7, these figures give a weighted average for VTTS of $6.66 on 1989/90 dollars.

The total value of the time savings is calculated in Table 7, using the above reasoning for the values given to induced vehicle benefits and to the value of time. The calculations of Table 7 give a total value of time saved during peak hours of $36,499 for base traffic and $4,070 for induced traffic, giving a total benefit of time savings per day during peak periods of $40,569 in 1989/90 dollars.

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[29] DEP, OP. CIT., p54

[30] Beder, S., COST BENEFIT ANALYSIS: AN EXPLANATION USING THE SYDNEY HARBOUR TUNNEL AS A CASE STUDY, Environmental Education Project, University of Sydney, 1992, p 12

[31] LOC. CIT.

[32] D. A. Hensher, "Behavioural and Resource Values of Travel Time Savings: a Bicentennial Update", Australian Road Research 19(3), September 1989, p223

[33] Beder, S., OP. CIT., p 14.

[34] D.A Hensher, F.W. Milthorpe, N.C. Smith and P.O. Barnard, "Urban Tolled Roads and the Value of Travel Time Savings" ECONOMIC RECORD June 1990 pp 146 - 156, Tables 5 & 6 p 152, 153

8.4 SAVINGS IN VEHICLE OPERATING COSTS DURING PEAK TIMES

To assess the actual savings in vehicle operating costs (VOC) due to the higher speeds attainable by vehicles after the provision of the SHT and GHF, the formula used by the DMR is:

VOC = 10.8 + 230/V ([35])

where VOC = vehicle operating costs in 1986 cents per km and
V = speed in km/hour

The calculation of VOC savings for the peak periods of a typical weekday is given in Table 8. This calculation uses the DMR formula and the values of time savings and vehicular speeds calculated from RTA measurements, The induced traffic is again given a benefit valued at half the rate per vehicle as that given to the base traffic. These calculations give a total of $10,495 (1989/90 dollars) for VOC savings during the peak periods on a typical weekday as a result of the provision of the SHT and the GHF.

8.5 SAVINGS IN FUEL COSTS DURING OFF PEAK TIMES

Following the method used by the DMR, for off peak times the savings to users of the SHT and GHF are assumed to be the fuel savings resulting from the shorter distances which users of the SHT and GHF need to travel compared with the situation before these facilities were built. ([36]) For peak periods these savings were included in the calculation of vehicle operating costs. The calculation of fuel savings is shown in Table 9, where the total

[35] DMR SHT ENVIRONMENTAL IMPACT STATEMENT, OP. CIT., p 7
[36] DMR SHT ENVIRONMENTAL IMPACT STATEMENT, OP. CIT., p 2[illegible]

TABLE 7

CALCULATION OF VALUE OF TRAVEL TIME SAVED AFTER THE CONSTRUCTION OF THE SHT AND THE GHF

	Time plus Varia-bility per vehicle (f)	SHB Peak Traffic per hour (g)	SHT Peak Traffic per hour (h)	Total Peak Traffic per hour (j=g+h)	Saving in Time and Variablity per veh. (k= f(1990)-f(1995))	Time saving for 1990 traffic (min.) (m=f x j)	Total Time Savings over 2 hr peak periods (hours) (r=sum of m	Induced Peak Traffic Per hour (n= j(1995)-j(1990)	Notion-al Time Saving for induced Traffic over 2 hour peak period (hours) (p=fxn)	Total Notional Time Saving for induced Traffic (hours) (sum of p)	Value of Time per hour in 1989/90 dollars (from q)	Value of Total Peak Travel Time Saved per day for base traffic (1989/90 dollars) (s=r x q)	Value of Notional Time Savings for Induced Traffic (at half the value per hour of base traffic) (t=pxq/2)	Value of Total Peak hour time savings in 1989/90 dollars per day (=s + t)
1990														
SB AM	12.33	10500	0	10500										
SB PM	11.36	5400	0	5400										
NB AM	15.81	5150	0	5150										
NB PM	8.426	9630	0	9630										
1995														
SB AM	7.71	8310	3450	11760										
SB PM	6.602	4510	2560	7070										
NB AM	5.983	3990	2820	6810										
NB PM	4.324	8190	3040	11230										
SB AM					4.62	48510		1260	194					
SB PM					4.758	25693		1670	265					
NB AM					9.827	50609		1660	544					
NB PM					4.102	39502	5477	1600	219	1221	6.66	36499	4070	40569

CALCULATION OF AVERAGE VALUE OF TIME SAVINGS

Cate-gory of vehicle	Prop-ortion of Traffic (a)	VTTS per Minute (cents) (b)	No. of adults per vehicle (c)	Prod-uct d=a.b.c	Average VTTS per vehicle (sum of column d) (cents/min.) (e)	Average VTTS per vehicle ($/hour) (q=e/60)
Private Commuter	0.6	7.75	1.12	5.21		
Business Commuter	0.1	13.12	1.2	1.57		
Travel as Part of Work	0.1	16.84	1.44	2.42		
Non-work Related Travel	0.2	4.82	1.97	1.90		
					11.11	6.66

TABLE 8
CALCULATION OF PEAK PERIOD VEHICLE OPERATING COSTS SAVINGS AFTER COMPLETION OF
THE GORE HILL FREEWAY AND THE SYDNEY HARBOUR TUNNEL

1990

SOUTHBOUND

	AM PEAK DIST	Av T	Av. Speed	Traff-ic	Prop-ortion	VOC/KM $89/90	VOC $89/90	VOC X Prop.	PM PEAK DIST	Av T	Av. Speed	Traff-ic	Prop-ortion	VOC/KM $89/90	VOC $89/90	VOC X Prop.
S/T PAC HWAY-STH TLL	9.04	21.6	25.11	3600	0.205	0.20	1.80	0.371	9.04	22.8	23.79	1850	0.196	0.20	1.85	0.363
S/T FALCON-STH TLL	3.79	10.87	20.92	6900	0.394	0.22	0.83	0.325	3.79	11.09	20.50	3550	0.377	0.22	0.83	0.314
S/T MOUNT-STH TLL	2.66	6.47	24.67		0.000	0.20	0.54	0.000	2.66	7.38	21.63		0.000	0.21	0.57	0.000
S/T LAV. ST-STH TLL	2.16	5.02	25.82		0.000	0.20	0.43	0.000	2.16	4.68	27.69		0.000	0.19	0.41	0.000
S/T SOUTH TLL-PYRMT	1.22	1.48	49.46	3470	0.198	0.15	0.19	0.037	1.22	1.57	46.62	1380	0.146	0.16	0.19	0.028
S/T SOUTH TLL-OXF.ST	3.1	5.36	34.70	3540	0.202	0.17	0.54	0.109	3.1	5.69	32.69	2640	0.280	0.18	0.55	0.155
S/T LAV.ST-OXF.ST	5.26	10.38	30.40		0.000	0.18	0.97	0.000	5.26	10.37	30.43		0.000	0.18	0.97	0.000
				17510	0.999			0.843				9420	1			0.861
TRAFFIC								10500								5400

