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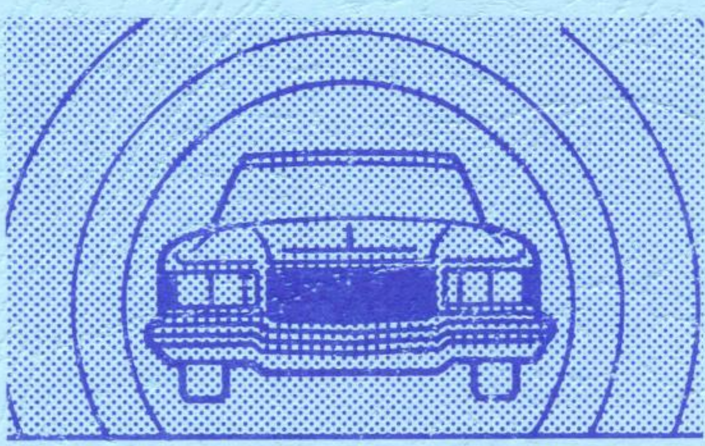

MOTOR VEHICLE AND TRAFFIC NOISE

PROCEEDINGS

24 to 26th November, 1985
Leura Gardens, N.S.W.

This conference was organised on behalf of the **N.S.W. Division of the Australian Acoustical Society** by the Conference Committee:

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The support of the **Australian Environment Council** and the **N.S.W. State Pollution Control Commission** is gratefully acknowledged.

The Proceedings are published by:

Australian Acoustical Society,
35 Clarence Street,
Sydney. N.S.W. 2000 AUSTRALIA

November 1985

ISSN 0156-6687
ISBN 0 909882 08 8

MOTOR VEHICLE AND TRAFFIC NOISE

PROCEEDINGS

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PRESENT AND FUTURE STATE OF THE NOISE ENVIRONMENT

Today, an estimated 16 per cent of the inhabitants of OECD countries -- some 130 million people -- are exposed to "unacceptable" levels of noise (over 65 decibels outdoors on a daily basis). A further 34 per cent (270 million people) suffer "acoustic discomfort" (55 to 65 decibels) [1].

The major source of noise in all OECD countries is road traffic (cars, trucks and motor cycles): 19 million people are exposed to over 65 decibels in North America, 53 million in Europe and 38 million in OECD Pacific countries, i.e. a total of 110 million people are exposed to "unacceptable" levels of road traffic noise in the OECD area. At this level of 65 decibels (to be precise, it is the noise level in dBA expressed in Leq-daytime and measured in front of the most exposed facades of the buildings) noise interferes with daily activities such as conversation, listening to radio and television, relaxing or sleeping.

The reasons for the high number of people exposed to road traffic noise are easy to understand: over the last 20 years the number of motor vehicles has tripled in OECD countries, reaching now more than 360 million units (of which 70 million commercial vehicles) and urbanisation has increased by 50 per cent, whereas during the same period progress in tightening noise emission limits for motor vehicles has remained rather slow in most countries: minus 3 dBA for cars and trucks between 1970 and 1985.

Road traffic noise is not evenly distributed between countries. In densely populated regions, the proportion of people exposed to levels above 65 decibels can reach 30 per cent whereas in low density areas, this proportion can be as low as 5 to 10 per cent (see Table 1). However, in big cities like London or Paris, half of the population is exposed to noise levels exceeding 65 dBA (Leq). And this situation has not substantially improved over the past ten years, except in the vicinity of very noisy motorways, where appropriate protective measures have been recently adopted (building insulation and noise barriers).

* The opinions expressed in this paper are the author's own and do not necessarily reflect the views of the OECD.

** Member Countries of OECD: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States.

Table 1: Proportion of Population Exposed to Road Traffic Noise in 14 Countries (early 1980s)(%)

	Outdoor sound level in Leq		
	> 65	65 to 55	< 55
Austria	16	34	50
Belgium	12	57	31
Denmark	12	26	62
France	13	31	56
Germany	8	26	66
Greece	20	30	50
Japan	31	49	20
Netherlands	6	34	82
Norway	5	13	60
Spain	23	51	26
Sweden	11	27	62
Switzerland	11	43	46
United Kingdom	11	39	50
United States	7	30	63

Note: Leq - average daily noise expressed in decibels A (dBA).
> 65: unacceptable levels.
65 to 55: acoustical discomfort.
< 55: comfortable levels.

Source: OECD.

As regards the future, forecasts indicate that the number of people exposed to noise levels exceeding 65 dBA (Leq) could increase by 30 per cent between now and the year 2000 if existing regulations are not strengthened, the reasons of this increase being the continued growth in vehicles/km (30 to 50 per cent increase between 1980 and 2000), the increase of diesel vehicles and the increase in leisure time, secondary homes and tourism.

If, on the contrary, strong noise abatement policies were pursued, i.e. noise emission limits of 75 dBA for cars and motorcyles, 80 dBA for buses and trucks and a compulsory regular acoustic inspection of vehicles in use -- then the number of people exposed to over 65 dBA (Leq) could be reduced by approximately 50 per cent in the year 2000 by comparison to the number of people exposed to this level in 1980.

These changes would lead to an acoustic environment in the year 2000 equivalent to the one prevailing in 1960 [3]. It should be noted, however, that such a drastic reduction of noise exposure would only be obtained for noise levels above 65 dBA (Leq).

STRENGTHENING MOTOR VEHICLE NOISE ABATEMENT POLICIES

The implementation of very stringent emission limits would almost eliminate what we could call the "black spots", i.e. the noisiest areas in cities and along highways. However, these emission limits would only slightly reduce or even stabilise the number of people exposed to levels 55 to 65 dBA (Leq), i.e. "the grey areas" of uncomfortable acoustic environment [4]. This means that a traffic noise abatement policy aiming only at strengthening noise emission limits would greatly improve the situation of the people exposed to excessive noise levels and therefore very much annoyed by these levels, but such a policy would not be sufficient to improve the situation of those exposed to "uncomfortable" noise levels.

Before looking at what types of policies would be needed to eliminate the "black spots" and to reduce the "grey areas", one should first describe the main regulations which have been adopted so far in OECD countries in order to reduce traffic noise.

MOTOR VEHICLE AND TRAFFIC NOISE CONTROLS

Noise emission limits

As mentioned earlier, the strengthening of noise emission limits for motor vehicles was rather slow between 1970 and 1985, except for buses as a result of the emergence of a demand for silent buses in many local communities. In most countries, limits for cars and trucks decreased by 3 decibels during that period and by 5-7 decibels for buses. Two important exceptions are worth mentioning: Switzerland and Japan (see Table 2). In less than one year from now (October 1986), Switzerland will have adopted the noise emission limits recommended during the OECD Conference on Noise Abatement Policies (except for the very heavy lorries), i.e. 75 dBA for cars and motorcycles, 80 dBA for heavy vehicles [2]. Swiss motor vehicle noise emission limits will then be the most stringent in the world. In three years from now, in 1988, noise emission limits will also be strengthened within the European Community (i.e. the twelve countries listed on Table 2), even if they will not have yet reached the stringency of the Swiss limits by that time. This move within the European Community is the result of a comprehensive approach to environmental problems caused by motor vehicles, which include air pollution, noise and fuel consumption. The new emission limits are expected to produce only a slight drop of 1.5 to 2.5 dBA of the Leq index and at any rate it will take a decade until the whole vehicle fleet is quietened. However it should be noted that 40 per cent of new cars in Europe already emit less than 77 dBA and 20 per cent less than 75 dBA (because many cars are now five gear cars tested in 3rd gear). If the noise emission limits recommended by OECD were to be implemented, then the ambient Leq levels would be reduced by 4 to 5 dBA, and most noise peaks would rapidly decrease, at least those noise peaks not due to the behaviour of the drivers.

It should be noted that, as noise emission limits related to engine and exhaust noise are slowly but progressively tightened, tire noise becomes more salient, especially on highways. It will therefore soon become necessary to regulate tire noise and even perhaps road noise, since the quality of the road surface contributes not only to tire noise but also to the noise radiated by the engine and the exhaust system.

Table 2: Present and Future Noise Emission Limits for Motor Vehicles (1)

Country	Passenger car	Small van (under 3.5t)	Small bus (under 3.5t)	Heavy lorry (under 150 KW)	Large bus (over 150 KW)	Very heavy lorry (over 150 KW)	Very large bus (over 150 KW)	Big motor-cycles (over 500 cc)
EEC (2)								
- Present	80	81	81	86	82	88	85	86
- Future (1988)	77	78-79	78-79	83	80	84	83	80 (1995)
Switzerland								
- Present	77	79	79	84	82	86	84	80
- Future (Oct. 1986)	75	77	77	82	80	84	82	78
Japan								
- Present	78	78	78	83	83	83	83	78
USA								
- Present	-	-	-	89	86	89	86	86
- Future	-	-	-	86	83	86	83	83
Australia								
- Present	81	82	82	87	86	89	88	84
OECD Conference proposals (1985-1990)	75	75	75	80	80	80	80	75

1. Measured at 7.50 metres from accelerating vehicle (ISO R362).
2. EEC-European Economic Community: Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, the United Kingdom; plus, as of 1.1.86, Portugal and Spain.

STRENGTHENING MOTOR VEHICLE NOISE ABATEMENT POLICIES

Controls on vehicles in use

Noise control regulations on operation of motor vehicles are fairly widespread and most often locally decided in OECD Member countries: traffic limitations, speed limits, traffic management, rerouting of heavy vehicles. In this respect it is worth mentioning Switzerland again, where the driving of heavy trucks at night and on Sundays has been prohibited for many years. In several countries (Germany, Switzerland, Sweden, the Netherlands, etc.), there are also on the spot controls of individual vehicles (especially motorcycles) as well as controls of individual vehicles every year or every two years linked with compulsory safety inspections. It should be stressed in this respect that enforcement is the key to any serious noise abatement policy. Lack of enforcement or lenient enforcement automatically renders a noise abatement policy ineffective. In Lausanne, two noise brigades have been in operation for 25 years. These brigades stop noisy vehicles on the spot, especially at night. If the stopped vehicle has been voluntarily modified in order to be noisy, the vehicle (generally a motorbike) may either have to be repaired or even destroyed. However, these brigades generally act in such a way and are so well known in Lausanne that their role is much more preventive than punitive.

Regulations on infrastructure and buildings

Land use management, urban planning, environmental impact assessments, regulations concerning the sound insulation of buildings, are tools which can help to prevent traffic noise problems by ensuring appropriate care is given to the location and type of construction of roads. In order to induce local authorities to include the noise factor in their planning decisions, certain countries (like the Netherlands) have adopted national noise ambient standards, at least in terms of long term objectives. Thus, construction is only authorised if it is compatible with the expected noise exposure. But the most interesting land use policy for noise protection is the UK Land Compensation Act of 1973 [2]. The main thrust of this Act can be seen as the avoidance of noisy situations where compensation would have to be paid. It confers on the highway authorities the power to acquire additional land so as to relieve the problems of noise caused by the project. If, despite noise abatement measures, dwellings are expected to be exposed to an Leq noise level exceeding 65 dBA [in fact 68 dBA on the L_{10} (18 hours) index], noise insulation must be provided at the expense of the highway authority and compensation for the loss of property value can even be required.

As to existing situations -- the most numerous ones -- are roads which cannot be removed nor significantly modified. In these cases, only noise barriers and sound insulation of buildings are possible since most land is ... already used. Many countries have adopted curative measures of this kind especially in very noisy areas: this has helped, over the past ten years, to reduce the number of "black spots", i.e. along urban highways. But it does not improve the outdoor environment.

These rehabilitation measures, which most often are adopted on a case by case basis, either rely upon the willingness of local authorities or must be heavily subsidised by central governments. This only underlines a commonplace remark about environmental policy: prevention is better than cure, but it is often too late to prevent. Since most infrastructure has already been built, there is not much which remains to be done in terms of land use planning.

Therefore any traffic noise abatement policy which includes zoning and building regulations should only expect limited results from these regulations. These results are far from negligible, especially in the cases where complete rehabilitation programmes are implemented (insulation of the most exposed buildings, construction of acoustic barriers and tunnelling of urban highways), but most actions on infrastructure and buildings must, in fact, be considered as a complementary measure to the reduction of motor vehicle noise at its source, simply because land use planning for abatement is, in most cases, no longer possible.

But, contrary to land use management, controls of vehicles in use are not simply a complementary policy instrument: they are and must be intimately linked to emission limits. The benefits of these controls may seem small when one looks at the resulting overall noise levels. However, annoyance is often due to noise linked to the behaviour of the drivers -- e.g. accelerating motorcycles, vehicles with defective exhausts -- and therefore to the daily enforcement or lack of enforcement of a motor vehicle noise abatement policy. Also, controls of vehicles in use and a serious enforcement of regulations are very necessary because it takes almost a decade to replace a vehicle fleet: if one wishes to quickly hear a reduction of noise, abatement efforts should not be limited to new vehicles.

The costs of reducing motor vehicle noise

Assuming again that the objective would be to reach noise emission limits proposed by the OECD Conference on Noise (75 dBA for cars and 80 dBA for lorries and buses), the extra costs of lowering motor vehicle noise have been calculated to be: 2-4 per cent for cars, 3 per cent for buses and 5-7 per cent for heavy lorries, i.e. 10-15 US dollars per year and per capita or 0.11-0.14 per cent of GDP [5]. The lead-time needed to produce much quieter vehicles is about 5-6 years (but it may be longer to reach the objective of 80 dBA for the very heavy vehicles).

