A CASE STUDY ON COST/BENEFIT ASSESSMENT OF ROAD TRAFFIC NOISE AMELIORATION WITHIN AND OUTSIDE THE ROAD RESERVE

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Abstract

Whilst the road network is essential for the community's environmental, social and economic well being, there is a growing concern for the adverse effects of its operation and use, including the levels of exposure to road traffic noise. In addition it is evident that in urban centres where the problem is relatively critical, all treatment options within the road reserve have been exhausted. The consideration of possible treatment options currently is largely based on the experience and knowledge of the decision maker and not necessarily on the costs and benefits associated with each treatment option and its value to the community. A research program that aims to develop a framework for conducting a cost/benefit evaluation of the alternative road traffic noise amelioration treatments is currently underway. The project aims to foster methods for the management of road traffic noise by control at the noise source, along the transmission path and at the receiver (architectural treatment to the building envelope). The benefit of such a study would adequately equip a decision maker to mitigate the problem where it is most effective with the potential to defuse traditional "authority" boundaries and produce the optimum outcome. The research described here was carried out by the Australian Cooperative Research Centre for Construction Innovation [1], in collaboration with the Queensland Department of Main Roads, Queensland Department of Public Works, Arup Pty. Ltd., and QUT. This paper presents a case study based cost/benefit assessment, comparing the road traffic noise amelioration alternatives within and outside the road reserve using a real project in Queensland, Australia. The cost/benefit assessment of the alternative treatments has been based on the existing pre-treatment data, the size, number and type of affected residences as well as estimates of outside the road reserve treatment costs. The assessment has been undertaken using the decision support tool currently being developed under the research program conducted at RMIT University.

Introduction

Noise barriers have been used to reduce the impact of road traffic noise on residential properties particularly along major road ways in Australian cities. However with the trend towards higher density living, residential properties are more often being constructed as higher rise developments.

In order to maintain their noise shadow effect, noise barriers have to increase in height as residential developments grow from low to high rise. As they increase in height the negative effects of noise barriers such as the reduction of aesthetic values, airflow, light and access to views increase. For this reason road authorities in Australia have placed limits on the maximum allowable height for noise barriers [2]. Accordingly traditional noise amelioration strategies used in Australia may no longer be practical in the future and alternatives would need to be sought.

In order to gain some insight into how noise amelioration is approached in higher density cities, the situation in Hong Kong has been investigated. Hong Kong is unique compared to other cities in that land availability is extremely limited and residential developments are commonly constructed as high rise developments.

In Hong Kong, strategies used for amelioration of traffic noise outside the road reserve involve both measures at the receiver and in the pathway between the source and receiver. An example of measures in the pathway between the source and the receiver involves using a noise tolerant building (car park) as a shielding structure [3]. Examples of measures at the receiver include the use of innovative layout (shielding noise sensitive with noise tolerant rooms), shielding noise sensitive rooms with balconies, architectural fins and building insulation [3]. Insulating buildings is used as a last resort because it deprives residents of the opportunity of opening sealed windows [4] and because an air conditioning system is often also required.

It has been demonstrated that high rise residential developments comprising between 140 and 500 flats that have been designed with innovative layouts can reduce the noise levels to noise sensitive rooms by between 7 and 19dB(A). The use of noise tolerant buildings can reduce the noise levels reaching noise sensitive buildings by between 5 and 16dB(A) and architectural fins reduce the noise level by between 1 and 2dB(A) [3].

The purpose of undertaking this study was to gain an understanding of the conditions under which noise amelioration outside the road reserve would be more beneficial and cost effective compared to within the road reserve noise amelioration.

It has been suggested that, "where there is less than 3 houses grouped together it is more cost effective to provide building treatment than noise barriers", [5]. This suggestion has been assessed in terms of the application presented in this paper.

Presented in this paper is a comparison of the costs and benefits of two noise amelioration treatments. One, within the road reserve which was actually implemented and the other, outside the road reserve, which was only hypothetically developed. Noise assessments involving monitoring and modeling have been undertaken for the study area. As a result a within the road reserve noise amelioration treatment was actually designed, and installed. For the purpose of this study the noise assessment data has also been used to develop the outside the road reserve noise amelioration treatment.