1995

SOUTHBOUND

	AM PEAK DIST	Av T	Av. Speed	Traff-ic	Prop-ortion	VOC/KM $89/90	VOC $89/90	VOC X Prop.	PM PEAK DIST	Av T	Av. Speed	Traff-ic	Prop-ortion	VOC/KM $89/90	VOC $89/90	VOC X Prop.
S/T LONG. RD-SOUTH TLL	8.71	13.7	38.15	4030	0.193	0.19	1.67	0.321	8.85	9.22	57.59	2400	0.192	0.17	1.49	0.285
S/T FALCON-SOUTH TLL	3.68	6.19	35.67	4860	0.232	0.20	0.72	0.168	3.82	5.42	42.29	1950	0.156	0.18	0.71	0.110
S/T MOUNT ST-SOUTH TLL	2.53	4.39	34.58		0.000	0.20	0.50	0.000	2.67	4.37	36.66		0.000	0.19	0.52	0.000
S/T LAV. ST-SOUTH TLL	1.66	2.54	39.21		0.000	0.19	0.31	0.000	2.1	3.77	33.42		0.000	0.20	0.42	0.000
S/T SOUTH TLL-HYMKT	1.2	1.05	68.57	3190	0.153	0.16	0.19	0.029	1.2	1.06	67.92	1470	0.118	0.16	0.19	0.023
S/T SOUTH TLL-OXF.ST	3.15	6.6	28.64	1930	0.092	0.21	0.67	0.062	3.15	8.83	21.40	1570	0.125	0.24	0.77	0.097
S/T SHT TOLLGATE-OXF.	5	10.26	29.24	3450	0.165	0.21	1.06	0.175	5	8.97	33.44	2560	0.205	0.20	1.00	0.206
ST. VIA SHT					0.000	#DIV/0!							0.000			
S/T FALC. ST-SHT TOLLGATE	1.25	3.09	24.27	3450	0.165	0.23	0.29	0.048	1.25	1.1	68.18	2560	0.205	0.16	0.20	0.041
				20910	1			0.8029				12510	1			0.7616
TRAFFIC								11700								7070
SAVINGS IN VEHICLE OPERATING COSTS PER VEHICLE SOUTHBOUND								0.040								0.099
SAVINGS IN VOC FOR BASE TRAFFIC FOR 2 HOUR PEAK PERIOD								832								1072
INCREASE IN PEAK PERIOD TRAFFIC BETWEEN 1990 AND 1995								2400								3340
SAVINGS IN VOC FOR INDUCED TRAFFIC FOR 2 HOUR PEAK PERIOD								48								166
VOC SAVINGS SUBTOTALS IN 1989/90 DOLLARS								879								1238

1990

NORTHBOUND

	AM PEAK DIST	Av T	Av. Speed	Traff-ic	Prop-ortion	VOC/KM $89/90	VOC $89/90	VOC X Prop.	PM PEAK DIST	Av T	Av. Speed	Traff-ic	Prop-ortion	VOC/KM $89/90	VOC $89/90	VOC X Prop.
S/T OXF.ST-SOUTH TLL	3.47	20.94	9.94	2470	0.276	0.34	1.18	0.325	3.47	8.43	24.70	3480	0.215	0.20	0.70	0.150
S/T CITY STH-SOUTH TLL	1.19	15.1	4.73	1340	0.15	0.59	0.71	0.106	1.19	2.84	25.14	3075	0.19	0.20	0.24	0.045
S/T SOUTH TLL- LONGUE	10.01	27.73	21.66	1720	0.192	0.21	2.14	0.412	9.96	19.41	30.79	2720	0.168	0.18	1.82	0.306
S/T SOUTH TLL- FALCON	3.63	3.67	59.35	3430	0.383	0.15	0.53	0.204	3.58	4.3	49.95	6910	0.427	0.15	0.55	0.235
S/T SOUTH TLL- MOUNT	2.5	2.74	54.74		0	0.15	0.38	0.000	2.45	3.37	43.62		0	0.16	0.39	0.000
S/T SOUTH TLL-LAV. ST	2	2.31	51.95		0	0.15	0.30	0.000	2	2.92	41.10		0	0.16	0.33	0.000
S/T OXF.ST-LAV.ST	5.47	23.25	14.12		0	0.27	1.48	0.000	5.47	11.35	28.92		0	0.19	1.03	0.000
S/T LAV.ST-LONGUE ST.	8.01	25.42	18.91		0	0.23	1.84	0.000	7.96	16.49	28.96		0	0.19	1.49	0.000
				8960	1			1.046				16185	1			0.736
TRAFFIC								**5150**								**9630**