In fact, these expenditures could probably be lower if allowance was made for the fact that noise emission levels of many new vehicles are already lower than laid down by the current regulations. In the Netherlands for instance, it has been calculated that annual expenditure per capita would not exceed 3.5 US dollars (0.03 per cent of GDP), i.e. four times less than indicated above [6]. But such a low figure may be valid only for the countries with least exposure to noise and with a very modern fleet of vehicles.

By comparison, calculations made in France and in the United Kingdom indicate that expenditure for the soundproofing of existing housing exposed to an Leq noise level above 65 dBA would amount annually during ten years to 0.05-0.14 per cent of GDP [5]. Therefore, there is not much difference in terms of costs between noise reduction at source and noise reduction at reception. In the first case, however, the polluters would pay for the reduction of the noise of their vehicles through an increased price of these vehicles, whereas in the second case, the financial burden would be on taxpayers through increased national or local taxes, except if the costs of insulating houses were to be paid through a special noise charge on vehicles or through partial subsidies to home owners. It should also be stressed that reducing noise at source has the advantage of protecting people from excessive noise wherever they are and not only at home. At any rate, these costs remain low when compared to expenditure for the improvement of the environment or when compared to the Gross Domestic Product of industrialised countries.

THE NEED FOR A DIVERSIFIED STRATEGY: INCREASING THE USE OF INCENTIVES

"Ensuring a more effective enforcement of existing noise abatement regulations" and "progressively strengthening noise control regulations, and in particular, noise emission limits (...) for motor vehicles (...) along the lines of the conclusions of the OECD Conference on Noise Abatement Policies": these two actions have been recommended to Member countries by the OECD Ministers of the Environment when they met last June in Paris [7]. However, OECD Environment Ministers, recognising the limits of the regulatory approach and the necessity of complementing regulations with other policy instruments to influence the behaviour of people, recommended that OECD Member countries improve their noise abatement policies by "complementing existing regulations with incentives and measures designed to promote production and use of quieter products, such as economic instruments, education and information, product labelling, favourable treatment of quieter products and in-use control of products and vehicles."

In one word, a modern noise abatement policy cannot be limited anymore to regulations; it should include incentive measures aimed at modifying noisy behaviour. This is necessary not only because regulations must be complemented by measures which provide incentives to bring down existing noise levels but also because many incentives can be undertaken quickly and at a low cost, which may be greatly appreciated by Governments at a time of fiscal and budget austerity.

Noise Charges

Economic instruments, such as charges on noise, can play an important persuasive and financing role for noise abatement. Charges on motor vehicle noise do not exist yet whereas they exist for aircraft noise in several countries (Japan, UK, France, Switzerland, Germany) [2]. However, in the Netherlands, there exists already a noise surtax on fuel which helps to finance the Dutch national noise abatement policy. A noise charge on motor vehicle sales (including on trucks and motorcycles) would do more to enable low-noise vehicles to enter the market than do regulations, which are simply meant to lay down maximum limits and do not really encourage manufacturers to do any better than these maximum limits. A noise charge accompanied by appropriate information to the consumers would guide consumer choice towards low-noise products.

However, progress still remains to be made not only with regard to the political acceptability of noise charges on motor vehicles and roads but also with regard to their principles and implementation. Relatively simple systems need to be worked out for traffic noise so as not to complicate their application. These systems should have both an incentive function -- to encourage the manufacturing and sale of quieter vehicles -- and a financing function -- to finance noise abatement programmes to soundproof houses exposed to excessive noise, etc.

Other Incentives

Although economic instruments may play an important role, particularly in financing noise abatement programmes and influencing economic behaviour, they may, in the long run, be limited by the fact that neither public nor private resources are infinitely extensible. In addition, some governments are reluctant to use what seem to be complicated procedures. So other types of incentives prove to be very useful if they can: encourage quiet behaviour, induce people to buy and use low-noise products, be incorporated in local programmes (see Table 3).

Table 3: Incentives for Traffic Noise Abatement in some OECD Countries

Type of incentive	Countries
Charges	(Proposed in the Netherlands and France but not yet adopted)
Financial assistance for purchase of quieter vehicles	(Proposed in the Netherlands)
Surtax on fuel	Netherlands
Noise abatement campaigns and information	Netherlands, Switzerland, France, United Kingdom, Germany, Austria
Pilot towns schemes	France
Noise labelling	(Not yet for vehicles)
Publicity for low-noise vehicles	Germany, Switzerland, Netherlands
Preferential treatment of low-noise vehicles	Germany
Local and national government policies	Germany, France, Netherlands, the United Kingdom
Restrictions on use of noisy vehicles	Germany, France, etc.
Traffic management improving the environment	France, Netherlands, Switzerland, Germany, Norway, Japan, Sweden, the United Kingdom

Table 3 (contd.)

Type of incentive	Countries
Anti-noise brigades	'Switzerland
Creation of noise abatement organisations	Most countries

Source: OECD.

Action focused on individuals may aim at the general public (noise abatement campaigns, pilot town schemes, educational advertising, etc.) or at particular categories of consumers (schools, decision-makers, elected representatives, professional people, etc.). This type of action is essential if the message is really to be brought home to the public.

Action with regard to products is not yet sufficient. It needs to be widely increased and oriented in two directions: a) informing the public of products' noise levels (labelling, certificate of acoustic quality); b) encouraging the purchase of low-noise products (procurement policies at local and national government level, local restrictions on the use of noisy vehicles, preferential treatment of quiet vehicles, i.e. special authorisation given to very quiet trucks and motorcyles to go through protected areas or to be driven at night).

The effectiveness of incentives varies, of course, with the type of action envisaged. They are obviously useful to back up regulations without introducing new constraints. But appropriate care should be taken in order to avoid giving the impression that some incentives --especially noise abatement campaigns and education -- are only a smoke screen, a substitute to action. In all cases, incentives should accompany or precede regulations and other direct interventions. In the future, two complementary approaches seem to be necessary: firstly, incentive action should, as far as possible, be left to the local level because of its intimate knowledge of local conditions and secondly, such action needs to be placed within a coherent overall policy.

Three kinds of complementarity are therefore required: a) between local and national authorities (to avoid inertia and a lack of co-ordination in what is done) as well as between public authorities and the private sector; b) between regulations and incentives, that are not enough on their own; and c) among the various incentives themselves so that they reinforce one another.

PROSPECTS

Noise increase is not inevitable. If stringent noise emission limits for motor vehicles (75 dBA for cars and motorcycles, 80 dBA for heavy vehicles) were enforced, the number of people exposed to noise levels above 65 dBA could be reduced to 50 per cent of the current figure in the year 2000.

Such a reduction of noise at source would result in an elimination of what we could call the "black spots", or the noisiest areas in cities and along highways. However, a strategy aiming only at strengthening noise emission limits would not be sufficient to improve the situation of those exposed to uncomfortable noise levels. "Black spots" would be eliminated but would be replaced by big "grey areas" of noise (above 55 dBA).

In order to reduce significantly the number of people exposed to noise levels in excess of 55 dBA as well, a more comprehensive strategy is needed, combining stringent emission limits and their serious enforcement with improved methods of traffic management and modifications of the infrastructure and buildings. In France, for example, it has been calculated that such a comprehensive strategy would reduce the number of people exposed to unacceptable noise levels by 80 per cent and those exposed to uncomfortable noise levels by 60 per cent. But the present economic situation is not favourable to such a comprehensive strategy, the costs of which may be considered by some as too high (although benefits would also be very high indeed, this suggests that a cost benefit assessment still needs to be done on this subject). In this climate, even new international regulations strengthening noise emission limits are difficult to achieve. The implications of the economic situation are such that realistic prospects for the future remain gloomy, except if some imagination is introduced in noise abatement policies and in particular if regulations are complemented by all kinds of INCENTIVES, direct and indirect, economic and informative in order to modify behaviour. Noise abatement campaigns (including international ones), labelling of quiet products, quiet pilot cities, noise charges, education in acoustics at school and at university, noise abatement brigades are examples of what could be done. But many other incentives may and must be invented if we really want to obtain a quieter environment.

These incentives present the advantage of being very flexible and therefore easy to adapt to future changes (traffic increase, ageing of the population, more leisure time) which will influence the acoustic climate.

The urbanisation process may also be more complex in the future: whereas the demand for single-family suburban homes may still rise in some countries, the desire to come back to live in the centre of cities close to services, leisure and cultural facilities will be felt by the young, the aged and more generally by the small households; at the same time, the population of big metropoles (in the OECD area) will stagnate or decrease, whereas the population of medium and small towns is expected to increase. There are still other changes which may affect the noise environment: increased use of telecommunications, the dislocation of some of the old industrial plants, the rise of new technologies and changes in energy use (until now, however, no contradiction has been found on the whole between traffic noise abatement and energy savings) [2].

The acoustic "implications" of these different factors are difficult to assess and predict. However, since they will probably play an important role in the determination of the noise climate in the year 2000, it is important to include them in policy formulation.

This brief look into the future of noise can be summarised in three points:

Firstly, noise will continue to spread in space and time: in space due to the development of small towns and of touristic areas; in time due to never ending mobility.

Secondly, leisure activities will create more and more noise problems, including new motor vehicle noise problems linked to an increased use of motorcycles, buggies, etc.

Thirdly, at a time when hearing may become more important than ever, with the wider use of the synthetic voice on equipment and machinery, as well as for telecommunications, there is a risk that the ageing of the population combined with an excessive exposure to noise by young people will result in a general decreased hearing capacity of future societies at the same time as there will be an increased sensitivity to noise and an increased need to hear correctly.

Finally, the economic climate and the need to be very selective in the definition of policy priorities in the environmental field may simply increase the size of the noise problem.

This outlook may seem pessimistic but it is an outlook predicting what may happen if no further action is undertaken. On the contrary, if a forceful noise abatement strategy is adopted, then not only existing problems would be solved but the future problems, briefly mentioned above, could be taken into account sufficiently in advance in order that, for once, a preventive noise abatement policy could be adopted.

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CONTRIBUTED PAPERS

STREAM A

TRAFFIC NOISE

TRAFFIC NOISE LEVEL - AN IMPROVED INDEX FOR ESTIMATING COMMUNITY EXPOSURE

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INTRODUCTION

Noise exposure indices are designed to predict the community impact of environmental noise. They are derived from socio-acoustic investigations of the relationship between noise measurement units and community reaction. Exposure indices are used primarily by planning and regulatory authorities for the prevention and control of community noise disturbance.

Studies of community reaction to traffic noise have been carried out in a number of countries [1, 2, 3, 4]. The main exposure indices developed from such studies are:

Leq:	Equivalent continuous sound level (24 hrs.)
L10(18hr):	Arithmetic average of hourly L10's over 0600 - 2400
Ldn:	Day Night Level = Leq with 10dB night-time weighting
TNI:	Traffic Noise Index = 4 (L10 - L90) + L90 - 30
Lnp:	Noise Pollution Level = Leq + kσ

In addition to these indices of overall noise, several studies have shown that noisy vehicle indices based on the flow of heavy vehicles (>1525kg) are highly correlated with reaction [1, 2]. It is the adequacy of these two types of index as predictors of community annoyance from traffic noise that forms the primary focus of the present paper.

DETERMINANTS OF TRAFFIC NOISE REACTION

There is evidence that traffic noise annoyance results from two relatively independent factors, namely, individually noisy vehicles and the bulk flow noise of traffic. Further, it can be shown that indices which assess overall traffic noise exposure [e.g., Leq, L10(18hr)] do not adequately take account of the impact of individually noisy vehicles [5]. This claim is based on three lines of evidence.

Several studies have reported simple correlations with community annoyance of a noisy vehicle index computed as the logarithm of the percentage of heavy vehicles (log %HV) as well as overall noise indices (e.g., Leq). Partial correlations were carried out on the results from the studies by Rylander [3], Langdon [1] and Brown [4]. It was found that the correlations between log(%HV) and annoyance were reduced only slightly when Leq was held constant (0.75 to 0.72, 0.66 to 0.56, 0.68 to 0.58 for the three studies, respectively). The same result occurs in these studies when L10(18hr) is held constant (See Ref. 5). This indicates that heavy or noisy vehicles have an effect on annoyance which is virtually independent of the overall noise exposure. In other words, noisy vehicles cause annoyance over and above that accounted for by an index of overall noise.

Further evidence on the determinants of traffic noise reaction comes from laboratory studies on the annoyance of noisy vehicles. In one study, Rylander [6] found that the percentage of subjects annoyed increased as the overall traffic noise level increased with the number of noisy vehicles held constant. Clearly, bulk flow noise is a primary determinant of annoyance. In a second experiment, Rylander increased the number of noisy vehicle passbys while lowering the bulk flow noise slightly to ensure that the overall Leq was constant. Again, there was a significant increase in annoyance indicating that noisy vehicles have an effect which is independent of that accounted for by overall exposure. In another study, Labiale [7] systematically varied both the overall traffic noise level and the number of noisy vehicle passbys. The results showed that both factors were significant determinants of annoyance.

