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The Economic Advantages of Tunnels Replacing Urban Road Networks

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SUMMARY

Tunnelling for urban roads has generally in the past been dismissed as an expensive option, only to be adopted where no other practicable means exist for constructing an essential highway link. However the growing resistance to surface and elevated roads makes it increasingly difficult to provide the additional road space that may be required.

Tunnels reduce noise, air pollution, community disharmony and are not visually unattractive as are surface roads. If only the capital costs of construction are used to compare alternative transportation routes, then tunnelling would never become a viable option. However, the intangible costs, such as effect on community health, air pollution and noise, make tunnelling viable if they are assessed. Currently the local community has to bear these costs as they are not recognised or accounted for in the normal evaluation of alternatives.

A cost study of the tunnelling alternative was made for a heavily trafficked inner city road - Alexandra Parade, Fitzroy, Victoria. The aim of the study was to determine the effects that large volumes of traffic have on property values, noise intrusion, and fuel consumption. It was found that 80% of the capital costs of constructing a tunnel can be traded-off against the costs of existing roads over the useful life of the tunnel, if values are placed upon these intangibles. The trade-off could be greater if the gain in surface space, health costs or visual aspects were included in the analysis. When these costs are assessed, tunnelling can become a cheaper alternative to new or planned surface roads, and has an environmental advantage over present roads in such inner city areas.

INTRODUCTION

Many conflicts arise when placing urban road networks through built up areas. Not all of these conflicts are easily recognised, and many are ignored in the evaluation of alternative traffic systems. The major problems are noise and air pollution, visual degradation, community disruption and detrimental effects on health. An alternative to surface road networks, which is often dismissed as too expensive, is the use of tunnels within urban areas. Tunnels are a means of providing new space at locations where it is most needed. A tunnel does not disturb existing development and, by exploiting the third dimension, serves to contain urban sprawl. Tunnels minimise instrusion into the urban scene, reduce noise and air pollution, and increase community living standards.

Traditional methods of evaluating tunnelling costs have tended to ignore the costs which are not involved in construction. These costs are the effects that the new construction has on the environment and the community.

This paper studies the main factors which affect tunnels and their construction, and then attempts to place a value on the benefits to the community that a tunnel provides. This value is then included in the comparison of alternative strategies. Three main areas are examined; property values associated with major traffic areas, fuel consumption values for city traffic, and an evaluation of noise polution.

FACTORS AFFECTING TUNNELLING ECONOMICS

Sources of Costs

There are two kinds of costs entailed in heavy construction - direct costs, ie the capital that must be financed and paid to get the job done, and external costs. External costs are the costs to the community that are inevitably entailed in construction - the dirt, the noise, the dislocation, the traffic congestion, etc.

External costs are elusive, difficult to measure, and are often highly subjective. Frequently it is dismissed as too intangible to take into account. Nevertheless, it is important to stress that external costs are just as real as the benefits, other than cash revenue, that are absolutely necessary to justify most public works. If cost-benefit analysis were simply a matter of setting cash revenue against direct cost, no public transit system would ever get built. If we insist that there are benefits other than cash revenue that are real and must be taken into account to justify public works, then we must also count costs other than cash costs to arrive at real net benefits and choose the optimum solution to be adopted from several alternatives. Specifically, the economic trade-offs between tunnel and surface road must entail an evaluation of external costs to be fully valid and realistic.

The term environmental not only means the natural habitat, but the living conditions of the community. Therefore an attempt must be made to quantify the effect of noise, pollution, and heavy traffic on surface roads when comparing them to underground alternatives.

In trying to place a cash value on the "hidden" costs of surface traffic, a study was made of a heavily trafficked area - Alexandra Parade, Fitzroy, Victoria. This study attempts to calculate how much the community has to pay for not having an underground road system. The effect on property values, fuel consumption, noise pollution, and visual instrusion upon the community of the existing road system is compared to the cost of a tunnel as an alternative to Alexandra Parade.

Construction Costs

Tunnelling Costs

It is often incorrect to come up with a standard figure for tunnelling projects and say that it will cost so many dollars per kilometre of tunnel. Each tunnelling project must be considered on its own merits, so that the cost components can be calculated from basics.

The cost of the tunnelling project is partially dependent on geology as the selected tunnelling method shoud suit the local geological conditions.

Studies of various tunnelling projects in Australia and overseas suggested that the unit costs/km. for constructing tunnels, as shown in Table 1, is a reasonable guide to estimating the costs of tunnelling projects within an environment such as Melbourne. Note that these are the excavation costs.