1995

NORTHBOUND

	AM PEAK DIST	Av T	Av. Speed	Traff-ic	Prop-ortion	VOC/KM $89/90	VOC $89/90	VOC X Prop.	PM PEAK DIST	Av T	Av. Speed	Traff-ic	Prop-ortion	VOC/KM $89/90	VOC $89/90	VOC X Prop.
S/T OXF.ST-SOUTH TLL	3.32	6.41	31.08	1210	0.112	0.21	0.69	0.077	3.32	6.02	33.09	1560	0.085	0.20	0.67	0.057
S/T HYMKT-SOUTH TLL	1.13	7.6	8.92	1390	0.128	0.42	0.47	0.060	1.13	1.3	52.15	3315	0.181	0.17	0.20	0.035
S/T SOUTH TLL-PAC HWY	8.3	7.12	69.94	860	0.079	0.16	1.33	0.106	8.3	7.32	68.03	2310	0.126	0.16	1.34	0.169
S/T SOUTH TLL-FALC ST	3.67	3.94	55.89	1720	0.159	0.17	0.62	0.099	3.67	3.85	57.19	5020	0.275	0.17	0.62	0.170
S/T SOUTH TLL-MOUNT ST	2.52	2.68	56.42		0	0.17	0.43	0.000	2.52	2.31	65.45		0	0.16	0.41	0.000
S/T SOUTH TLL-LAV ST	2	2.27	52.86		0	0.17	0.34	0.000	2	1.91	62.83		0	0.16	0.33	0.000
S/T OXF. ST-SHT TOLL	4.76	7.8	36.62	2820	0.261	0.19	0.92	0 241	4.76	5.61	50.91	3040	0.166	0.17	0.83	0.138
VIA SHT					0								0			
S/T SHT TOLL-PAC HWY	5.87	4.52	77.92	940	0.087	0.16	0.92	0.080	4.63	4.86	57.16	860	0.047	0.17	0.73	0.037
S/T SHT TOLL-FALC. ST	1.24	1.34	55.52	1880	0.174	0.13	0.16	0.028	1.24	1.39	53.53	2180	0.119	0.17	0.21	0.025
				10820	1			0.6905				18285	1			0.539
TRAFFIC								6810								11230
SAVINGS IN VEHICLE OPERATING COSTS PER VEHICLE NORTHBOUND								0.356								0.198
SAVINGS IN VOC FOR BASE TRAFFIC FOR 2 HOUR PEAK PERIOD								3660								3811
INCREASE IN PEAK PERIOD TRAFFIC BETWEEN 1990 AND 1995								3320								3200
SAVINGS IN VOC FOR INDUCED TRAFFIC FOR 2 HOUR PEAK PERIOD								590								317
VOC SAVINGS SUBTOTALS IN 1989/90 DOLLARS								4250								4128

TOTAL SAVINGS IN PEAK PERIOD VEHICLE OPERATING COSTS IN 1989/90 DOLLARS 10495 savings are found to be $7,466 per weekday in 1989/90 dollars.

8.6 SAVINGS IN ACCIDENT COSTS

It is debatable whether accidents are costs which must be faced by motorists, as insurance protects motorists from the full costs of traffic accidents. However, motorists often lose no-claim bonuses if they have accidents and must face a general increase in premiums if accidents increase in frequency.

Since the data provided by the Bureau of Transport and Communications Economics is for the external costs of accidents and since there is no doubt that traffic accidents impinge on society as a whole and not just on vehicle users, the savings in accidents costs are not included here in the benefits which will perceived by motorists in their use of the SHT and GHF. The assumption that savings in accident costs are an external cost not included in the consumer surplus does not have a strong effect on the relative size of the costs and benefits of the SHT and GHF. The assumption allows these savings to be added separately as a benefit given by the roadworks.

8.7 COMPARISON OF CONSUMER SURPLUS AND MEASURED BENEFITS

As stated above the consumer surplus for a typical weekday in 1995 for the SHT and GHF has been estimated to be:

Lower Estimate	Most Likely Estimate	Upper Estimate
$20,527	$37,024	$73,572

The measured benefits are listed below:

Value of travel time saved	$40,569
Value of peak hour VOC saved	$10,495
Value of fuel saved off peak	$7,466
Total measured benefits	$58,530

Therefore, for an average weekday, the total of benefits calculated from measured time savings and traffic volumes is within the 95% confidence interval of consumer surplus calculated from the demand curve derived from regression analysis of the time series of traffic flows. It can therefore be concluded that the two measures of the benefits derived from the SHT and GHF are in agreement with each other. It can also be concluded that the assumptions regarding the form of the capacity constrained demand curves are consistent with the results obtained and therefore the validity of these assumptions is not disproved. Figure 1b indicates that there will be an inaccuracy in the measure of consumer surplus used because of the exclusion of portions of the area underneath the constrained demand curve. However, the comparison of measured benefits and calculated consumer surplus appears to show that the magnitude of this exclusion is within the error inherent in the confidence interval of the regression analysis coefficients used to calculate the consumer surplus. This comparison was done for weekdays, mainly because information on weekday peak hour traffic was the most readily available travel time data. However, to assess the overall costs and benefits of the SHT and GHF, the average traffic for all days will be used. It is assumed, now that the measure of consumer surplus for an average weekday has been corroborated by other measurements, that the consumer surplus for the average traffic for all days of the year is a valid measurement of total daily benefits for users of the SHT and GHF.

TABLE 9

CALCULATION OF FUEL SAVED IN OFF PEAK TIMES BECAUSE OF REDUCED TRAVEL DISTANCE AFTER THE SHT AND GHF

	Time	SHB Peak Traffic per hour	SHT Peak Traffic per hour	Total Peak Traffic per hour
1990				
SB AM	10.1	10500	0	10500
SB PM	10.48	5400	0	5400
NB AM	14.75	5150	0	5150
NB PM	7.45	9630	0	9630
1995				
SB AM	7.076	8310	3450	11760
SB PM	5.901	4510	2560	7070
NB AM	5.544	3990	2820	6810
NB PM	4.058	8190	3040	11230

RATIO OF 1995 AADT TO 1990 AADT 1.24

	Distance saved in one SHT trip metres	Number of Weekday Trips per day	Number of off peak SHT week-day trips	Distance saved per day on weekday on SHT Veh-km Off peak	Distance saved in one GHF trip	Number of Weekday Trips per day	Number of off peak GHF week-day trips per day	Distance saved per day on weekday on GHF Veh-km
SB 1995	640	37410	25390	16249.6	330	34270	21410	7065.3
NB 1995	1090	39800	28080	30607.2	1710	34590	23710	40544.1
SUBTOTALS				46856.8				47609.4
FUEL SAVINGS PER WEEKDAY OFF PEAK				6653.7				6760.5