Indirect evidence on the role of noisy vehicles relates to the sleep disturbance effects of traffic noise. Whereas aircraft noise is more likely to disturb communication rather than sleeping, traffic noise is most likely to disturb sleeping [8]. The presence of noisy vehicles in the traffic stream will make the traffic noise pattern intermittent rather than continuous, and will result in increased sleep disturbance [9]. Further, a heavy truck or an unmuffled car on a suburban street can produce indoor levels well in excess of the 50dBA level which has been found to be sufficient to awaken 50% of people [10]. It follows therefore, that a single noisy vehicle can cause extensive annoyance from sleep disturbance in areas where the overall traffic noise level is quite low and would be predicted to cause little annoyance.

It is clear, then, that noisy vehicles cause annoyance in excess of that accounted for by their contribution to the overall traffic noise level. This implies that the predictive ability of a traffic noise exposure index would be increased if it included a term for noisy vehicles.

EXTENDED INDICES OF TRAFFIC NOISE EXPOSURE

The notion of including a noisy vehicle term in an exposure index has been proposed by several investigators. In Langdon's [1] socioacoustic study around 53 sites, heavy vehicles were shown to be a major determinant of noise nuisance, particularly where the traffic conditions were congested rather than free-flowing. It was found that by using the noisy vehicle term log(%HV) to extend the exposure indices Leq and L10(18hr), the correlation with community reaction was increased from 0.51 to 0.70 for both indices. Langdon suggested that traffic noise nuisance may be predicted "by means of a weighted combination of externally measured noise level and the proportion of heavy vehicles"([1], p.282).

Yeowart [2] tested a range of exposure indices in a study of community reaction at 27 sites with varying types of traffic flow. The results indicated that none of the conventional indices (Leq, L10, Ldn, Lnp, TNI) "was sufficiently general to be able to predict reliably the community response to a broad sample of traffic flow conditions" (p.136). Yeowart hypothesized that there was some factor that existing indices failed to account for, and suggested that this factor was the sleep disturbance caused by heavy vehicles at night. Therefore, he explored extended indices which included a term for night-time vehicle flow, defined as the average number of heavy vehicles per hour from midnight to 0600 hours. It was found that the extended Leq and L10(18hr) indices had improved correlations with community dissatisfaction for all traffic flow conditions. The overall correlations with reaction were improved from 0.74 to 0.83 for Leq, and from 0.70 to 0.82 for L10(18hr).

TRAFFIC NOISE LEVEL

Derivation

The general form of an extended index is given by the equation:

$$\text{Extended Index} = \text{Basic Index} + K \times (\text{Noisy Vehicle Term}) \quad (1)$$

To develop a suitable extended index the three components of the above equation need to be determined. The basic index should be chosen from those which have consistently been found to be reasonable predictors of reaction. Out of contention are the indices TNI and Lnp which failed to predict in accordance with their underlying assumptions in Yeowart's study [2]. Also, Ldn can be ruled out because it already includes a weighting for night-time vehicle movements. Of the two most suitable basic indices, Leq and L10(18hr), the former is to be preferred. Although L10(18hr) performs as well as a predictor of reaction, the fact that it altogether ignores noise during the critical night-time hours casts serious doubt on its construct validity. Also, Leq is preferable because it is suitable for assessing many noise sources besides traffic, and is widely accepted as a general exposure index.

On the assumption that it is primarily the sleep disturbance effect of noisy vehicles which makes them an independent determinant of annoyance, it is logical to follow Yeowart in adopting a night-time heavy vehicle measure as the noisy vehicle term. However, the hours over which heavy vehicle flow is averaged should be based on sleep data. Yeowart selected midnight to 0600 simply because these hours complemented those missing from the L10(18hr) index. In Australia, sleep data from Brown's [4] traffic noise study indicated that the hours during which 50% of respondents reported sleeping were 2150-0645. This corresponds closely to the period 2200-0700 which is typically used to define night-time hours in noise exposure indices (e.g., Ldn, NEF).

Finally, the value of the constant K in the equation needs to be chosen so as to ensure that the extended index is an improved predictor of reaction. Using multiple regression analysis, Yeowart found that the best prediction of reaction was obtained with values of K of 0.11 for Leq and 0.13 for L10(18hr) and ranging from 0.10 to 0.23 for other indices. However, if the extended index is to be valid, there must be an *a priori* limit on the amount by which the overall exposure level can be increased by the addition of the noisy vehicle term. With the busiest highways carrying up to 150 heavy vehicles per hour between 2200 and 0700, a value of K= 0.1 would mean that the traffic noise level measured by the extended index could be 15dB higher than for the basic index. Considering that doubling the vehicle flow increases the overall level by 3dB, it seems appropriate to limit the value of K to 0.1 so as to limit the level increase to 15dB.

Empirical Evaluation

The only major socioacoustic study of traffic noise in Australia is that conducted by Brown [4] at 19 sites in Brisbane, Sydney and Melbourne. Data from this study was used to carry out an empirical evaluation of extended indices for application in Australia. The reaction measure used here, percent highly annoyed (%HA), is the percentage of respondents rating the top two categories on Brown's seven-point annoyance scale. The correlations between reaction and a number of exposure indices are shown in Table 1. Whereas the indices based on heavy vehicles had acceptably high correlations greater than 0.6, the overall noise indices had correlations of only around 0.4.

When the basic indices Leq and L10(18hr) are extended by the term 0.1(MNV), the correlations with reaction are improved from 0.43 and 0.39 to 0.62 and 0.60 for the two indices, respectively. (MNV is the mean number of heavy vehicles per hour from 2200 - 0700). As can be seen from Table 2, higher correlations with reaction are obtained when MNV is averaged over the period 2200 - 0700 rather than 2200 - 0600 or 2400 - 0600. The use of 0.1(MNV) as the noisy

Index	Correlation	Index	Correlation
Leq	0.43	TNI	0.20
L10(18hr)	0.39	log(%HV)	0.68
Ldn	0.46	log(NHV)	0.63
Lnp	0.38	MNV	0.72

Table 1 Correlations with community reaction for various exposure indices in Brown's study [4].

Extended Index	Hours over which MNV averaged		
	2200 - 0700	2200 - 0600	2400 - 0600
Leq + 0.1 (MNV)	0.62	0.58	0.57
L10(18hr) + 0.1(MNV)	0.60	0.56	0.54

Table 2 Correlation with reaction of extended indices using different night periods as the basis for MNV

vehicle term in an extended index is supported by the fact that there was an appreciably higher correlation with reaction (0.62) when it was used to extend Leq rather than either log(NHV) or log(%HV) both of which had correlations of 0.46.

Multiple regression analysis indicated that the optimum value of K in the predictive equation using Leq and MNV is 0.458. Although this value of the constant could improve the correlation of the extended index from 0.62 to 0.71, this value would give unrealistically high adjustments in exposure levels. A value of K=0.1 places an appropriate limit on exposure level adjustments, while still giving a satisfactory prediction of community reaction. The values of the term 0.1(MNV) for Brown's 19 sites are as follows: 1)0.1, 2)0.3, 3)0.8, 4)1.1, 5)3.2, 6)3.4, 7)0.1, 8)0.6, 9)0.5, 10)2.6, 11)1.7,12)2.0, 13)0.1, 14)0.5, 15)1.8, 16)0.2, 17)0.7, 18)2.4, 19)13.8. For most sites the value of the extension term is small (<2dB). However, an exceptionally high extension term is obtained for site 19 (13.8dB) which had an unusually large number of night-time heavy vehicles. This explains the very high level of community reaction at this site (55.9%HA) and indicates that an unextended index would underestimate the real impact of the noise.

Application

The preceding analysis leads to the following as the most suitable form of extended index, here termed the Traffic Noise Level (TNL):

$$\text{Traffic Noise Level} = Leq + 0.1(MNV) \qquad (2)$$

where MNV is the mean number of heavy vehicles (>1525kg) per hour in the period 2200 - 0700. The dose/response relationship between noise exposure assessed in terms of TNL and community reaction is shown in Figure 1. Note that with an extended index based on L10(18hr) the dose/response function is: %HA = 1.16[L10(18hr) + 0.1(MNV)]-57.3.

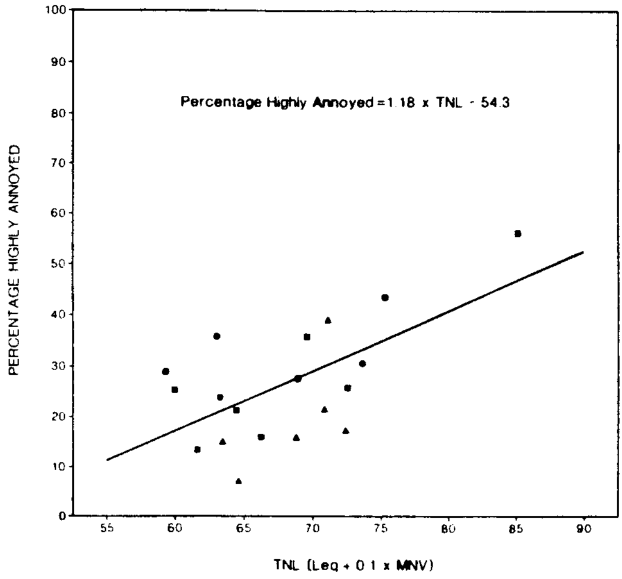

Figure 1 Community reaction as a function of traffic noise exposure in terms of TNL. (Based on Brown's[4] data: ● Brisbane; ■ Sydney; ▲ Melbourne)
[For reaction measured as percentage annoyed (rating $\geq$ 4) The dose/response function is: %A = 0.59 x TNL + 16.3].

The traffic noise index most commonly used in Australia is L10(18hr). This index which was incorporated into U.K. legislation in 1975, was adopted in Australia before there was any local validation data. Reviewing the implications of "importing" L10(18hr) Modra [11] in 1979, noted that extended indices were better predictors of annoyance, and pointed to the need for continued research under Australian conditions. Now that Australian data has been used to validate an extended index, it is appropriate to adopt this improved indicator of the community impact of traffic noise. Continued use of an unextended index will result in gross underestimation of traffic noise impact on residents along roadways carrying noisy trucks at night. As a basic index, Leq is preferable to L10(18hr) on conceptual grounds and also because it is a generally applicable exposure measure. Therefore, it is recommended that TNL rather than extended L10(18hr) be used in Australia.

CONCLUSION

The case for using an extended index of traffic noise exposure is founded on both theoretical and empirical grounds. Noisy vehicles have been shown to cause annoyance in excess of that accounted for by their contribution to the overall traffic noise level. This excess annoyance effect can be accommodated by using a noisy vehicle term to extend a basic index of overall noise exposure.

Australian data has been used to develop and validate an extended index termed Traffic Noise Level. The correlation with reaction improves from 0.43 for basic Leq to 0.62 for TNL. If planners and regulatory authorities are to avoid underestimating the impact of traffic noise on residential communities, then an extended index should be adopted for use in Australia. The Leq-based TNL index is recommended.

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RESPONSE TO A CHANGE IN TRAFFIC NOISE: ADAPTATION AND RESPONSE BIAS

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INTRODUCTION

The impact of any new noise source, or the benefits from any noise reduction, should be assessed by the change in community response which results from the change in levels. Most data on community response to transportation noise has been collected under "steady-state" conditions and there is little direct data available on response to a change in exposure. However, it should be expected that a change in noise exposure would lead to a change in community response which would simply be the difference between responses to the before and after steady states. This need not be so, of course, if communities adapt, over time, to a new noise exposure. The small study reported here examines both adaptation and response to change by surveying residents on one roadway over a period of nearly two years from just before the quiet street on which they lived was opened to through traffic.

THE STUDY

In late 1980, a residential street in Brisbane was reconstructed and connected to other roadways so that it could function as a through route. After the road opening, traffic volumes increased considerably. Residents were interviewed on three occasions: the first immediately before the roadway was opened to through traffic, the second seven months afterwards and the last a further twelve months after the second interview.

Traffic and Noise Level Data at the Study Site on Three Occasions

INTERVIEW (SERIES)	DATE	TRAFFIC veh per day	% hv	Leq peak hour	Leq 24h	L10 peak hour	L10 18h	Ldn
Before(B)	Oct80	1999	7%	65	60	68	60	61
After(A1)	May81	7925	8%	69	66	72	68	69
After(A2)	Jun82	11238	2%	71	67	74	71	71

The analysis reported here is based on 20 respondents who were interviewed three times. Annoyance was measured by the question "Looking at this card, to what extent does traffic noise annoy you here?" using a seven-point semantically labelled scale: not at all; very little; a small amount; a fair amount; quite a bit; a lot; a great deal (for convenience, categories are labelled 1 to 7 in the figures). The questionnaire used in Interview B was also used in Interviews A1 and A2, but with the addition of a question asked immediately after the road traffic annoyance question: "Looking at this card, to what extent did traffic noise annoy you here before the roadway was changed?".

ADAPTATION AND RESPONSE BIAS

CURRENT ANNOYANCE RESPONSES

Change in Annoyance Scores Over the Three Interviews.
Figure 1(I,II and III)shows the distribution of respondents' Annoyance Scores reported for conditions at each of the three interviews ("highly annoyed" arbitrarily defined as scores of six and seven on the seven-point scale). As could be expected, reported annoyance increased after the first interview corresponding to the increase in noise when the through roadway was first opened. Median Annoyance Scores for the group increased 3, and 1.5, intervals on the six-interval scale over the three interviews and the percentage of highly annoyed respondents increased by 30% and 10% respectively. Some 30% of respondents reached saturation on the seven-point scale at the time of the second interview and it can be noted that these respondents would be unable to report an increase in Annoyance Score between A1 and A2 even if they had experienced an increase in annoyance between these interviews.