Table 1. Estimated Costs of Tunnels in Melbourne ($1983)

SIZE OF ROADWAY	Costs for Different Excavation Methods		
	Road Header or TBM $/km	Compressed Air $/km	Bentonite Shield $/km
2 lane	$13.0 M.	$30 M	$25 M.
3 lane	$16.0 M.		

It is important to stress that these figures can only be used as a guide since it was found that in some cases costs vary by up to 100%, depending on local conditions.

The cost of ventilation stations, service diversions and of internal construction must be added to the excavation cost to realise the overall construction cost. For simplification the cost of internal construction can be considered as 15% of tunnel excavation costs, and service diversions may cost 8% of tunnel construction costs.

Non Construction Costs

Noise

For tunnel schemes the effects of traffic noise are virtually limited to the tunnel portals. Some additional noise may occur during construction of the tunnels, compared with surface schemes, arising from the removal of spoil.

A tunnel handling a large volume of traffic must also, of necessity, significantly reduce the propagation of traffic noise to neighbouring residential areas. Furthermore the depressed road surface at the portals has a distinct advantage for controlling the propagation of noise when compared with an elevated portion of a freeway.

Pollution

The main pollutants from exhaust fumes include lead, unburnt hydrocarbons, carbon monoxide and the oxides of sulphur and nitrogen. Insofar as tunnel schemes remove pollutants arising from traffic, which would otherwise use existing streets, their effects are significantly beneficial - the benefits increasing proportionately with the length of the tunnel involved.

Tunnels have two advantages over surface roads in reducing air contaminants:

- exhaust stacks can be located in areas where dispersion forces are greater;
- tunnel exhausts can be treated to remove most pollutants.

Visual Intrustion

The complete removal of traffic from view and the virtual avoidance of any distruptive scar over large areas are among the more significant gains of tunnelling. Even at portals, visual instrusion should be less than for elevated routes and need not be significantly greater than for those on the surface. Lighting of buildings is unaffected and there is less clashing of style or scale with the existing architecture.

Sites for ventilation plants can be chosen to minimise the distruption of residential areas or open spaces. Where practicable, such structures can be designed in a form that is compatible with their environments.

Social Impact

Social disruption caused by surface roads is an important factor affecting the quality of life of a community. In this respect the benefits of tunnels would clearly be very considerable. The construction of any cut-and-cover sections would cause short-term disruption but this can minimised and is of short duration compared to the long term disharmony due to surface schemes. Only at portals would some local routes be permanently severed. The only other way of limiting social impact is by the use of continuous viaducts, so frequently criticised for their psychological impact.

The social impact of surface and cut-and-cover road systems can be either short-term (during the construction stage) or permanent. Typical social effects include:

- apprehension over loss of business revenue adjacent to the route,
- concern over loss of home due to relocation,
- irritability due to traffic congestion,
- disruption of normal working patterns,
- interference with normal social activity,
- negative visual impact,
- pedestrial hazards, and
- reduction of open space.

Tunnelling would provide an increase in open space on the surface. With the small amount of open space in the city, any new or saved open space would provide a benefit to the community as a whole, and an increase in the standard of living.

Fuel Economy

Tunnels often result in routes being shortened by being more closely aligned with traffic demands since there are fewer pressures to locate the facility along the open chinks in the urban fabric. By having shorter routes, with fewer or no disruptions due to intersections, a more efficient use of,and a reduction in fuel consumption is available.

Other Costs

One aspect which is often overlooked in evaluating the tunnelling alternative is the cost of traffic related health problems. The difficulty in doing this is that no figures exist on health expenditure in relation to the place of residence.

To show how important this factor may be, we can examine how much is spent on health per year for the Melbourne area. The Australian Bureau of Statistics indicates that the health expenditure was $752 per person in 1982. Melbourne, with a population of 2.8 millions (1982), therefore generates a total expenditure on health of $2.1 billion per year.

If 5% or less of this annual cost was associated with traffic related illness which could be reduced by tunnelling, a large localised tunnelling project can be justified manually.

Case History Study

Introduction

Alexandra Parade carries 52,000 vehicles per day from the end of the Eastern Freeway towards the city. During peak hour, traffic is banked up for nearly its entire length, resulting in conditions which are most unfavourable to adjacent properties.