TOTAL FUEL SAVINGS PER DAY IN LITRES	13414
ESTIMATED PROPORTION OF FUEL SAVINGS FOR BASE TRAFFIC	0.806
BASE TRAFFIC FUEL SAVINGS	10818
PRICE OF FUEL PER LITRE IN 1995	0.7
PRICE OF FUEL PER LITRE IN 1995 IN 1989/90 DOLLARS	0.616
VALUE OF FUEL SAVINGS FOR BASE TRAFFIC PER WEEKDAY	6666
ESTIMATED FUEL SAVINGS FOR INDUCED TRAFFIC	2596
VALUE OF FUEL SAVINGS FOR INDUCED TRAFFIC	800
TOTAL VALUE OF OFF PEAK FUEL SAVINGS IN 1989/90 DOLLARS FOR SHT AND GHF	7466

TABLE 10

CALCULATION OF TRAVELLING DISTANCE SAVED BY BASE TRAFFIC BECAUSE OF THE PROVISION OF THE SHT AND GHF

RATIO OF 1995 AADT TO 1990 AADT "k" 1.24

	Distance saved in one SHT trip in metres "a"	Average Daily Trips per day "b"	Average daily distance saved on SHT Veh-km "c" c=a x b/1000 Km	Distance saved in one GHF trip in metres "e"	Daily average Trips per day "f"	Average daily distance saved on GHF Veh-km "g" g=e x f/100 Km
SB 1995	640	35510	22726	330	31860	10513.8
NB 1995	1090	38050	41475	1710	32380	55369.8
SUBTOTALS			64201			65883.6
TOTAL TRAVELLING DISTANCE SAVED FOR 1995 TRAFFIC =		64201 +		65884	=	130085
TOTAL TRAVELLING DISTANCE SAVED FOR 1990 TRAFFIC	=		130085	/ k =	104907	km

9. CALCULATION OF COSTS

9.1 AVERAGE VEHICLE TRIP LENGTH

Since the environmental costs of vehicle operation are expressed in terms of costs per kilometre, and since the additional traffic on the SHB, SHT and GHF are measured in numbers of trips, it is essential to have a measure of the average trip length in order to calculate total environmental costs. The SATS Report of 1974 stated that the average vehicular trip length in Sydney in 1971 was 9.58 km and predicted that the average trip length in the year 2000 would be 12.09 km ([37]). The ABS publish a measure of the average total annual km travelled by vehicles in Sydney of 11,900 km in 1991 ([38]), but do not give a figure for the number of trips or the average trip length in km. In a survey conducted in 1991 the NSW Transport Data Centre found that the average person in Sydney makes 3.6 trips per day, but does not state if the average vehicle does this many trips per day ([39]). If one assumes that the average vehicle does make 3.6 trips per day then the average trip length would be 9.06 km. However, the Transport Study Group of the NSW Department of Transport state that the unpublished average trip length for motor vehicle in the Sydney area, calculated from the results of the 1991 Home Interview Survey, is 10.39 km [40]. This is the figure which is used in this paper. The figure may be an understatement for cross harbour traffic, which must travel a minimum of usually 3 km before it can reach any allowable destination, but no other measures of average cross-harbour trip length are known at this time.

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[37] Minister for Transport, NSW, SYDNEY AREA TRANSPORTATION STUDY, Sydney, 1974, p I-10

[38] Australian Bureau of Statistics, SURVEY OF MOTOR VEHICLE USE AUSTRALIA, p 11

[39] TDC 1991/92 Sydney Region Travel Surveys HOME INTERVIEW SURVEY: SURVEY RESULTS First published May 1994, Revised Feb 1996 p 5

[40] NSW Department of Transport, Transport Study Group, information provided by Sue Bell on phone 02 9268 2800 on 10/10/96.

9.2 COSTS OF ACCIDENTS, NOISE, POLLUTION, CONGESTION AND LOSS OF PUBLIC TRANSPORT PATRONAGE FROM INDUCED TRAFFIC.

External costs result from induced traffic. The costs of noise, noxious emissions, accidents and congestion have been estimated to be 0.3, 0.7, 1.2, and 8 cents per vehicle kilometre by the Bureau of Transport and Communications Economics.([41]) Here it will be assumed that the cost of accidents has not been 'internalised' by users of the SHT and GHF and has therefore not been included in the personal net benefits perceived by each user, nor in the estimated consumer surplus. The accident cost savings are calculated from the estimated distance travelled by induced traffic less the reduced distance given by the SHT and GHF to users. A standard amount for the cost of accidents is used. This cost is here taken to be 1.2 cents per vehicle per km in 1993 dollars. ([42]). The calculation is shown in Table 11. Note that in Table 11, where the costs and benefits are calculated, that the costs of extra pollution, noise and accidents are negative in some cases. This is because the reduced travelling distance offered to base traffic by the SHT and GHF outweighs in some cases the effects of the increase in traffic. The total reduction in vehicle-km for base traffic is calculated in Table 10.

Loss of public transport patronage, in this case measured by the loss of train patronage, is a loss to the State Rail Authority that is not a cost to the motorists who use the SHB and SHT. It is assumed here that the loss of train patronage which followed the opening of the SHT and

[41] Bureau of Transport and Communications Economics, "Goods and Bads in Urban Transport", OP. CIT., p 20

[42] Bureau of Transport and Communications Economics TRANSPORT AND COMMUNICATIONS INDICATORS, "Goods and Bads in Urban Transport" Bulletin 42, September Quarter, 1993 p20

GHF can be counted as an external cost of the new roads. The benefits to people who chose to no longer travel by train across the Harbour and to drive vehicles instead are included in the measure of consumer surplus. Therefore whatever net benefits these people gained by no longer paying for train tickets but incurring the costs of driving instead are already included in the consumer surplus. The loss of patronage for the SRA may have allowed the SRA to save some costs by reducing services but reductions in services will inflict additional travelling time costs on the passengers who continue to use the trains. To examine the effects of reductions in train frequency, let us assume that the SRA is free to reduce the number of trains running in proportion to the loss of patronage. Using the most likely estimate of loss of train patronage of 22,141 trips per day, this represents a loss of 11% of average daily patronage in the northwest sector in 1991/92 of 69,947,329 per year or 191,637 per day. In October 1995, according to the SRA North Shore Train Timetable, there were 154 trains running south through Milsons Point across the Bridge, between 4.56 a.m. and 12.47 a.m. on weekdays. This represents one train every 7.73 minutes, or an average frequency of trains of 7.76 trains per hour. If the number of trains running were reduced by 11%, then the average frequency of trains would be 6.9 trains per hour, or an average of one train every 8.69 minutes. For those people who are continuing to use the trains, there is now an increase in time between trains of 0.93 minutes (0.0155 hours) average, and it is assumed here that the average increase in waiting time is increased by the increase in time between trains. This increase affects those who continued to use the trains in the Northwest Sector after the SHT and GHF opened, which shall be taken here as the average number of passengers per day in the 12 months following the opening of the SHT and GHF, which is calculated to be 177,761 people per day. Assuming that the value of travelling time is the same for train users as for car drivers, without weighting for vehicle occupancy, using the values shown in Table 7, this gives a value of time per person of 8.58 cents per minute, or $5.15 per hour. The reduction in service frequency can therefore be said to result in an increase in total travelling time for train passengers with a value of:

5.15 x 177761 x 0.0155 = $14,190 per day

According to the 1994/95 SRA Annual Report, The SRA total costs in 1991/92 were $2.50 per passenger, and therefore the reduction in service proportional to the loss in patronage could be said to save the SRA 22,141 x $2.50, less the loss of fares of $22,999 (based on the average fare paid per passenger, as shown on Table 11) in 1989/90 dollars, i.e.

Savings to SRA from service reductions
= 22,141 x 2.5 - 22,999
= $32,354 per day.

Change in welfare from SRA service reductions
= $32,354 - value of passengers' time lost
= $32,354 - $14,190
= $18,164

It should be noted that this argument does not take into account the further loss of patronage which results from the diminished convenience of the train system following a reduction in service frequency. This further loss of patronage, which can lead to a vicious circle of service reductions and passenger desertions of the train system, is of course difficult to quantify. It must also be noted that the average fare level used in the calculation of Table 11 would be an underestimate of the fares lost to the SRA because of people changing their mode of transport to private vehicle usage. This is because the average fare must take into account those passengers who are travelling with concession fares, such as pensioners and children, and it is unlikely that any significant portion of the transport mode-changers will be from these groups. Also, the average cost to the SRA for each passenger carried would be much larger than the marginal cost, since a large portion of the SRA's costs are devoted to track and infrastructure maintenance. Therefore the increase in welfare calculated above from SRA service reductions is not accepted as accurate. If one assumes that the loss of fare per mode-changer is the usual train fare for say, Chatswood to Wynyard (distance about 10 km), for which the fare from a weekly ticket per day would be \$1.54 (\$1.36 in 1989/90 dollars) and that the marginal cost of carrying a passenger is 80% of the average, or \$2, then the change in welfare for the service reduction is:

$$22,141 \times 2 - 22,141 \times 1.36 - 14,190 = -\$20$$

This means that the above modest and plausible adjustments to average fare for mode-changers and marginal cost of transporting train passengers have resulted in a negative change in welfare if the SRA reduces services proportional to the reduction in patronage. Since the Railway Authority is unlikely to recover costs to offset loss of patronage without inflicting welfare losses on remaining passengers, the working assumption that the welfare losses equal the Railway Authority's cost savings is adopted here. This is equivalent to the assumption that the change in external costs from train passengers changing their mode of transport to private vehicles is appropriately measured by the loss of fare income to the SRA

To demonstrate that it is unlikely that the SRA has been able to recover the lost fares by service reductions, in

June 1991, before the opening of the SHT and GHF, the SRA North Shore Timetable of 3/6/91 showed that 882 trains per week passed north and the same number passed south through Milsons Point station. From the Timetable of 30/5/93, after the opening of the SHT and GHF, the corresponding figure is 897, an increase in the number of trains per week of 1.7% even though there was a marked reduction in the number of passengers in the Northwest Sector over this period, with the 1992/93 year having 9.4% less passenger journeys than 1990/91.

In practice, therefore, the SRA was not able to save costs by reductions in service in response to the loss of patronage after the opening of the SHT and GHF. This is because the SRA is still obliged to maintain a level of service in terms of frequency despite the loss of patronage caused by greater competition from private cars and growth in patronage has occurred for other reasons, such as economic growth and even a suggested increase in awareness of the environmental cost of private car usage. ([43]) In these circumstances the SHT and GHF, if they have taken passengers from the trains, have deprived the SRA of the ability to improve the frequency of service and convenience of the system which would have arisen from a larger increase in patronage. From the above considerations, therefore, it appears reasonable to assume that the net cost of loss of train patronage following the opening of the SHT and GHF is the cost of lost fare revenue to the SRA, and this cost is included in the cost benefit analysis. In 1994/95 the income from fares for the SRA was $294 million for 249,600,000 passenger journeys, giving an average income of $1.18 per passenger in 1994/95 dollars, as shown on Table 11. ([44]) As noted earlier, this is a conservative estimate of the loss of revenue to the SRA from loss of patronage.

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[43] Bob Beale, "Smog-wary commuters switching to bus, train" SYDNEY MORNING HERALD, 17/9/96, p 5.

[44] State Rail Authority of NSW, ANNUAL REPORT, 1994/95.

FIGURE 5

AVERAGE ANNUAL DAILY TRAFFIC FROM 1985 TO 1995 SHT AND SHB

WEEK	YEAR	AADT	TOLL $1989/90
52	85	177687	0.2926
52	86	180155	0.2685
20	87	181384	0.2473
52	88	183722	1.1537
8	89	183966	1.6094
52	90	180003	1.5
52	91	181385	1.4533
36	92	181196	1.43897
52	93	205314	1.8842
52	94	231457	1.8492
52	95	224230	1.75981