Adaptation?
A decrement in scores over the twelve month period between A1 and A2 would mean that residents had adapted to the new noise environment, but there is no evidence of any such decrement (Wilcoxon Matched-Pairs Test for two related samples, $p > .05$ [1]). To this extent the present study supports, with some caveats, Weinstein's [2] observation that there is no good evidence available that the negative impacts of noise on a community diminish over time. Weinstein based this observation on a comprehensive review of longitudinal, cross-sectional and other studies of adaptation to transportation noise and on his own study. If one accepts that no adaptation occurs, then one would expect that community response to the change could be measured simply as the difference between the community's before and after assessments of the noise environment.

RETROSPECTIVE ANNOYANCE RESPONSES

Assessment of Before-Change Conditions.
Respondents gave three separate assessments of their annoyance with noise from the roadway as it was before the increase in traffic. In addition to the current assessment made at B (a steady-state assessment of before-change conditions), retrospective assessments of these same conditions were made at A1 and A2. Figure 1 (I, IV and V) shows these different assessments. It can be seen that respondents retrospectively reported low Annoyance Scores in comparison to the scores they reported before the change occurred. A Friedman Two-way Anova showed that these three distributions were not drawn from the same population ($p <.005$) and specific contrasts found that there was a difference between each pair of distributions. For example, a Wilcoxon Matched-Pairs Test indicated that recalled assessments at A2 were negatively shifted from the recalled assessments at A1 ($p <.01$, one-tailed test).

CHANGES IN ANNOYANCE SCORES BETWEEN BEFORE AND AFTER CONDITIONS

Annoyance Scores increased between B and A1, and the median increase in individual scores was 1.5 intervals on the 6 interval scale (also 1.5 intervals between B and A2). However, because retrospective assessments of before-change conditions are also available, current Annoyance Scores at A1 (and at A2) can

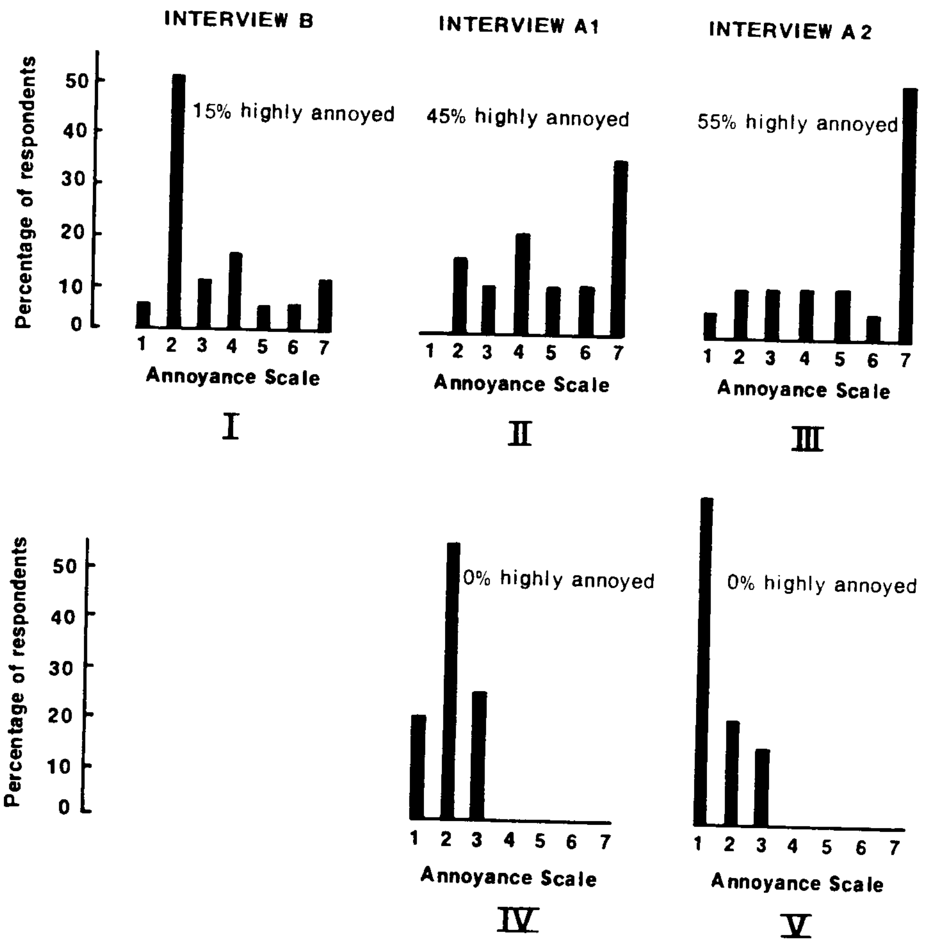

Fig 1. Respondents' current assessments of annoyance with conditions at each of the three interviews (I, II, III) and retrospective assessments of annoyance with before-change conditions (IV, V).

also be compared to the retrospective assessment of the before-change conditions made during the same interview. Using this alternative measure, the increments in Annoyance Scores are much larger, with median increases in individual scores being 3 and 4 intervals on the six interval scale at A1 and A2 respectively. This means that respondents have indicated that, in retrospect, the effects of the change are very much larger than would be suggested from the results of steady-state surveys. We thus have two measures of the effects of the change. The first is the difference between steady-state assessments. The second is the difference between an assessment of a currently experienced environment and a retrospective assessment of a previously experienced environment. It is necessary to look for some mechanism which can explain this difference.

RESPONSE BIAS

An explanatory model of the ambiguities between current and retrospective assessments must also account for several previous observations about response to a changing noise environment. It is useful to summarize all the observations here:

- Following an increase in noise levels, retrospective assessments of annoyance with previous low-noise conditions are much lower than were assessment of the same condition made before the change occurred (this study)

- following a decrease in noise levels, retrospective assessments of annoyance with previous high-noise conditions are much higher than were assessments of the same condition made before the change occurred [3]

- steady-state studies successfully predict community response to noise conditions existing before a change but the effect of reducing the noise exposure is to reduce reported dissatisfaction more than would be predicted from the difference between two steady states [4]

- respondents' assessments of the effects of noise following an increase in noise exposure do not attenuate with time (this study; [2].

A Response Bias Model can go some way to explaining all these observations. The starting point for the model is that all respondents do not interpret the Annoyance Scale in the same way. Instead, chronically exposed (steady state) populations interpret the Annoyance Scale differently depending on the level of their noise exposure. That is, a population exposed to high levels of noise may use an elevated scale when compared to that used by a population exposed to low levels of noise. In the present study, respondents in the before interview were chronically exposed to low levels of noise and would not have used an elevated Annoyance Scale to assess conditions before the change. Their Scores are, as shown in Fig 1 (I), clustered towards the lower end of the scale but still distributed over its full range. After the increase in noise levels, it is suggested that respondents reinterpreted the Scale, anchoring the low end as before, but extending its upper end in response to increased effects of noise. It is this expanded scale which they would then have used in Interviews A1 and A2 both to assess the new high noise environment (Fig 1 (II and III)), reporting higher Annoyance Scores than would a population chronically exposed to the same high level, and to retrospectively assess the previously experienced low noise environment (Fig 1 (IV and V)), reporting lower Annoyance Scores than they did in their previous assessment.

An analogous explanation of reinterpretation of the Annoyance Scale would also apply to any population relieved of high noise exposure. Using an expanded scale after the change, this group would report lower Annoyance Scores than reported by populations chronically exposed to the lower level (hence a larger benefit than expected) and higher Annoyance Scores in their retrospective assessment of their previously experienced high noise environment. In attempting to explain this result previously Brown et al [3] were sceptical that a population could transition from a higher to a lower Scale following a reduction in noise, arguing that it would require them to forget their previous experience. However, if the transition is actually to an expanded Scale, one which reflects a wider range of experience, such a transition is intuitively feasible.

The absence of adaptation merely requires that respondents continue to use the expanded scale to assess their current environment, at least over the year or two examined in adaptation studies to date, showing no tendency to shift towards the scales used by chronically exposed populations. Again it quite reasonable that people should retain their experiences in this way.

In summary, a response-bias model has considerable explanatory power. It explains the difference between current and retrospective assessments of the same noise environment. It also explains the hysteresis-like effect observed after a change in noise exposure. But why do people use very different frames of reference for the Annoyance Scale depending on the level of exposure? One reason is that these biased frames of reference may depend solely on limited experience of different noise environments and their effects. If this is so, then steady-state assessments of noise annoyance quite clearly bear an ambiguous relationship to the effects of noise. However, there may also be another effect [3], particularly at higher levels of exposure, with the Annoyance Scale measuring the effect of noise only above some adaptation level (expectation level may be a more appropriate term). Whether this elevated threshold for self-reports of the effects of noise also means an elevated threshold for the actual effects of noise is not clear. Evans et al [5], in a study of long-term adaptation to air pollution, suggested that an elevated response criteria for a chronically exposed population is an adaptation level, accounted for, not by physiological adaptation, but by psychological adaptation, and notes:

> An adapted individual's response bias might shift in a conservative direction because a typical way in which people cope with chronic stressors is to deny their presence as a potential threat to health and well-being. Psychological denial would translate into a more conservative response criterion for acknowledging the presence of air pollution when low level cues are present. Bias would not affect perceptual sensitivity.

RAMIFICATIONS OF SCALE BIAS

Scale bias, of the magnitudes suggested, undermines the validity of the Annoyance Scale as a measure of the effect noise has on people when they are surveyed under steady-state conditions in their homes. There are major practical ramifications. The first is that judging the benefit or cost associated with a decrease or an increase in noise by reference to steady-state conditions provides a serverely attenuated measure of the effects that the noise level change has on people. The second ramification is that bias fundamentally affects our assessments of the dose-response relationship for environmental noise derived from steady state surveys. In the main, these relationships have tended to be of relatively low gradient with a large variance in response residuals. Steady state surveys make the assumption that each individual is using a common and unbiased Annoyance Scale. The results of the present study suggest that this may not be so, and that the distribution of Annoyance Scores would have to be transformed before they could be regarded as unbiased. Present indications are that the overall effect would be a steepening of the gradient in the dose-response regression line, and a much reduced variance of residuals.

SUMMARY

Results have been presented of a small longitudinal study of community response to road traffic noise following an increase in traffic along a residential street. Respondents showed no evidence of adaptation to the increased noise over the period between seven and nineteen months after the increase in traffic. Respondents assessments of annoyance with the before-change conditions, made retrospectively after the change, were quite different to the assessments of annoyance that were made before the change occurred. This, together with other evidence on response to changed conditions, suggests that response bias is present in steady-state assessments of annoyance, and of a magnitude which would significantly effect the validity of self-reports of annoyance.

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TRAFFIC NOISE RESEARCH NEEDS IN AUSTRALIA

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INTRODUCTION

When faced with a problem Australia often looks to overseas experience in the matter with a view to selecting the most appropriate solution. Traffic noise is no exception. Some countries have been dealing with this problem for many years. Consequently there is a good deal of information available. Whilst it may well be that evaluation and remedial techniques developed overseas are suitable for Australian conditions, it would be prudent to confirm any assumptions by appropriate research. Funds for research are scarce in these economic times so efficiency is vital, being achieved best by targetting specific priority needs.

Road authorities have a role to play in limiting the public's exposure to noise from traffic. To tackle traffic noise an authority needs: a method of predicting noise; guidelines on acceptable levels of noise; the means to assess various noise reduction techniques. Each of these must have a sound basis, withstanding rigorous scientific testing.

This paper presents some of the current research needs on the subject of traffic noise. A considerable amount of work is involved probably requiring a nationally co-ordinated effort to ensure efficient use of resources. Such an approach will yield the information which authorities need to overcome practical problems and benefit the public.

COMMUNITY RESPONSE

The ultimate goal of research into traffic noise is to benefit the public, so it follows that the fundamental requirement is to establish how the (Australian) community at large reacts to traffic noise. This is achieved by a socio-acoustic study, which is a combined social survey and noise measurement programme. Relating people's exposure to noise (noise dose) to their reaction or response to that noise provides a dose/response relationship. A well planned study has the potential to reveal a wealth of information which can be applied to the task of benefitting the public, ie reducing exposure to traffic noise.

Although the results of extensive overseas studies are available they have not been shown to be appropriate for Australian conditions. There is only one known Australian socio-acoustic study of traffic noise of significant magnitude [1]. This revealed some interesting trends, but the correlation between noise exposure and annoyance was very low compared with a UK study[2]. Unfortunately, in the ensuing 7 years researchers have not pursued the matter.

ACKNOWLEDGEMENT

This paper is presented with the permission of the Commissioner of Main Roads, Western Australia, Mr D H Aitken. The views expressed are those of the author and not necessarily those of the Main Roads Department.

A major socio-acoustic study of traffic noise thus becomes a priority in traffic noise research. It has been demonstrated that not only does Australia have world class expertise but also funding can be made available for research on a national scale [3]. It follows then that to meet the need of a traffic noise study a co-ordinating group must be established and appropriate funds sought. The findings of the study will produce a corner-stone of Australian traffic noise data which will not only provide a sound basis for deciding noise control strategies, but also shape future research.