The Study Area, Noise Criteria and the Noise Assessment

The study area is located in Albany Creek, a suburb of Brisbane in Queensland, Australia. The noise source is a segment of the Old Northern Road between Jinker Track and Keong Road. The existing road surface pavement was dense-graded asphalt, the sign posted speed was 70km/h, the percentage commercial vehicles was 6.0% and the Average Annual Daily Traffic flow (AADT) was 22,839 at the time of the noise assessment in 2002 [6].

The noise sensitive receivers are represented by eleven residential dwellings adjacent to the eastern side of the road reserve. The dwellings all have brick veneer external walls, pitched tiled roofs, single glazed windows and appeared to be in good condition.

Road traffic noise level criteria are defined in the Queensland Department of Main Roads, Road Traffic Noise Management: Code of Practice [2]. The criterion applicable to this study involving existing residences and existing roads (no road works) is an external level equal to 68dB(A) L_{A10}(18hour).

The noise assessment involved the prediction of noise levels for the years 2002, 2007 and 2012 which involved a growth rate in the AADT of 4.27%. In the most severe case, which involved the prediction for the year 2012 and a road surface of dense graded asphalt, nine of the eleven dwellings were found to exceed the criteria. The highest noise level was found to be 76dB(A) L_{A10}(18hour), 8dB(A) above the criteria.

Road Traffic Noise Amelioration Outside of the Road Reserve

For the purpose of this paper, outside the road reserve noise amelioration refers to treatment of the building envelope. The procedure presented in the Australian Standards [7] has been used to determine the type of building construction necessary to achieve acceptable indoor noise levels .

The road traffic noise management code of practice does not specify an internal noise criterion for residential properties [2]. In this case the selection of a satisfactory internal noise level (L_{Arec}) has been determined based on the relevant external criterion and not on that recommended in the Australian Standards [8]. The reason for this is to ensure that the treatments for both inside and outside the road reserve are both being used to reduce the noise level by comparable amounts. In this way the benefits and costs associated with each treatment can be more directly compared.

In the case of the outside the road reserve treatment the criterion for the external noise level is 68dB(A)L_{A10}(18hours). As there is no restriction on opening windows the loudest internal noise level corresponding to the external noise level would occur when the windows are open. A category 1 façade with open windows (the opening representing up to 10% of the exposed façade) would result in a traffic noise reduction of approximately 10dB(A) [7]. Accordingly the equivalent internal noise level corresponding to the external noise level of 68dB(A) has been considered to be approximately equal to 58dB(A).

In order to determine the traffic noise reduction it is first necessary to convert the criterion from L_{A10} to the equivalent L_{Aeq} descriptor by subtracting 3dB(A) [7]. The traffic noise reduction is determined using Equation (1) to be 18dB(A).

$$TNR = L_{AeqT} - L_{Arec}. \quad (1)$$

A TNR of 15dB(A) corresponds to construction category 2. Category 2 is defined as, “Standard construction, except for lightweight elements such as fibrous cement or metal cladding or all-glass facades. Windows, doors and other openings must be closed.” [7].

The nine brick veneer dwellings exposed to noise levels exceeding the criterion are not constructed from lightweight elements, so they are considered to represent a standard construction type.

The sound reduction indices (Rw) obtained from Appendix B of the Australian Standards [7], for each building element along with the area ratios of each component are presented in Table 1. The area ratios have been estimated based on measurements of a brick veneer dwelling that was not one of the nine exceeding the criterion.

Table 1. Sound reduction indices (Rw) and area ratios for the building elements in the nine dwellings exposed to noise levels above the criterion.

Building Component	Component type	Rw (dB(A))	Room Area (m2)	
			Bed	Living
External wall	Brick Veneer	39	21	42
Ceiling Roof	Pitched/ tiled	33	14	54
Window	Single glazing (6mm)	24	3	7.5

The next step was to determine if the sound reduction indices of the building components were sufficient to provide the required TNR. The traffic noise attenuation required of each component (TNAc) was evaluated using Equation (2).

$$TNAc = TNR+10\log_{10}((Sc/Sf)*3/h*2/T60*C) \quad (2)$$

Where, Sc/Sf is the area ratio of the components, h is the ceiling height of the room, T60 is the reverberation time of the room and C is the number of components.

The TNAc values were converted to equivalent Rw indices in order to identify components with the desired TNAc values by adding a factor of 6 to account for the spectral composition of the noise [7].

The TNAc and Rw indices required to provide a sufficient TNR for the three building components have been evaluated and the results are presented in Table 2, (Sc/Sf was determined based on the area ratios in Table 1, h was 2.8m, T60 was 0.5s and C was equal to 3).