Construction Costs

Tunnel Construction

The geology beneath Alexandra Parade consists of Quaternary basalts overlying Tertiary marine sands, old river beds, and swamps which are likely to contain water. These thin out towards the Princes Street or western end, as Silurian base rock is more predominant. It can be estimated from the geology, that out of a tunnel length of approx. 2.2 kms, 1.54 kms. would be by roadheader or TBM, while 0.66 km. would be with a Bentonite shield.

Other design information is summarised below:

Approx. Length	:	2.2 kms.
Tunnel dimensions	:	2 x 2 lane
Semi-tranverse Ventilation Scheme		
Portals Locations	:	One at the Eastern Freeway end, one at the top end of Princess Street, and two (single lanes) in Nicholson Street.

Therefore the cost per tunnel kilometer ($1983) is shown below:

1. Tunnel Construction per km

1.1 Road Header or TBM $\frac{1.54}{2.20}$ x \$13m/km = \$9.1m

1.2 Bentonite Shield $\frac{0.66}{2.20}$ x \$25m/km = \$7.5m

Sub-Total $16.5m.

1.3 Internal Construction @ 15% of \$16.5m \$2.5m.

1.4 Services Diversion @ 8% of \$16.5m \$1.3m.

2. Ventilation

2 shafts, 1 km. apart
Construction Costs: $1.2m
Plant Costs: \$0.5m \$ 1.7m.
Operating Costs (at \$30,000 per annum) \$ 0.9m.

Progressive Total $ 22.9m.

3. Portals and Contingencies:

Allow 20% of 22.9 $ 4.6m.

Total $ 26.6m./km

Since two tunnels are required, per surface kilometer,ie one each for incoming and outgoing traffic, then the total tunnel cost is:

$53.2m./km. surface

Freeway Construction

The construction cost for an alternative 4 lane surface freeway is based on figures used on a proposed "C3" Surface Freeway in the recent Gardiners Creek freeway study. This was $30 million per km.

Land Aquisition

To construct a freeway it would be necessary to purchase property on either side of Alexandra Parade. These purchases have been assessed at a market value at nearly $9 million per km.

Non-Construction Costs

Property Values

It has been recognised for some time that large volumes of through traffic adversely affect the environment and depress residential value. In attempting to quantify the change in property values resulting from traffic movement, property values for a segment along Alexandra Parade were compared with properties at a distance from Alexandra Parade. The study confines itself to the Fitzroy area.

Three streets running parallel, and one perpendicular to Alexandra Parade were studied as a comparison.

These streets were Cecil Street, Westgarth Street, Leicester Street, and Napier Street.

The value of each residence adjacent to these five streets, in 1978 dollars, is compared with their subsequent selling values. Out of 335 houses studied, nearly 33% had been sold at least once since 1978. For each street, a comparison is made to determine the rate of return in real terms on each property. This comparison will show the effect that the large flow of traffic on Alexandra Parade has on the value of the property adjacent or near to Alexandra Parade.

A summary of the findings is given in Table 2.

It was found that Alexandra Parade has a low property value,and the properties are losing value at a rate of 7.2% p.a. compared to other properties studied. This can be attributed to the existing major road through the area due to:

1. Disturbance from large traffic flows resulting in high noise and pollution levels, very close to residences.

2. Less community cohesion since Alexandra Parade provides a barrier between opposite sides of the street.

Therefore it is reasonable to suggest that the cash value resulting in this loss of 7.2% per annum can be traded directly against the cost of constructing a freeway as an alternative a tunnel scheme.

Thus over the expected useful life of the tunnel, a figure of $311,700 per year per km. can be placed on property values, along Alexandra Parade.

Fuel Consumption

Because tunnels can be aligned along the shortest and most direct route, with fewer grades and curves, a net saving in fuel consumption of vehicles using that tunnel can be achieved. Fuel consumption for vehicles travelling in city traffic with persistent delays at intersections and long idling times, compared with freeway or highway travel, have long been available for a wide range of vehicles. It is reasonable then to use this saving in fuel as a direct cash benefit of a tunnel scheme over the life of the tunnel.

The results obtained suggest that a difference of 4 litre /100kms. between city and highway travel is a reasonable figure.

A dollar value can then be attached to fuel savings:

Assuming 45 cents/litre
in 1.8 cents/km./vehicle

and 52,000 vehicles per day, 360 days per year, gives a figure of:

$337,000 per km. per year
over the life of the tunnel.