Gathering The Right Information

To obtain maximum benefit from a socio-acoustic study it would need to include information on numerous variables. Consider first the source of noise: traffic. Comparing noise exposure with annoyance may yield poor correlations unless the character of the noise is identified. For example a measured value (L_{10} or Leq) of say 65 dB(A) could occur in either of the three following conditions:

- short distance from a busy inner suburban road
- moderate distance from an outer suburban highway with a high proportion of heavy vehicles and a high speed limit
- relatively large distance from a very busy urban freeway.

The response of residents may differ significantly for each condition so the study must accommodate this aspect. More specifically it could be established if interrupted traffic flow (caused by traffic lights, roundabouts) results in increased annoyance.

Heavy vehicles are often singled out as being major contributors to annoyance. Their role could be clarified by a combination of suitable questionnaire structure, and data on traffic composition and conditions. The practical use of determining if heavy vehicles are the prime source of annoyance for significant numbers of people and under what traffic conditions, would be to use this information when formulating strategies on heavy vehicle noise limits and traffic management.

Further points for consideration include information on residents' habits (eg windows open or closed, use of front yard and front rooms) and on the residences (eg type, construction). These are considered relevant as people's responses are compared with externally measured noise levels. It will also be useful to know what people are prepared to pay to achieve desirable noise levels.

The time of year during which the social survey is carried out may be a variable, as many cities experience extremes of climate. Outdoor activities are dependent on the seasons as is the opening/closing of windows, so it may well be that the timing of the survey is important.

Community response to a change in traffic noise level is of interest to authorities especially at the planning stage of new roads or traffic management schemes. Although an opportunity to gather suitable data may not arise during a major socio-acoustic survey, the question of what constitutes a significant change will still require an answer.

ESTIMATING IMPACT

When construction of a major road is proposed an environmental assessment is often required at the planning/design stage. If an estimate of the impact of traffic noise is to be included, then an assessor needs to have:

- a means of calculating future and existing noise levels
- guidelines on acceptable levels of noise.

Guidelines may be established on socio-economic grounds in that they are a compromise between what noise climate the public may desire and what it is prepared to pay to achieve it. In Australia there are no statutory limits on traffic noise levels, however, some State Road Authorities have a policy on the matter [4].

Calculation methods are available which estimate existing and future levels of traffic noise. As these are likely to be well covered in other papers only specific aspects are presented below. A number of studies have been carried out on the performance of calculation methods under Australian conditions [5, 6] which indicate that the UK Dept of Environment (DoE) method [7] is suited to our current needs. The most detailed investigation was by a National Association of Australian State Road Authorities (NAASRA) Working Group [8] which established the accuracy of the DoE method in calculating an L_{10} (18 hour) in free-field conditions as ±3.6 dB(A) at a 95% confidence level. It was also found that overprediction occurred, by 0.7 dB(A). As a sufficient number of Victorian measurements were near a building facade, its effect was examined, revealing a further overprediction of 1.0 dB(A), with 95% confidence limits of ±5.0 dB(A). The next logical step would be to verify if this facade correction is applicable to other States. British research [9] found facade reflection is quite variable, so it may be appropriate to collect more data on the effect of facades in Australian conditions. Recent work [10] on reflection by facades on the opposite side of the street could be investigated with a view to confirming the finding and applying it to the DoE method.

The NAASRA study of the DoE method did not involve testing of individual algorithms so here lies fertile ground for further work. For example, traffic variables such as flow rate, composition, and speed could be examined on similar lines to a comprehensive British study [9]. Other factors for attention include:

- adapting the method to calculate Leq
- evaluating the calculation of barrier performance
- testing if interrupted traffic flow is accommodated
- determining typical operator variability.

It is recommended by the Australian Standards committee on community noise that further consideration be given to the use in Australia of the descriptor Leq [11]. The likely reasons for this include uniformity, simplicity of measuring equipment and ease of mathematical manipulation. For traffic noise, it appears that Leq and L_{10} will have similar correlations with annoyance [2] so it is time to seriously consider Leq as a traffic noise descriptor in Australia.

Noise barriers in one form or another are probably built in most States, to a design based on the DoE calculation method. The cost of these devices can be significant [12], so a high degree of confidence in the results of calculations is required. Investigations which compare measured and predicted barrier performance are uncommon and often restricted to a specific aspect [13, 14]. Thus there is a need to confirm the ability of the DoE method to estimate barrier performance over a range of conditions.

The UK DoE [7] claims that interrupted flow (near an intersection) is accommodated by its calculation method. References contained in a literature review [15] present varying views on the subject. The most important question to arise however, is one of significance, ie when comparing interrupted and freely flowing conditions is there a significant difference in (a) noise level and (b) community response. It was previously suggested that a comprehensive socio-acoustic study could provide some answers, or at least guide further investigation on the effect of interrupted flow.

Variability due to the human factor (operator) in calculating traffic noise is considered to be caused mainly by interpretation of the calculation method. Interpretation becomes very important in critical situations such as when a calculated value is close to a noise guideline. In particular the average propagation height (APH) will need calculating, and for sites which are close to the roadway, departure from the carriageway separation criteria can produce significantly different results. Appropriate action would be to formulate some additional, more specific rules on interpretation thus resulting in greater consistency in the application of the DoE method.

Many of the above suggestions for further investigation involve considerable data. Fortunately, the NAASRA study established a relatively large data base of traffic noise levels and site details, which is mounted on computer file at the Australian Road Research Board in Melbourne [8]. This is an excellent resource for researchers and one that should be built upon.

NOISE REDUCTION

Control of individual vehicle noise is a logical first step in reducing annoyance from traffic noise, but as the subject is expected to be well covered at this conference it is not further discussed. Other ways to reduce noise often rely on expenditure of public money and deserve close attention as considerable funds can be involved. These methods include building noise barriers, increasing propagation distances and traffic management techniques.

Noise barriers can be of two basic types:
- earth mounds usually formed during construction of the new road
- fences or walls which can be erected at any stage.

The practical performance of barriers is not well researched probably because of infrequent opportunity to carry out a closely controlled field experiment. Some information is available from the UK and US [13, 16] as well as a limited amount from Australia [14]. A review of the results of these and any other minor investigations could reveal deficiencies and direct future efforts. Of interest would be the acoustic performance of earth mounds and crash barriers at distances typical for freeways.

Attenuation of traffic noise by increasing the propagation distance requires additional property acquisition. As land value is the main cost factor, massive sums can be involved. Whilst it is acknowledged that the fundamentals of sound propagation over a ground plane require little attention, planning authorities are likely to be interested in a comparison of the cost of creating wider road reserves with other methods of noise attenuation.

Selection of the type of road surface can be considered a noise reduction option. Whilst engineering and safety requirements will restrict the choice of road surface for a given set of operating conditions, there may be instances where this option is most appropriate eg where space, access or aesthetics rule out other options. The effect of road surface is receiving attention world wide particularly as the lower limit of total sound level of vehicles appears to be governed by the road/tyre component [17]. Accordingly research has centred on testing of individual vehicles. Recent findings point to open-graded asphalt having the potential to reduce noise by 2 to 5 dB(A) when compared with the more common dense-graded asphalt [18, 19]. Conversely, if the running surface is a chip seal an increase of 2 to 4 dB(A) is likely [19, 20]. These studies were based largely on individual vehicle pass-by and have not yet been shown to reflect the practical situation in real traffic flows. However, there is a potential total span of 9 dB(A) which is of similar magnitude to the effect of noise barriers. Continued investigation of the road surface effect is clearly required so that corrections may be applied to traffic noise calculation methods and this option may be given serious consideration as a method of noise control.

In the UK upgrading of a building facade near new roadworks is a publicly funded option open to residents when other methods of reducing traffic noise are expected to be inadequate [21]. Upgrading (noise insulation) can involve installation of double-glazing, a more suitable door, plus the fitting of improved seals to these elements, and the provision of mechanical ventilation. For facade treatment to be considered as a noise control option in Australian conditions more facts are required. Namely, typical noise reductions, and costs (including air conditioning where required).

CONCLUSION

Traffic noise, particularly in the Australian context, requires more attention to ensure that public funds are used efficiently in combatting the problem. Summarised below are suggestions for further research:

(a) The dose/response relationship for the Australian community needs to be established. A comprehensive socio-acoustic study will provide essential information which can be used in determining:
- the magnitude and extent of existing annoyance
- the likely impact of proposed roads
- what aspect of traffic noise is most annoying (total traffic flow, individual noisy vehicles)
- if interrupted traffic flow causes a significantly different response compared with free-flow conditions
- what constitutes a significant change in noise level with respect to public response.
- what people are prepared to pay to achieve a desirable noise climate.

(b) The commonly used DoE method of calculating traffic noise should be examined to see if -
  (i) it can be adapted to calculate Leq
  (ii) prediction of barrier performance is adequate
  (iii) algorithms are appropriate
  (iv) some existing rules could be better defined.

(c) The significance of road surface effect needs to be confirmed and quantified for real flows of traffic to enable its consideration as an alternative method of noise reduction and to provide corrections to the DoE calculation method.

(d) Barrier performance requires more field assessment over a range of conditions.

(e) Before upgrading of building facades is considered as a viable means of noise reduction, typical attenuation values and costing (including suitable ventilation) are required.

A considerable amount of research lies ahead, particularly as the above list does not include all aspects of traffic noise. To maximise the return on research funds, it is essential to have co-ordination at the national level. A collaborative effort to address the problem of traffic noise common in all States will go far in aiding authorities in their efforts to improve the Australian way of life.

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MOTOR VEHICLE AND TRAFFIC NOISE - A QUEENSLAND PERSPECTIVE

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LEGISLATION

Two pieces of legislation, both administered by the Department of Transport, provide for the control of motor vehicle noise in Queensland.

The Traffic Act

The Traffic Act 1949-1982 and the Traffic Regulations, 1962 [1] contain provisions which prohibit the use upon any road of a motor vehicle which is fitted with an ineffective silencer or causes undue noise by reason of its state of disrepair, its manner of loading, the construction, condition or adjustment of its engine, motor or other equipment, or the manner in which any of them is operated. This legislation also delineates the powers of Police officers to inspect, examine and test any vehicle, to order repairs to it and to prohibit its use until such work is completed.

In addition, the Regulations specify that motor vehicles must comply with, inter alia, Australian Design Rules No. 28 and 28A at the time of first registration and at all subsequent times. It is anticipated that the Regulations will be amended this year to provide also for compliance with ADR No.39.

The Motor Vehicles Safety Act 1980

This Act [2] provides for the inspection of motor vehicles to ensure that only roadworthy vehicles are allowed on roads. Inspectors and authorised officers are empowered to carry out motor vehicle inspections to determine compliance under the Act and to issue notice to a vehicle owner requiring him to produce it for inspection at a prescribed time, date and place. The Act prohibits the use on a road of a motor vehicle which has been altered or modified from the manufacturer's specifications unless that alteration or modification has been approved by the Commissioner for Transport.

MOTOR VEHICLE TESTING

Requirements for Testing

It follows from the above legislation that noise tests are required on vehicles:

(a) which are of new design and must be tested before initial registration for compliance with ADR 28 and 28A;

(b) which have been significantly modified since initial registration; and

(c) whose owners have been directed by a Police officer or a Department of Transport inspector to present them for inspection and testing at an authorised testing centre because of the suspicion that they have been excessively modified or are in a significant state of disrepair.

Arrangements for Inspections

Inspectors from the Department of Transport carry out regular road patrols accompanied by Police officers from the Commercial Vehicle Squad who have been assigned to the Department. This work consists mainly of road checks on heavy commercial vehicles. If a vehicle is judged to be unduly noisy because of extensive modifications, the driver is directed through issuance of a notice to have it inspected at an approved inspection station. As a result of this inspection, a direction may be given to the owner to have the vehicle undergo a noise test and to obtain a certificate of compliance from an authorised officer. A defective vehicle notice may be issued when a vehicle is found to have an obvious defect in its exhaust system such as a holed muffler.

There are approximately 330 officers authorised under the Motor Vehicles Safety Act to carry out compliance tests to Australian Design Rules. They are located in major cities and towns throughout the State and are employed in industrial firms, the Government Motor Garage and the garages of the larger Government Departments.

The Department has authorised certain officers in private industry to carry out noise tests to ADR No. 28 and 28A. Any major modification to a vehicle must be accompanied by a drive-by test certificate. Use of the stationary noise test method in AS2240 [3] is permitted for a comparison test when only a minor modification is carried out on a vehicle. The modification will be approved only if a final stationary test indicates a noise level not exceeding that obtained in an initial test.

For the 1983-84 year, the following statistics were compiled by the Department:

Inspection Category	No.of Vehicles	% Defective
Compulsory motor vehicle inspections	80503	-
Commercial vehicle road patrol inspections	812	46
Private vehicle inspections:-		
inspected for Police Department	2019	81
identified by Departmental inspectors	346	47
inspected on used car dealers' premises	201	56
Motor vehicle modification applications	1212	-

At present, separate statistics are not compiled for vehicles defective on noise grounds.

PLANNING FOR NOISE CONTROL

Main Roads Department

This Department is responsible for the design, construction and maintenance of main roads in Queensland. The Department, as a responsible body, is required under the State Development and Public Works Organisation Act [4] to give consideration to the environmental aspects of undertakings which are under its control and to seek the assistance of advisory bodies. For some projects Departmental officers carry out Environmental Impact Studies while other studies are performed by consultants.