Table 2. Traffic noise attenuation (TNAc) and sound reduction indices (Rw) providing a sufficient traffic noise reduction (TNR)

Component type	Bedroom (dB(A))		Livingroom (dB(A))	
	TNAc	Rw	TNAc	Rw
Brick Veneer	22	28	19	25
Pitched/ tiled	20	26	20	26
Single glazing (6mm)	13	19	8	14

The actual Rw (Table 1) was found to be greater than the required Rw (Table 2) for each building component. Accordingly the building elements in the nine dwellings exposed to noise levels exceeding the criterion were considered capable of being used to provide a TNR that would sufficiently reduce the internal noise level to below the recommended indoor noise level (L_{Arec}).

The overall transmission loss of the dwelling construction (Rw,av) comprising the brick veneer, pitched tiled roof and a single glazing was also evaluated to determine the reduction in the sound transmission loss of the façade with an open window or an air gap [7].

The procedure involved converting the component Rw's to transmission coefficients (T) using Equation (3). The average transmission coefficient (Tav) for the dwelling construction was determined by substituting the areas of the individual components (s) and the transmission coefficients into Equation (4). The overall Rw,av for the dwelling construction was evaluated by substituting the average transmission coefficient back into Equation (3).

$$Rw = -10*\log_{10}T \quad (3)$$

$$Tav = (T1*s1+T2*s2+T3*s3)/(s1+s2+s3) \quad (4)$$

The overall transmission losses of the dwelling construction with the window varying from 100 to 0 percent open are presented Figure 1.

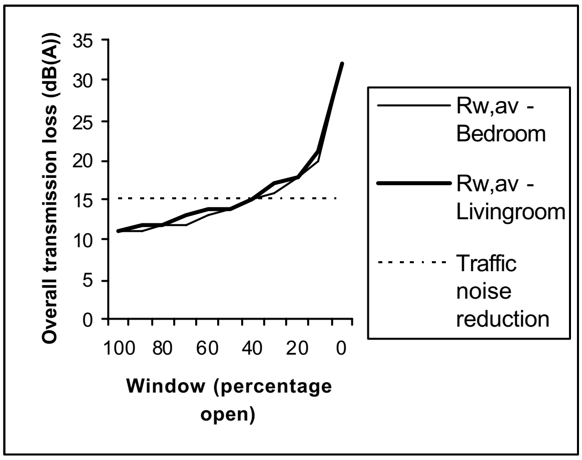

Figure 1 The overall transmission losses (Rw,av) for the bedroom and living room with the window varying from 100 to 0 percent open.

With the window area up to 40% open or with air gaps having an equivalent opening (and the window closed) the required traffic noise reduction was found to be satisfactory. In this case there would be no requirement for sealing the façade. However due to the limitation on the opening of the window and the unknown size of air gaps in the façade, mechanical ventilation and air conditioning were considered to be required.

Cost of Outside the Road Reserve Noise Amelioration

The cost of providing mechanical ventilation/air conditioning and sealing of wall vents has been estimated and was in the order of between $5000 and $15000 per dwelling [5]. Although only mechanical ventilation and air conditioning may be required in this case the cost per dwelling has been assumed to be $15000. This cost is assumed to include the purchase of the mechanical ventilation and air conditioning units, instillation as well as thermal insulation if required. The total cost of noise amelioration for the nine dwellings was then found to be equal to $135,000.

Maintenance costs and running costs have been assumed to be the responsibility of the dwelling owner. The running cost has been estimated at approximately $400 per year (estimate based on: 0.13c/kwh, 2kw, 10hours*7days*4.3weeks*5months). The maintenance cost has not been estimated.

Road Traffic Noise Amelioration Within of the Road Reserve

Noise barriers were designed and installed in order to reduce the road traffic noise level to below the criterion. The noise barrier was manufactured from timber, was approximately 297m long and varies in height from 1.9 to 5.0m

Cost of Within the Road Reserve Noise Amelioration

The total cost of providing the noise barriers was approximately $300,000. This included project management, survey, design, construction, planning, landscaping costs as well as the cost of site specific civil works and contingency costs. The largest of these costs was the cost of construction of the noise barrier which represented approximately half of the total cost. There is an ongoing maintenance cost which has not been estimated and would be the responsibility of the road authority.