Noise Intrusion

Bridle (1977) and Holmes (1977) established a relationship between noise levels before and after the construction of road systems in Britain during the mid seventies. They derived a formula which can be used to determine the noise intrusion cost for properties adjacent to a major roadway. It is based solely on noise levels.

TABLE 2

PROPERTY VALUES, ALEXANDRA PARADE AREA

LOCATION	SAMPLE SIZE	PERCENT SOLD	AVERAGE VALUE $(1983)	RATE OF RETURN Since 1978 % p.a.	WEIGHTED AVERAGE
Alexandra Parade	64	35%	47,101	-3.6%	
Cecil St.	73	37%	60,774	5.2%	
Westgarth St.	89	38%	66,810	7.3%	5.6%
Leicester St.	44	25%	60,055	2.6%	
Napier St.	65	25%	68,887	4.5%	

This relationship should be interpreted with care, and is not considered valid when applied to individual properties. The relationship is:

$$I_C^P = K_1 \quad C_i^P \left\{ \sin(K_2B)^O - \sin(K_2A)^O \right\}$$

where I_C^P = Intrusion cost in $ for property

A = noise in dB after construction at the property facade

B = noise in dB before construction at the property facade

C_i^P = cost of the individual property

In applying this to Alexandra Parade in Fitzroy, it was assumed that the noise level before construction of the tunnel would be 59dB and the noise level after construction of the tunnel would be 15dB, due to background noise only.

The constants K_1 and K_2 have been tested for various values in the U.K. and it has been proposed to use here.

$$K_1 = 0.3, \text{ and } K_2 = 2$$

The property value per km is:

$$C_i^P = \$3,611,433$$

so $I_i^P = 0.3C_i^P \quad \sin 118^o - \sin 30^o$

$= \$414,900/km$

so that, over a 30 year life of a tunnel, the benefit in terms of noise pollution is $12.4 million/km.

Land Acquisition

An advantage of replacing a surface road with a tunnel is that extra land area becomes available for housing or public use. To place a value on this would depend on many variables such as proposed land use, and restrictions if any on structures above the tunnels. Assuming continuation of typical land use in the neighbourhood a figure of $9 million per km. of surface road was calculated. This value is based on the average price for vacant land in the area as given by the Fitzroy City Council.

COMPARISON OF COSTS

The gains which have been reviewed above can be accounted for by assuming that the tunnel has a useful life of 30 years.

They are:

Land Value	$ 9 mill/km.
Property Values ($311,700 py. x 30 yr)	$ 9.4 mill/km.
Fuel Consumption	$ 10.1 mill/km.
Noise Intrusion ($510,640 py. x 30 yr)	$ 12.4 mill/km

Nett Indirect Gains due to Tunnelling $40.9 $m/km

Note that gains due to health and many other factors are not included in the above.

On this basis, a comparison of tunnelling and freeway costs yields:

		Tunnel $mill/km	Freeway $mill/km
1.	Direct Costs	53.2	30
2.	Accounting for Land values	-	9
3.	Environment Costs		9.4 10.1 12.4
	Total	53.2m	70.9m.

If tunnelling costs are compared against the cost of replacing an existing road or freeway, the real cost is $53.2m/km for a tunnel but is $40.9m/km for the existing road. These costs exist whilst the road exists but they are not seen as they are mainly bourne by the adjacent neighbourhood. The nett cost of tunnelling is approx. $12 m/km. It is positive but is lower than usually considered.

On the other hand, if the freeway is not already installed, tunnelling is by far the cheaper alternative to putting in a freeway, due to the environmental advantages that it presents.

CONCLUSIONS

An attempt has been made to assess some of the non-construction costs due to tunnelling in an inner city Melbourne environment. The value of such items has been assessed - land acquisition/availability, property values, fuel consumption and noise intrusion. It could be argued that there is some duplication in the effects of noise intrusion and the loss in property values. However, the loss in property values was only assessed along the actual frontages to Alexandra Parade and not to properties on the streets behind. Noise pollution is only one of the adverse effects on property values and it extends much further into the adjacent neighbourhood than the immediately adjacent properties. The value of many other social and health effects on the adjacent neighbourhood has not been assessed although it would appear that they would give further favourable consideration to tunnelling.

The cost assessment suggests that, in such an environment, tunnels are possibly a viable alternative to leaving existing heavily trafficked roads as they are at present. In addition, if the roads were ever to be replaced, it is far better to use tunnels instead of freeways.

REFERENCES

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