The Department used the U.K. DoE or CORTIN procedure for noise prediction and estimates the percentage of residents who will be bothered by traffic noise resulting from proposed road developments. As a result of these calculations, planners may decide to re-route traffic so as to by-pass residential areas. Alternatively, the decision may be made to erect acoustic barriers beside a road to achieve a desired noise reduction. Major undertakings where barriers (timber fences or timber fences on earthen mounds) have been erected include the South-East Freeway and the Western Arterial. The Department is at present involved in planning the access roads for the Gateway Bridge which will enable coastal traffic to by-pass the central city area.

Local Authorities

Under Section 32A of the Local Government Act [5], a Local Authority, when considering an application for approval, consent, permission or authority, is required to take account of any deleterious effect that could be produced on the environment. Local Authorities have the power to cause an applicant to submit an Environmental Impact Study in support of his application when it decides that adverse environmental aspects are likely. Section 33 of the Act requires a Local Authority to consider whether a proposal would create a traffic problem or would detrimentally affect the amenity of the neighbourhood. Any appeal against a Local Authority's decision on an application on the grounds that traffic-generated noise would create a nuisance is heard in the Local Government Court.

Noise Abatement Authority

Local Authorities are required under the Noise Abatement Act [6] to refer to the Noise Abatement Authority all proposals which they consider likely to produce excessive noise. In addition, the Division of Noise Abatement provides advice on proposals submitted to it by industry, Local Authorities, Statutory Authorities and Government Departments. Certain types of proposal involve consideration of noise from motor vehicles, both on site and on access routes. Examples include mining projects, quarries, gravel extraction plants, concrete batching plants, transport depots and shipping terminals.

On a major project the applicant may engage an acoustic consultant to assess the noise impact of the proposal. In general the noise annoyance due to the increase in local traffic flow will not be significant unless the ratio of heavy vehicles to cars is drastically increased or vehicles enter or leave the site during the night or early morning when background noise levels are relatively low.

NOISE ANNOYANCE

Noise Surveys

Surveys have been carried out by the Department of Psychology at the University of Queensland to determine the reaction of the community to noise. Damm [7], in a 1977 survey of the reactions to noise stress among elderly people, established that there was a high correlation between the level of traffic noise and the level of annoyance produced. High level traffic noise was shown to cause disturbance of sleep, interference with conversation and television viewing, and negative effects on health. A general neighbourhood noise survey reported by Damm [7] in 1980 showed that road traffic noise (especially motor-cycles and trucks), dogs and loud music were the most common sources of noise annoyance. During the survey, twenty-five percent of respondents nominated general road traffic noise as a major noise source.

Brown and Law [8] in 1976 published results of a definitive survey to determine the magnitude and distribution of the effects of noise from the South-East Freeway in Brisbane. An annoyance scale was drawn up and its validity was established by the reasonably high correlation between annoyance scores and the tangible effects of noise.

Noise Complaints

One way in which members of the community can express their annoyance at motor vehicle noise is to make a complaint. Under the Noise Abatement Act, the Police have the responsibility of abating excessive noise from motor vehicles on residential premises. The Police are also responsible under the Traffic Act for controlling the emission of undue noise from motor vehicles on roads. The Division of Noise Abatement receives numerous complaints about motor vehicle and traffic noise which are recorded and forwarded to the Police for direct action. The numbers of complaints forwarded over the last three years are given below. It is evident that there has been a progressive increase in the number of complaints about noise from vehicles on a road.

Category of Vehicle	1982-83	1983-84	1984-85
Motor Vehicle on a road	22	58	65
Motor vehicle not on a road	33	32	24
Refrigerated vehicle	-	10	6
Trail bike	49	23	33
Total	104	123	128

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ROAD TRAFFIC NOISE 1975-1985

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INTRODUCTION

In the early 1960's the widespread impact of road traffic noise on urban communities was first quantified [1]. Since traffic noise levels on many roads exceed by some 20 to 30 dB(A) recommended acceptable noise levels for residential buildings [2] motor vehicle and road traffic noise has been the subject of much research in many countries. Over the last ten to fifteen years, a number of national and international vehicle noise control guidelines and regulations have been published. This paper discusses whether or not there has yet been any significant reduction of motor vehicle and road traffic noise resulting from this work.

ROAD TRAFFIC NOISE MODELS

Road traffic noise is composed of the noise emitted by the individual vehicles near and passing a receiving point at any time. There are several theoretical and empirical models which enable traffic noise levels to be predicted. Although there are some differences between the prediction methods, most tend to have the following form:-

$$L_{Aeq,T} \text{ or } L_{A\%,T} = A + B \log Q + C\,(\%p) - D \log d \qquad (1)$$

where A,B,C,D are constants (determined theoretically or empirically), Q is the total flow rate of vehicles per hour, %p is the percentage of medium and heavy vehicles in the mix and d is the distance from the centre of the nearside stream of traffic to the observer.

(There may also be additional factors, such as vehicle speed, grades, shielding, reflections from buildings, etc. included in the model.)

There are thus four basic approaches available for reducing road traffic noise:-

1. Reduce the total flow rate (but note the logarithmic nature of the term)
2. Reduce the percentage of heavy vehicles (because they emit more noise than passenger cars)
3. Increase the distance between source and observer (again, the term is logarithmic)
4. Reduce the noise emitted by individual vehicles (which affects the constants in the equation)

Traffic management schemes attempt to employ the first two approaches, but their application is limited to minor roads and may well be negated by the increasing number of vehicles registered each year. The third approach is part of good planning practice for new areas and new roads, but it is not applicable to most existing areas. The fourth approach to traffic noise reduction, the control of individual vehicle noise emission, is the subject of regulation in Australia and in other parts of the world.

VEHICLE NOISE REGULATIONS

In 1968, following earlier regulations in some European countries, the UN Economic Commission for Europe (ECE) adopted uniform provisions for the control of vehicle noise. This was incorporated in Regulation 9 which specified a wide-open-throttle acceleration test, with the noise levels being measured at a distance of 7.5m from the vehicle's path. The EEC endorsed this approach in 1970 and the agreed maxima were 84 dB(A) for cars and from 85-92 dB(A) for trucks and buses, depending on their gross vehicle mass and engine size. It was anticipated that 90% of existing vehicles would comply with these limits. Nevertheless, when the levels were revised four years later, there was only a reduction of 1 dB(A) for cars and an increase in the level for trucks and buses in the 3.4t to 12t range of 1 decibel.

In Australia there was strong pressure not to be more stringent than Europe and Australian Design Rules 28 and 28A dealing with noise limits for new vehicles followed the ECE standard. These regulations first took effect from 1974 for petrol-engined vehicles and from 1975 for diesel-engined vehicles. Since that time, the levels have been reduced by 3 dB(A) for cars in 1981 and by 3 to 4 dB(A) for trucks and buses, in July 1980. (New motorcycles have had their permitted levels reduced by from 1 to 2 dB(A) over the 10 years from 1975 to 1985.)

As well as new vehicle noise limits, many States have introduced in-service limits. These refer to close-proximity, stationary vehicle exhaust noise tests and they are mainly designed to check increased noise emission due to faulty or modified exhaust mufflers.

INVESTIGATION INTO THE EFFECT OF VEHICLE NOISE REGULATIONS IN AUSTRALIA

Road traffic noise has been investigated by the University's Acoustics Research Unit since the late 1960's and it was decided that if historical data could be compared with fresh measurements, made in 1984 and 1985, the effectiveness of the introduction of new and in-service vehicle noise limits could be assessed.[3]

Over fourteen hours of recorded data from sixteen historical sites were re-analysed to determine the L_{Aeq} and percentile levels in dB(A). In addition, the maximum noise levels of individual vehicles were determined. These vehicles were classified as cars and derivatives; lights (four-wheeled commercial vehicles and forward control passenger vans); mediums (two-axled commercial vehicles with dual tyres on the rear axle); and heavies (three or more axled vehicles).

Originally it was intended to visit all sixteen of the historical sites (with the exception of those which had been affected by altered road conditions) to obtain new data. However, after a pilot study it was decided that better statistical reliability would be obtained by concentrating new data collection over longer periods at fewer sites. Consequently only four of the original sixteen sites were selected for new data collection and two new sites were added as being suitable for enlarging the new data base. One of the new sites was a typical 6-lane divided arterial road, with a high percentage of heavy and medium vehicles; the other was a 4-lane road in a purely residential area, with a moderate traffic flow and a low percentage of commercial vehicles.

As far as possible the instrumentation and measurement techniques used were the same as those used for the original data collection. Generally the microphone was located 1.2m above ground and 9.0m from the centre of the nearside traffic flow. The output of Bruel & Kjaer precision sound level meters was recorded on Nagra Type IIIB or IVSJ tape recorders for subsequent laboratory replay and analysis. A continuous commentary was recorded on a separate channel. Nine hours of new data were obtained at the revisited sites and over six hours of data were recorded at the new sites, giving some fifteen hours of new data for analysis.

ACOUSTIC DATA ANALYSIS

Figure 1 shows a typical example of an annotated paper chart recording of the traffic noise. When an individual vehicle's maximum noise level could be clearly distinguished from the general traffic noise (usually 10 dB(A) above the level before and after its passby) its sound pressure level, vehicle category and the lane in which it was travelling were noted.

The data for each category of vehicle for each site was analysed using the Statistical Package for Social Scientists (SPSS) programme. Distribution histograms for each vehicle category for each site were obtained as well as the mean, standard deviation, standard error, minimum and maximum values and the 95% confidence intervals for the mean of the individual vehicle noise levels.

In addition, for each traffic noise sample (usually of 10 minutes duration) the percentile levels were determined using a statistical distribution analyser and curve fitting programme and $L_{Aeq,T}$ was calculated. These results were combined for each site and tabulated together with traffic flow and composition data, counted simultaneously with the traffic noise recording period.

RESULTS

Table I shows the results for individual vehicle passby levels for each category. It can be seen that there has been little change in the mean levels between the historical data obtained in 1975-78 and the new data obtained in 1984-85.

For cars there has been a change ranging from -2.72 to + 1.96 dB(A) (depending on site), with an average reduction of 0.34 dB(A) for all sites.

It is interesting to note that the category "light" vehicle was too small to provide any significant results at the historical sites, with one exception; for the new data the light vehicle mean levels were 3 to 4 dB(A) higher than for passenger cars. This is important since this type of vehicle is frequently being used as a replacement for station wagons, which were passenger car derivatives and subject to the same noise limits.

Medium vehicles show an increase in level, ranging from 0.27 to 1.35 dB(A), with an average mean increase for all sites of 0.95 dB(A). The actual mean levels are from 6 to 10 dB(A) higher than those for cars.

For heavy vehicles there has been very little change in level, ranging from -0.67 to + 0.07 dB(A), with a mean reduction of 0.04 dB(A). This category of vehicle has means averaging some 10 to 13 dB(A) above cars. Subjectively, the percentage of the large, 6-axled vehicles seems to have increased- this category is allowed the highest noise emission level.

Motorcycles, which are frequently mentioned by lay persons as a serious noise problem, were in insignificant numbers at all sites and thus it was not possible to assess the effect of noise control regulations on this category of vehicle.

Table II shows the historical and current traffic noise levels for the various sites and it can be seen that there has been little change in the traffic noise levels. L_{Aeq} changes ranged from - 1.5 to + 1 dB(A) with an average decrease of 0.34 dB(A). L_{10} decreased by 0.14 dB(A) and L_{90} by 2.1 dB(A).

It is also interesting to find that there has been little change in the traffic flow rates and percentage of medium and heavy vehicles at the revisited sites, notwithstanding the increase in the number of registered vehicles on the roads in N.S.W. (Presumably this means that the traffic has simply spread over more roads?)

CONCLUSION

When the 1984-1985 series of measurements was made, over 20% of all passenger cars and station wagons and nearly 28% of other types of vehicle on the road in N.S.W. should have complied with the 1980-1981 Australian Design Rule noise limits. Approximately 12% of vehicles other than passenger cars and derivatives and some 7% of the latter category of vehicles would also have had to comply with the N.S.W. in-service noise control limits.

It can be seen that there has been little or no effect on the noise levels emitted by these vehicles in typical traffic streams, and overall traffic noise levels have been reduced, on average, by about one-third of a decibel. Trucks and buses show either no reduction or an increase of about one decibel, whilst cars and derivatives have mean maximum levels about one-third of a decibel lower. However, this small achievement is offset by the increased number of panel vans and forward control passenger vehicles on the road, which have mean maximum levels from 3 to 4 dB(A) higher than the station wagons they are replacing.

This project has shown that a decade of motor vehicle noise legislation has failed to have any noticeable effect on traffic noise levels. There are several reasons for this. Firstly, it has always been recognised that the ADR levels are too high to affect all but the very noisiest of vehicles in each category. Secondly, the wide-open-throttle acceleration test has serious limitations as an indicator of vehicle noise emission in typical traffic conditions. Thirdly, ADR tests are only applied to representative vehicle models. Finally, the in-service regulations in N.S.W. are only applied in practice when a particularly noisy vehicle happens to be detected by one of a handful of inspectors.