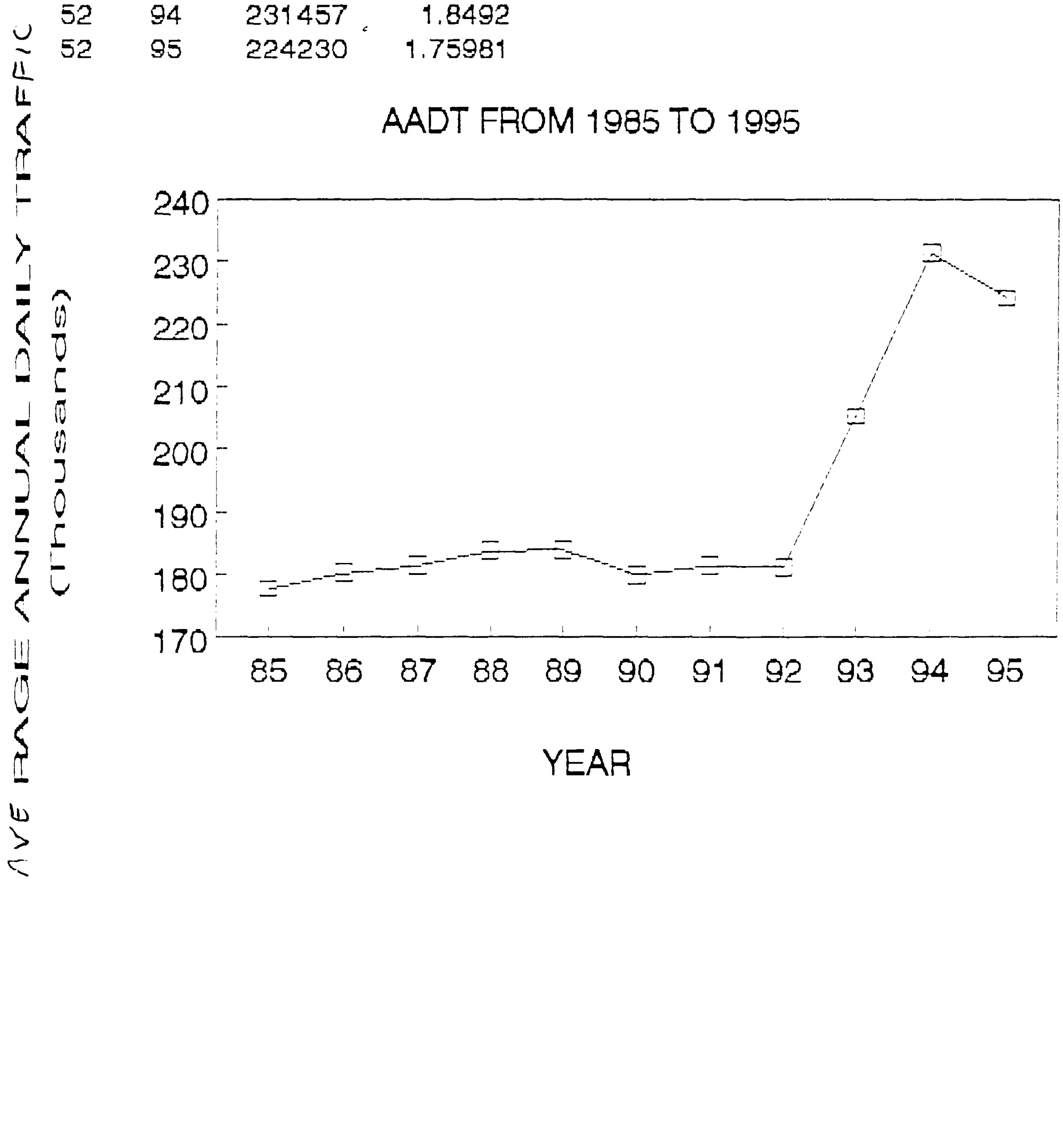

TABLE 11

CALCULATION OF NET BENEFIT PER DAY FROM PROVISION OF SHT AND GHF
OF SHT AND GHF

	RATE	NUMBER OF KM PER TRIP	NUMBER OF TRAV-ELLING UNITS	INDUCED TRAFFIC TOTAL VEHICLE-KMS	SAVINGS IN VEHICLE-KM FROM SHT AND GHF	NET INCREASE IN VEHICLE-KMS	COSTS OR BENEFITS PER DAY	CORRECTION FOR 1989/90 DOLLARS	COSTS OR BENE-FITS IN $1989/90 PER DAY	TOTALS PER DAY	
BENEFITS:											
CONSUMER							17570		17570		Low end of C.I.
SURPLUS							31205		31205		Most likely
							60072		60072		High end of C.I.
ADDITIONAL TOLL	($1993)		11530				23060	1.061	21734		Low end of C.I.
RECEIPTS FROM	2		12592				25184	1.061	23736		Most likely
INDUCED TRAFFIC			13653				27306	1.061	25736		High end of C.I.
TOTAL										39304	Low end of C.I.
BENEFITS										54941	Most likely
										85808	High end of C.I.
COSTS											
	($1994/94)										
LOSS OF	1.18		12764				15062	1.136	13258		Low end of C.I.
PUBLIC	1.18		22141				26126	1.136	22999		Most likely
TRANSPORT	1.18		31518				37191	1.136	32739		High end of C.I.
PATRONAGE											
	($1993)										
CONGESTION	0.08	6.5	6651	43231.5			3459	1.061	3260		Low end of C.I.
	0.08	6.5	9295	60417.5			4833	1.061	4556		Most likely
	0.08	6.5	11939	77603.5			6208	1.061	5851		High end of C.I.
POLLUTION	0.7	10.39	6651	69104	104907	-35803	-251	1.061	-236		Low end of C.I.
	0.7	10.39	9295	96575	104907	-8332	-58	1.061	-55		Most likely
	0.7	10.39	11939	124046	104907	19139	134	1.061	126		High end of C.I.
NOISE	0.3	10.39	6651	69104	104907	-35803	-107	1.061	-101		Low end of C.I.
	0.3	10.39	9295	96575	104907	-8332	-25	1.061	-24		Most likely
	0.3	10.39	11939	124046	104907	19139	57	1.061	54		High end of C.I.
ACCIDENTS	1.2	10.39	6651	69104	104907	-35803	-430	1.061	-405		Low end of C.I.
	1.2	10.39	9295	96575	104907	-8332	-100	1.061	-94		Most likely
	1.2	10.39	11939	124046	104907	19139	230	1.061	216		High end of C.I.
MAINTENANCE						COST PER YEAR IN 1986 $					
SHT						7900000	21644	0.745	29052		
GHF						216000	592	0.745	794		
COSTS OF CAPITAL					PRINCIPAL 1992 $	ASSUMED RATE OF INTEREST					
SHT					560000000	6	92055	1.042	88344		
GHF					130000000	6	21370	1.042	20509		
TOTAL COSTS										154475	Low end of C.I.
										166081	Most likely
										177686	High end of C.I.
NET BENEFITS										-115171	Low end of C.I.
										-111140	Most likely
										-91878	High end of C.I.