Benefit Assessment

The Roads Traffic Authority of New South Wales (RTA) have developed an index (PI) for prioritizing noise abatement strategies which in part is reproduced here as Equation (5). For noise abatement strategies such as building treatment the index is divided by a factor of 2. This is a subjective and arbitrary figure that at least goes some way to account for the fact that only the indoor noise level is reduced and so only half of the benefit is realized [9].

$$PI = Nd*R*Nr*1000/c \qquad (5)$$

Where Nd is the difference between the existing noise level and the criterion, R is the number of similarly affected receivers, Nr is the noise level reduction due to the noise treatment and c is the cost of the treatment.

The priority index represents a measure of the benefits in relation to the cost of alternative treatments. The index has been used to compare the noise barrier with the building treatment noise amelioration strategies and the results are presented in Table 3.

Table 3. Priority index for the noise barrier and building treatment noise amelioration alternatives

Noise amelioration strategy	Nd	Nr	R	PI
Noise barrier	3	5	9	0.5
Building treatment	3	10	9	1

(NB: Average values were determined for Nd and for the noise barrier Nr. Nr for the building treatment was considered to be the noise reduction with windows and doors open (10dB(A)) subtracted from the noise reduction with windows and doors closed without sealing (20dB(A))

In this case the priority or benefit of the building treatment option was found to be twice that of the noise barrier option. The reason for this result was due to the building treatment option having a lower cost and a larger noise reduction compared to the noise barrier option even though only half the benefit was gained (indoor noise reduction only).

Comparison of Costs and Benefits of Within and Outside the Road Reserve Noise Amelioration

The cost of noise amelioration outside the road reserve was found to be less than half that of noise amelioration within the road reserve. Although lower in initial cost, building treatment has an additional running cost. Over a ten year period such a running cost could amount to hundreds of thousands of dollars. If the running cost was included the outside the road reserve noise amelioration option may be even greater than that of the within the road reserve treatment.

The major difference between the noise amelioration treatments in terms of benefits is that the noise barrier can be used to reduce both the internal and external noise levels. An additional benefit of noise barriers is that all dwellings in the shadow of the noise barrier and not just those exposed to a noise level exceeding a criterion could be exposed to lower noise levels.

The value of reducing the external noise level compared to the internal noise level is difficult to evaluate. Evaluating such a benefit depends on such factors as the activities undertaken outdoors, the number of people and how long they spend outdoors.

Accordingly the value of such a benefit may depend on an individual's preference.

However it can be said that reducing indoor noise levels is more important than reducing outdoor noise levels. This is in part because typical indoor activities such as sleeping, working, studying and relaxing are more likely to require a quiet indoor environment and because the population in larger cities spends over 90% of their time indoors [10]. From a health perspective the intrusion of road traffic noise indoors presents a greater health risk.

Other factors concerning the erection of noise barriers are that they may reduce air flow around dwellings which in sub-tropical environments such as Brisbane could result in a need for mechanical ventilation/air conditioning. Noise barriers may also reduce natural lighting and reduce the aesthetic value of a view. The most significant problem with treatment to buildings is that when the façade is sealed the occupants are unable to open the windows.

Conclusions

In terms of initial cost (excluding running costs), the cost of the hypothetical outside the road reserve treatment was found to be approximately half that of the actually implemented within the road reserve treatment. It has been found that, the suggestion presented earlier, in which it was only considered cost effective to provide building treatment for less than 3 closely grouped houses, may not always be true, because in this case nine houses would have been treated. However if this statement was written with running costs in mind then in the long term it may prove to be accurate.

In terms of benefits the hypothetical building treatment option ranked higher than the actually implemented noise barrier option when evaluated using the priority indexeven though there was no reduction in the external noise level. The index involved a subjective factor to deal with the lack of a reduction in the external noise level associated with the hypothetical building treatment strategy. By changing the factor the priorities could be reversed as they may if running costs were also included.

Benefit is a difficult quantity to measure because there are many different factors involved including individual preferences, aesthetic values, as well as identifying the relative value of internal and external noise reductions. It is recognized that further work is required to address the question of when noise amelioration outside the road reserve would be more beneficial and cost effective than within the road reserve noise amelioration. The decision support tool currently being developed under the research program carried out by the Australian Cooperative Research Centre for Construction Innovation, will enable many different scenarios to be evaluated and compared which will contribute further to our understanding of this issue.

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