The technology is available to enable passenger car noise limits to be reduced by at least 5 dB(A) and truck noise limits could be reduced by 10 dB(A). Extensive research overseas has resulted in a number of "Quiet" heavy vehicles, some of which are now in production. There is at present no incentive for their introduction in this country.

Even if more stringent vehicle noise emission limits were introduced with the shortest possible lead times, and if enforcement procedures were strengthened, it is quite apparent that there is still a long way to go before traffic noise levels on even moderately busy roads will be compatible with residential land use.
If typical facade attenuations are added to acceptable internal noise levels for living and sleeping areas, external noise levels should not exceed 40 to 55 dB(A) during daytime or 35 to 45 dB(A) at night. Table II shows that the measured daytime traffic noise levels ranged from 69 to 79 dB(A), the lowest levels being found for quite modest flow rates of 280 to 500 vehicles per hour.

It is obvious that additional methods of reducing the traffic noise problem must be employed. In some countries, monetary compensation is paid to people adversely affected by road traffic noise. This enables the facade attenuation to be improved and mechanical ventilation to be installed. Although this is not an ideal solution, it does afford some relief, at least inside a building. At this stage, perhaps it may be more effective to direct the major effort to the provision of compensation by highway authorities, rather than trying to force vehicle manufacturers to comply with noise limits one or two dB(A) below those existing. Funds could be raised from fuel excise, with perhaps some concession given to owners of vehicles significantly quieter than that permitted for their category.

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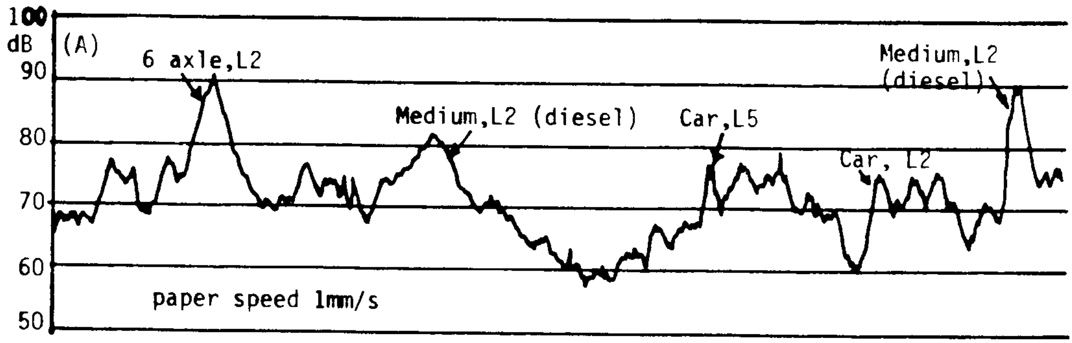
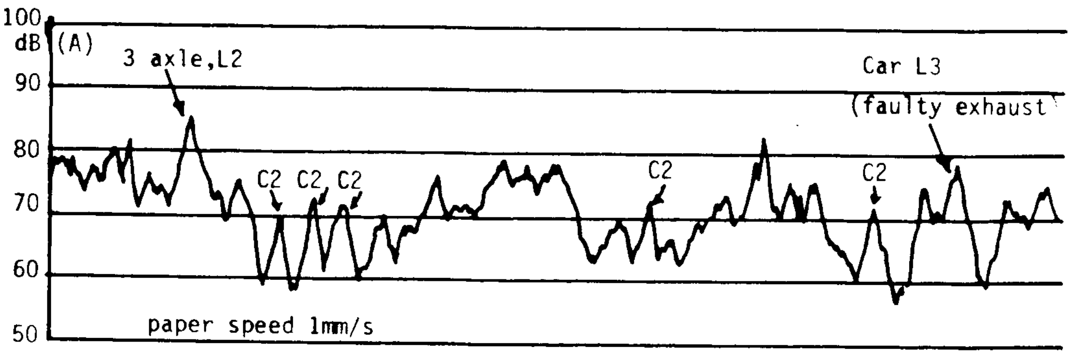
ACKNOWLEDGEMENTS

The assistance of R.Rosenberger and C.T.Dinh in measuring, recording and analysing the road traffic and vehicle noise is gratefully acknowledged. This project was funded by the N.S.W.State Pollution Control Commission, however, the opinions expressed are of the author alone.



SITE NO.3 1975 (6-lane highway, 10% gradient)



SITE NO.3 1985 (all as for 1975)

FIG.1. TYPICAL LEVEL RECORDER CHART SHOWING IDENTIFIED VEHICLE MAXIMA

TABLE I

MEAN INDIVIDUAL VEHICLE MAXIMUM PASSBY SOUND PRESSURE LEVELS

SITE	YEAR	MEAN ± 95% CONFIDENCE LIMITS, dB(A)				SAMPLE
		Cars	Lights	Mediums	Heavies	Minutes
1.	1978	75.63 ± 2.35	....	80.73 ± 2.99	84.90 ± 1.98	20
1.	1984	77.59 ± 0.97	81.35 ± 1.77	81.97 ± 1.41	84.83 ± 1.36	50
2a.	1977	70.70 ± 0.66	....	....	....	60
2a.	1984/5	70.79 ± 0.45	....	....	....	80
2b.	1977	72.13 ± 0.84	....	....	....	40
2b.	1984/5	71.99 ± 0.50	....	....	....	80
3.	1975	74.01 ± 0.59	77.47 ± 1.26	81.59 ± 1.02	85.76 ± 1.76	80
3.	1985	73.10 ± 0.48	77.26 ± 0.98	81.86 ± 0.82	85.09 ± 1.14	120
4.	1977	75.67 ± 2.44	....	80.77 ± 1.42	84.67 ± 2.62	20
4.	1985	72.95 ± 0.48	77.51 ± 0.72	82.12 ± 0.62	85.27 ± 0.63	120
5.	1984	74.71 ± 0.26	77.16 ± 0.48	81.14 ± 0.31	84.84 ± 0.35	240
6.	1984	72.14 ± 0.25	....	....	....	160

TABLE II

MEASURED TRAFFIC NOISE LEVELS, TRAFFIC FLOW RATES & PERCENTAGE HEAVY + MEDIUM

SITE	YEAR	L_{Aeq}	L_{A10}	L_{A90}	Q,v/h	%p
1.	1978	74.3	77.5	62.5	2715	8.97
1.	1984	75.3	78.7	61.8	2899 ± 172	8.10 ± 1.22
2a.	1977	65.6	69.0	47.2	363 ± 51	5.18 ± 2.36
2a.	1984/5	64.4	68.5	42.8	279 ± 30	3.31 ± 2.59
2b.	1977	66.1	69.2	47.6	363 ± 51	5.18 ± 2.36
2b.	1984/5	65.7	68.9	42.8	279 ± 30	3.31 ± 2.59
3.	1975	76.3	79.1	62.8	2368 ± 193	8.98 ± 1.79
3.	1985	74.8	78.0	61.1	2252 ± 115	8.77 ± 0.82
4.	1977	75.2	78.8	61.1	2088	20.10
4.	1985	75.6	78.8	62.2	1937 ± 90	15.14 ± 1.03
5.	1984	75.7	79.0	64.1	1854 ± 61	18.52 ± 1.08
6.	1984	65.6	69.5	45.3	490 ± 42	4.76 ± 1.43

TRAFFIC NOISE AND LATM

E.A. Smith

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INTRODUCTION

Over the last decade or so, there has been increasing concern with the deterioration of living environments in existing urban areas caused by overflow of through vehicle movements, especially regarding the traffic noise.

In the past, urban streets have generally been seen as facilities whose prime function is to serve the demands of the motorist, and traffic management work was accordingly directed towards increasing the level of service which these streets could provide. More recently the emphasis has been turning to consideration of the liveability of streets and the degree of environmental protection that their residents are entitled to.

BASIC ISSUES

The main issue to be resolved regarding motor vehicle activity in urban residential areas is the conflict between the rights of accessibility of vehicle users and the rights of residents to a safe and pollution free environment; to ignore either of these rights simply avoids the issue.

In order to satisfy vehicle travel requirements in urban areas, wide variations in traffic volumes must occur on individual residential streets; there is simply no practical alternative to this situation. In the context of environmental management of such traffic, two questions must therefore be addressed:

- Which streets should carry more traffic than others?
- What is an acceptable level of traffic flow for individual streets?

The first question implies the necessity for a functional road hierarchy to be established within the street system while the second demands definition of environmentally acceptable traffic conditions for residential streets.

THE TRAFFIC DILEMMA

The management of traffic is perhaps the greatest planning problem currently facing local government in the residential suburbs of the Sydney Region. The plain fact of the matter is that there is insufficient capacity in the arterial road network to accommodate the traffic volumes that seek to move through these areas.

This excess traffic, and other motorists who wish to avoid the congestion points on the existing arterial routes, overflows into residential streets thereby causing environmental deterioration and creating safety hazards in the midst of residential areas. There seems little likelihood that this situation will change in the immediate future given the unresponsive attitude of respective governments to major investment in the urban arterial road network.

It is not that these authorities don't recognise the problems associated with traffic flow through urban suburbs - they are just not willing or able to justify the scale of financial allocation that is necessary to correct the situation. A dilemma is therefore created which centres around:

- the rights of motorists to pass through an urban precinct
- the rights of urban residents to a safe and pollution free environment.

The road hierarchy for the region and for each municipality defines the arterial and sub-arterial roads for use by through traffic flows as well as for access to each residential precinct. The local area plan, incorporating the traffic management scheme, for each residential precinct is the main basis for defining the rights of urban residents.

TRAFFIC IMPACTS ON RESIDENTIAL STREETS

Over the last decade the growing concern with environment, in conjunction with greater participation by residents in their community, has meant that environmental and land use issues are more closely scrutinised in traffic management planning for residential areas. It is most appropriate that these issues be given adequate consideration in the development of the municipal road hierarchies and the local area planning following on from it.

The types of traffic impacts on residential streets can be identified as:

- physical effects which arise from the actions and characteristics of moving motor vehicles. The major impacts in this regard are safety, noise and air pollution, vibration and visual intrusion.

- community effects which pertain more to the socio-cultural aspects of urban lifestyle which are influenced by traffic flow. The major impacts here revolve around disruption to normal community functions such as shopping, school or neighbourhood recreation trips, loss of privacy and disturbances to social interaction.

Of the physical impacts, safety and noise pollution are recognised as the most deleterious by residents. Noise pollution tends to be rather location specific, related as much to the physical conditions along the street as to traffic volume.

The definition of traffic levels which satisfy environmental quality criteria is an extremely difficult task and, to date, no comprehensive and reliable standards have been produced. In the interim, it is necessary to rely on existing research data based on noise pollution modified by known resident reaction to particular traffic conditions to establish broad environmental quality guidelines. In this regard:

* it is generally recognised that traffic volumes of 300-400 vehicles per hour constitute relatively safe conditions for average residential streets

TRAFFIC NOISE AND LATM

* although traffic noise is a very location specific impact, the noise generated by a traffic flow of up to 750 vehicles per hour is generally recognised as falling within acceptable limits for normal residential streets. In streets with steep inclines, sharp bends etc, the acceptable vehicle flow might be less

* while resident reaction will vary between Local Government Areas and can be affected by such factors as length of residence, rate of increase in traffic activity etc. past experience suggests that streets with traffic volumes of the order of 500-750 vehicles per hour will often attract resident protest, particularly when they occur in streets which are generally considered to be local residential streets.

TRAFFIC MANAGEMENT MEASURES FOR RESIDENTIAL PRECINCTS

The elimination of noise and air pollution associated with the operation of motor vehicles has traditionally been the prime objective of traffic management schemes in residential precincts. More recently safety is being acknowledged as a major issue and now contemporary management strategy embodies environmental initiatives.

To achieve these overriding objectives, a three prong strategy is usually proposed as a general basis for the management of traffic in residential precincts comprising:

* reduction of through traffic
* reduction of travel speed
* reduction of accident potential especially at intersections

This strategy is directed towards achieving a reduction in gross traffic volumes to only locally generated traffic which is generally more sympathetic to the amenity of the neighbourhood. By reducing traffic speed, vehicle pollution is lowered while safety is enhanced. Treatment of intersections aims to improve safety conditions by addressing the major cause of vehicular accidents in a street system.

A limited range of options is open to Councils who wish to implement this type of strategy in residential precincts. These comprise traffic management schemes based on:

* Traffic control devices - signs, signals etc.
* Traffic diversion devices - road closures of various types, one-way streets etc.
* "Slow point" devices - angle slow points, road humps, small roundabouts etc.
* A combination of the above devices.

Particular characteristics of individual residential precincts will determine which devices are most appropriate and practicable.

Three major considerations in selecting the best scheme are public acceptance, ease of implementation and low cost. The 'bottom line' in this case, is that public acceptance is the most important consideration.

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Measures designed to eliminate through traffic in residential precincts, such as road closures, almost always involve a restriction on resident accessibility to the precinct and therefore create local opposition. In this respect, traffic control and slow point devices are less restrictive for traffic management than street closures.

The term "slow point" can refer to various types of traffic management devices such as angled slow points (one lane or two lanes), road humps, roundabouts, T-intersection treatments, divider islands or street narrowing at precinct entrances (thresholds) etc. Slow points by their nature are intended to reduce vehicle speed to safe and acceptable figures. Some of the devices can also be used to alter movement patterns, particularly at intersections.