It is stressed that it is not assumed here that the marginal cost for the SRA to carry a train passenger is zero. Instead, it is reasoned that the SRA cannot recover lost fare revenue without inflicting welfare losses on society through increased waiting times for the remaining train passengers. These welfare losses are assumed to be comparable to any savings which the SRA may achieve. Therefore the lost fare revenue is used as a measure of the loss of welfare to society of train passengers changing their mode of transport.

9.3 MAINTENANCE AND CAPITAL COSTS OF THE SHT AND GHF

The maintenance costs of the SHT were estimated by the DMR to be $7.9 million per year in 1986 dollars.([45]) For the GHF the maintenance costs were estimated, also by the DMR to be $216,000 per year in 1986 dollars.([46])

With regard to capital costs, for the SHT it is assumed that the capital costs can be calculated simply as an annual 6% charge on the total capital costs of $560,000,000. The DMR did give the Tunnel Company an interest free loan of $222.6 million, and the capital costs of this loan are borne by the taxpayer. In its Annual Report for 1994/95, the RTA called this loan a "Disbursement", thus counting the principal of this loan as a cost in the overall assessment of the RTA's financial position with regard to the SHT. In that report, the RTA considered that its accumulated surplus by 30/6/95 for the SHT project, since the commencement of the project, was $13.730 million. As this surplus was accumulated over the construction period as well as the period of operation of the SHT, it does not give an accurate figure for the ongoing capital costs of the SHT. Therefore the above assumption is made that capital costs for the SHT are 6% of $560 million, for the purposes of

[45] DMR SHT ENVIRONMENTAL IMPACT STATEMENT, OP. CIT., p3
[46] Travers Morgan for DMR, GORE HILL FREEWAY ECONOMIC EVALUATION REVISED FINAL REPORT Nov 1988, p11

this cost benefit analysis. For the GHF, the cost of construction of $130 million was funded by the government and the interest payments for this capital are assumed to be 6%.

10. COST BENEFIT ANALYSIS

The net costs or benefits for the SHT and GHF per day in 1989/90 dollars are calculated in Table 11. The results of Table 11 are summarised below.

SUMMARY OF COSTS AND BENEFITS PER DAY FROM THE PROVISION OF THE SHT AND GHF IN 1989/90 DOLLARS (from Table 11)

BENEFITS	Low end of C.I.	Most likely	High end of C.I.
BENEFITS:			
Consumer Surplus	17,570	31,205	60,072
Additional toll receipts from induced traffic	21,734	23,736	25,736
Total Benefits	39,304	34,941	85,808
COSTS:			
Loss of Public Transport Patron.	13,258	22,999	32,739
Congestion	3,260	4,556	5,851
Pollution	-236	-55	126
Noise	-101	-24	54
Accidents	-405	-94	216
Subtotal External Costs	15,776	27,382	38,987
Maintenance	29,052	29,052	29,052
GHF	794	794	794
Capital Costs			
SHT	88,344	88,344	88,344
GHF	20,509	20,509	20,509
Total Costs	154,475	166,081	177,686
Net Benefits	-115,171	-111,140	-91,878

NOTE: Increased toll payments by base traffic are regarded as a transfer payment with zero net effect on welfare.

As calculated in Table 1, the average total consumer surplus per day gained from the SHT and GHF is likely to be within the 95% confidence interval of $17,570 to $60,072 in 1989/90 dollars. This study will not include an attempt to derive a total flow of benefits over the life of the roads, apart from an assumption that the benefits over the lifetime of the roads will remain in the same ratio to the costs as they have to date. That is, it is assumed that the cost benefit ratio which applies to date will continue to apply. The reason for making this assumption is mainly that the costs of the induced traffic are largely the cost of loss of public transport patronage. To estimate future losses in public transport patronage, it would be necessary to have a reliable estimate of the relationship between this patronage and projected traffic levels. Since it has not been possible to estimate this relationship with statistical significance, the growth in costs with various traffic projections cannot be estimated. However, it is reasoned that, if vehicular traffic grows strongly, the time savings per vehicle will be reduced as the flow on the harbour crossings approaches saturation. Any large growth in vehicular traffic is also likely to be associated with a loss of public transport patronage and an increase in congestion costs on approach roads, and these additional costs will tend to nullify the increase in consumer surplus which will be gained by the increased traffic. Another factor which will inhibit the growth in the consumer surplus will be toll increases which will occur as the growth in consumer price index grows. The assumption that the benefits to costs ratio measured to date will continue to apply for the life of the project therefore appears reasonable.

Toll receipts from additional traffic to the operators of the SHT have been included as a benefit because the consumer surplus was calculated excluding these toll payments. These additional toll receipts are calculated as $2.00 per vehicle for southbound additional traffic in 1993. Southbound traffic is 48.2 % of bothway additional traffic, as this is the ratio of toll-paying southbound daily traffic to total traffic on the SHT in 1993.

The costs of pollution and noise are reduced in this calculation by the amounts attributable to the reduction in distance which is allowed for base traffic which uses the SHT and GHF, calculated in Table 10 to be 104,907 vehicle-km per day. Calculations are performed for the extremes of the confidence intervals estimated in the regression analyses. Congestion costs are calculated excluding that portion of the average trip when traffic is actually on the SHB, GHF or SHT, since when the vehicles are using these facilities they are only causing congestion to other vehicles on the same facilities, and therefore the congestion costs while on the harbour crossings are effectively already 'internalised'. That congestion costs for a new road can be increased for traffic not using the road is referred to in 1995 by Mills, who noted that:

> "Experience in Sydney suggests....a principal source of delay on the ordinary road can be the presence of intersections governed by traffic lights; these signals may be reset to assist traffic going to or coming from the new road, and by itself this can delay traffic using the parallel ordinary road. (Such resetting can add to aggregate welfare; but it may be poorly regarded by those adversely affected, who may note that it adds to the profitability of the toll road..." p 145.[47]

From the above analysis, the overall loss per day is between $91,878 and $115,171 in 1989/90 dollars. From these calculations the benefit to cost ratio is between:

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[47] Mills, G., "Welfare and Profit Divergence for a Tolled Link in a Road" JOURNAL OF TRANSPORT ECONOMICS AND POLICY, Vol XXIX No. 2, pp137-146, May. 1995, p 145.

39,304 / 154,475 = 0.254 and
85,808 / 177,686 = 0.483.
Here the highest cost is assumed to be associated with the highest benefit, as both will result from the highest traffic estimate. If the highest benefit co-existed with the lowest cost the highest possible benefit to cost ratio would be achieved, amounting to:
85,808 / 154,475 = 0.555.
This benefit to cost ratio is still less than one.

This compares with the benefit to cost ratios of at least 1.91 for a 7% discount rate predicted for the GHF ([48]) and a corresponding ratio of 1.2 for the SHT ([49]).

There is clearly a disagreement between the predictions of the economic justifications of the SHT and GHF and the results of this study. As can be seen in Table 11, the effects of loss of train patronage are a major cost, with the most likely estimated cost of loss of train patronage being 74% of the most likely consumer surplus estimate. No allowance for this was made in the DMR economic justifications of the SHT and GHF, which simply considered land acquisition costs, construction and maintenance costs.([50])([51]) The omission of the costs of loss of public transport patronage in these economic justifications is therefore a serious oversight. It has been argued above (in Section 9.2) that the savings from any attempt to reduce public transport services to recover the losses in fare revenue will be offset by the resulting further losses in welfare from travel time cost increases to the remaining passengers. Reductions in service also accelerate the vicious circle of service deterioration and further loss of patronage. It was concluded in Section 9.2 that the loss of fare revenue is a reasonable estimate of the cost of loss of public

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[48] DMR GORE HILL LINK ENVIRONMENTAL IMPACT STATEMENT 1986 p 22
[49] DMR SHT ENVIRONMENTAL IMPACT STATEMENT, OP. CIT., P 37
[50] DMR SHT ENVIRONMENTAL IMPACT STATEMENT, OP. CIT., 2
[51] DMR GORE HILL LINK ENVIRONMENTAL IMPACT STATEMENT 1986 p 20

transport patronage. Another omission in these economic justifications is the congestion costs caused by induced traffic, for which the most likely estimate is 15% of the most likely estimate of consumer surplus. The omission by these economic justifications of pollution and noise costs from induced traffic does not appear to be a significant problem in these cases, as the SHT and GHF offer savings in vehicle kilometres travelled to base traffic which largely cancel out the effects of the induced traffic. However, even without taking into account the external costs of induced traffic, only the highest extreme of the confidence interval for consumer surplus covers the estimated maintenance and capital costs of the SHT and GHF.

11. POLICY SUGGESTIONS ARISING FROM THESE FINDINGS

While statistically significant estimates have been calculated for the increase in road traffic and loss in train patronage which followed the opening of the SHT and GHF, it has not been possible to find a significant relationship between public transport usage and the level of the toll. Since loss in public transport usage represents the largest component of probable external costs of these roadworks, it is not possible to estimate a welfare maximising level of toll.

However, from the analyses undertaken a level of toll can be estimated which would theoretically reduce traffic such that the induced traffic from the increased road capacity is zero. Since the estimated additional traffic after the opening of the SHT and GHF is 26,124 vehicles per day and since the response of traffic to the toll is estimated to be a loss of 8724 vehicles per day for each dollar increase in toll, the toll which would nullify induced traffic would be $2.99 larger (in 1989/90 dollars) than the present toll of $2.00 or a total toll of approximately $6 in 1995 dollars. This represents a toll of $3 in each direction, since at present the $2.00 toll is only charged for southbound traffic. Such a toll may not stop the increase in traffic which arises from land use changes or economic growth, but would theoretically reduce traffic to a level which would have applied if the SHT and GHF had not been built.

If the extra revenue from the toll increase is spent on improving public transport, it is also probable that this level of toll would increase public transport usage and therefore perhaps nullify the external costs which arose from the SHT and GHF, although the consumer surplus to drivers would of course be reduced.

Since the NSW Government is presently proposing to build the Eastern Distributor, for which the demand largely arises from the increase in traffic caused by the SHT and GHF, the option of such a toll increase should be considered by the Government as a means of alleviating traffic problems on the approaches to the SHT and SHB. The toll increase option would be an alternative to expensive roadworks.

The Eastern Distributor project is being presented as a project which has a large present value as calculated in a cost benefit analysis which does not take into account the costs of loss of public transport patronage or the costs of induced traffic.[52] The analysis done here on the realised costs and benefits of the SHT and GHF demonstrate the dangers of neglecting these costs in assessing the value of roadworks such as the Eastern Distributor.

12. CONCLUDING REMARKS

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[52] Rust PPK Pty Ltd, Eastern Distributor Environmental Impact Statement, Working Paper No. 3: Traffic and Transportation, November 1996, Table A1.

The statistical analyses undertaken here have given an estimate of the consumer surplus for users of the SHT and GHF. This estimate for consumer surplus has been supported by calculations of the benefits given by measured values of travel time savings, speeds and traffic volumes. Estimates have been made of public transport patronage losses and increased congestion costs which are probably attributable to the induced traffic encouraged onto the roads by the SHT and GHF. These estimates have demonstrated that the costs of these major roads, if external costs are included, outweigh their benefits by an amount of between $91,878 and $115,171 per day in 1989/90 dollars. A clear lesson to be drawn from this study is that the costs of induced traffic must be taken into account when considering future roadworks, especially the costs of loss of public transport patronage and of congestion on approach roads. Predictions of the magnitude of induced traffic can be made from experience gained from past roadworks, and such predictions should be used to assess a wider variety of costs than those included in the economic justifications of the SHT and GHF. A study in 1994 by the Department of Transport in Great Britain concluded that "induced traffic can and does occur, probably quite extensively, though its size and significance is likely to vary widely in different circumstances." [53] and that ".. studies demonstrate convincingly that the economic value of a scheme can be overestimated by the omission of even a small amount of induced traffic." [54]

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[54] IBID., p iii

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