LATM SCHEMES IN THE SYDNEY AREA

The East Roseville scheme was the first LATM scheme implemented in NSW and it was to serve as the demostration project. It was implemented about two years ago; it has experienced many problems associated with being the first scheme.

Canterbury Council initiated the second LATM scheme in Belmore/Lakemba about a year later. Only recently, three more councils have had schemes approved which will be implemented over the next three months in Mosman, Concord and Hornsby.

Before/after noise surveys and assesments were undertaken by the SPCC in the East Roseville and Belmore/Lakemba schemes.

CONCLUSIONS FROM SPCC ASSESSMENT

The SPCC studies in the East Roseville scheme covered traffic noise generated by the total traffic flows on a residential street affecting the living environment and the noise contributed by individual control devices.

The following conclusions regarding traffic noise were presented in the SPCC report:

> The scheme had a dramatic noise impact insibde the local area with significant noise decreases (benefits) in some heavy trafficked streets and significant noise increases(disbenefits) in some low trafficked streets. With 'fine tuning'of the scheme, it may be posible to achieve a more confortable and equitable acoustical environment for residents inside the local area.
>
> Traffic control devices become significant noise generators only with aggressive drivers. With 'fine tuning' of the scheme, this may be minimised.

Noise levels inside the scheme were about 70 to 74 dB(A) $L_{10(A)}$ before the introduction of the scheme and these were reduced by 1-2 dB(A). On one of the lightly travelled streets, the noise level was about 60 dB(A) and it raised to about 70 dB(A) with the increase in traffic flows due to diversions from an adjacent street.

TRAFFIC NOISE AND LATM

RECOMMENDED NOISE LEVELS IN RESIDENTIAL AREAS

The SPCC has indicated draft recommended background noise levels for different land use zonings in the Environmental Noise Control Manual released earlier this year. The acceptable levels for a residence in an urban area is stated as 45 and 35 dB(A) L_{90} respectively during the day and night while the maximum levels are stated as 50 and 40 dB(A) respectively.

COST-BENEFIT ANALYSIS OF TRAFFIC NOISE INSULATION FOR HOUSES

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INTRODUCTION

Most houses facing onto arterial roads in major cities are significantly impacted by road traffic noise. This problem cannot be solved in the short to medium term through vehicle noise controls [1]. Where an immediate reduction in the noise impact of arterial roads is required the only realistic option is to retrofit noise insulation measures to the houses affected. This paper uses cost-benefit analysis to derive the optimum level of traffic noise insulation for a particular house believed to be typical of many facing arterial roads in Australia. It is adapted from a report prepared by the author and published by the Victorian Environment Protection Authority [2].

STAGES OF NOISE INSULATION FOR HOUSES

Six stages of noise insulation are shown in Table 1. These have been adapted from work done by the CSIRO Division of Building Research [3,4] and the (US) Wyle Research Laboratories [5,6]. This work is summarized in some detail by Modra [2]. For each stage of noise insulation an increment of noise reduction is identified. The noise insulation stages are;

1: Property Line Barrier

2: Close Front Windows and Install Mechanical Ventilation

3: Weather Strip Front Windows and Door, and Seal Cracks

4: Upgrade Front Windows and Fit Solid-Core Front Door

5: Install Thermal Insulation in the Ceiling

6: Modifications to Interior Walls

It is important to observe that the six stages of insulation need not be undertaken in the order in which they are listed above: the constraints on their ordering follow from the general need [4] to treat the front windows (and door) first, then the roof and then the walls (and finally, if appropriate, the floor), and are fully discussed by Modra [2, pp 51-2].

COSTS OF NOISE INSULATION STAGES

The basic source of cost data for each insulation stage was a number of quotations received from contractors for undertaking the work relevant to that stage at a particular property [2, p103] thought to be typical of houses situated on arterial roads in Melbourne. Specifications for work were prepared with the assistance of published information and verbal advice from CSIRO and acoustical consultants.

TABLE 1 NOISE INSULATION STAGES

STAGE OF INSULATION	INSULATION DETAILS	RANGE OF INCREMENTAL NOISE REDUCTIONS, dB(A)	MEAN OR TYPICAL INCREMENTAL NOISE REDUCTION, dB(A)
STAGE 1 Property line barrier	Barrier at property line. Height, metres 2.0 2.5 3.0	Compared with no barrier. 6.3 8.3 10.3	8.3
STAGE 2 Facade	Leave front windows closed permanently. Install mechanical ventilation system for front rooms.	5 to 13	9.0
STAGE 3 Facade	Weather strip front door, and windows in front rooms. Plug any small cracks around window frames, skirtings, cornices and front door with a suitable filler or sealant.	1 to 4	2.5
STAGE 4 Facade	Upgrade front windows and fit solid-core front door with seals.	4 to 10	7.0
STAGE 5 Ceiling	Install thermal insulation in the ceiling	4 to 8, for pitched roof.	6.0
STAGE 6 Facade	In front rooms glue battens 25 mm thick to existing plasterboard wall. Place 25 mm thick rockwool or fibreglass batts between battens and fix new plasterboard wall.	about 4	4.0

The cost information is summarized in Table 2.

TABLE 2. SUMMARY OF COSTS OF INSULATION STAGES

STAGE	RANGE OF COSTS ($, 1983)	AVERAGE COST ($)
1	1142 - 2408	1796
2	630 - 900	793
3	489 - 696	589
4	730 - 1505	1249
5	285 - 548	398
6	4248	4248

QUANTIFICATION OF BENEFITS: SELECTION OF NOISE DEPRECIATION INDEX

The Group of Economic Experts of the OECD Environment Committee has indicated [7, p5] that "significant progress has been made over the past ten years in developing the methodologies for estimating environmental damage cost (the inverse of benefits), in certain cases reaching a high degree of sophistication". For example, where houses are impacted by traffic noise the OECD Economic Experts recommend the use of a noise depreciation index (NDI) of 0.5% of property value per decibel change in traffic noise level when estimating damages or benefits. Modra [2] reviews and summarizes the literature in this field. After considering five North American and three Australian studies of the effect of traffic noise on house prices Modra concludes that an NDI value of 0.5% is appropriate for Australia.

HOUSE PRICE FOR BENEFIT EVALUATION

Because the NDI expresses the benefit of noise reduction in terms of percentage increase in property value per dB(A) decrease in noise level, it is necessary to identify an appropriate property value to enable benefits to be expressed in dollar units. NDI values are derived by using market price as the measure of property value. Hence, price is also the appropriate measure to use in analyses which apply the NDI.

The Statewide Index [8] indicates that in the second half of 1983 (when the costs to which benefits are to be compared were collected) the average price for a house and land in the Melbourne metropolitan area was $65,043.

However, because of other, non-noise-related disutilities of living on arterial roads (eg visual impact of traffic, difficulty of driveway entry/exit), it may be appropriate to assume a lower average price for residential properties on arterial roads than for all residential properties. Bearing this in mind, an average house price of $60,000 is used in the subsequent analysis in this paper.

It should be noted that an NDI of 0.5% used in conjunction with a house price of $60,000 implies that the property value changes $300 for each decibel change in traffic noise level.

COST - BENEFIT ANALYSIS

Modra [2, pp12-16] shows that the optimum level of noise insulation is achieved when the marginal benefits (ΔB) of the insulation equal the marginal insulation costs (ΔT). In other words, insulation stages should only be applied as long as the additional benefits exceed or equal the additional costs.

The expression for the optimum level of insulation

$$\Delta B = \Delta T$$

can be rearranged as

$$\frac{\Delta B}{\Delta T} = 1$$

Prior to reaching the optimum point the ratio of ΔB to ΔT exceeds unity
Past the optimum point this ratio is less than unity

It is therefore necessary to develop a sequence of stages of insulation so that the first stage has the highest value of the ratio of ΔB to ΔT. Subsequent stages should be applied in decreasing order of this ratio. It is also necessary for the sequence to satisfy the constraints on ordering identified previously (ie it is necessary to treat the windows and front door before treating the roof, etc). These two constraints can only be satisfied by combining stages.

Modra [2, p63] shows that the sequence which best satisfies these contraints is : stage 2, stages 3,4 and 5 simultaneously, stage 1, then stage 6. Values of ΔB to ΔT for each of these stages are shown in Table 3. The noise reduction values (ΔNR) are taken from Table 1. The incremental benefit values are for a house price of $60,000 and an NDI of 0.5% of property value per decibel change in traffic noise.

TABLE 3 $\frac{\Delta B}{\Delta T}$ VALUES

STAGE	ΔNR dBA	ΔB $	ΔT $	$\frac{\Delta B}{\Delta T}$
2	9	2700	793	3.4
3+4+5	15.5	4650	2236	2.1
1	8.3	2490	1796	1.4
6	4.0	1200	4248	0.28

For stages 2, 3+4+5, and 1, the ratio ΔB to ΔT is greater than 1. For stage 6 this ratio is less than 1. Hence stages 2, 3+4+5, and 1 can be justified on the basis of cost-benefit analysis. The total cost is $4825.

TOTAL RETROFITTING COST FOR MELBOURNE

In Melbourne there are approximately 1800 kilometres of major urban roads [9]. Assuming 57 houses or other residential buildings per kilometre[10] and that 81% of residences facing these roads are exposed to more than 68 dBA L_{10} (18 hour) [11], it follows that approximately 83,000 residential buildings in Melbourne are exposed to more than this level of traffic noise. If all of these residences were to be treated with a comprehensive noise insulation package costing $4800 per house, the total cost would be $400 million. This result can be compared with the $630 million total public expenditure on roadworks in Victoria in 1983/84 [12].

CONCLUSION

This paper has identified six stages of traffic noise insulation for houses and shown that the application of five of these stages to a particular house can be justified on the basis of cost benefit analysis. The total cost of these five stages is $4825 dollars (1983 costs). To apply this package of noise insulation stages to all the houses in Melbourne exposed to more than 68 dB(A) L_{10} (18 hour) would cost nearly two thirds the annual budget for roadworks for the entire state of Victoria.

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APPENDIX : FURTHER DETAILS, INSULATION STAGES

Stage 1: Property Line Barrier

The noise reductions in Table 1 assume that kerb-to-property line and property line-to-facade distances are 4.1 and 7.6 metres respectively [2, p 107]. These distances are believed to be typical of many houses facing arterial roads.

Stage 2: Close Front Windows and Install Mechanical Ventilation

This stage is not identified explicitly either by the CSIRO or by the Wyle Research Laboratories yet it is clearly a low-cost option available to all householders. Mechanical ventilation for the front rooms has been included in this stage to avoid any possibility of stuffiness.

Stage 3: Weather Strip Front Windows and Door, and Seal Cracks

This stage aims to eliminate air leakage paths.

Stage 4: Upgrade Front Windows and Fit Solid-Core Front Door

The most common method of upgrading the acoustic performance of windows is to install double glazing with a suitable pane-to-pane spacing.

Stage 5: Install Thermal Insulation in the Ceiling

Provided materials such as fibreglass or rock wool are used, this stage introduces absorption into the roof space.

Stage 6: Modifications to Interior Walls

This stage increases the mass of the interior walls and introduces sound absorbent material into the wall cavity.

TRAFFIC NOISE REDUCTION OF DOMESTIC WINDOWS

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INTRODUCTION

For buildings of conventional construction facing busy roads the primary pathway for traffic noise transmission is via the windows. Most of the data on the sound insulation of windows has been determined under laboratory conditions and with glass in a fixed framework. To estimate the traffic noise reduction this data is often applied to domestic windows which incorporate openable sashes. The limitations of applying this data to real windows will be discussed with particular reference to the effects of some types of frame.

MEASUREMENTS OF TRAFFIC NOISE REDUCTION OF WINDOWS

There have been few conprehensive studies of the traffic noise reduction of domestic windows. In the United Kingdom, Noise Insulation Regulations were introduced in 1973 (with a revision in 1975 [1]) which required compensation for people exposed to high levels of road traffic noise from new or altered road systems. The main form of compensation involves the installation of the "Noise Insulation Package" which provides for secondary windows and a small ventilation unit. In 1979 a study was undertaken by the Building Research Station (BRS) to determine the performance of facades with the secondary windows installed. Some of the results of this study have been reported by Utley et al [2]. The measurements were made for 154 rooms, at 27 sites and an average level difference of 34 dB(A) was obtained however there was considerable variability in performance both within and between sites - the range being from 25 dB(A) to 41.5 dB(A) [3]. While it was possible to explain some of the low insulation values by faults in the construction, lightweight surrounding construction etc, the reasons for the remaining wide range of values was not clear.

A second series of measurements were undertaken by the BRS in 1980 on 100 untreated windows, i.e. single glazed windows or replacement thermal double glazed windows, the average level difference was 28.6 dB(A) with a standard deviation of 3 dB(A). The standard deviation of the average values for each one-third octave frequency band varied from 3 up to 5 dB. To investigate this large variation in values of sound insulation, correlations with various room and window characteristics were investigated. These included whether the window was on ground floor or first floor level, bay or flat style and window area, floor area, reverberation time. The analysis showed that none of these factors could explain the variance in the results.

From the level difference data over frequency there was found to be a difference between the performance of the windows based on frame type i.e. metal casement, wooden casement and wooden sash. As can be seen from Figure 1 the level differences for the low frequencies are almost the same but at the higher frequencies there are dips which occur at different frequencies for the metal casement windows and for the wooden casement windows while the data for the wooden sash windows show no dip.

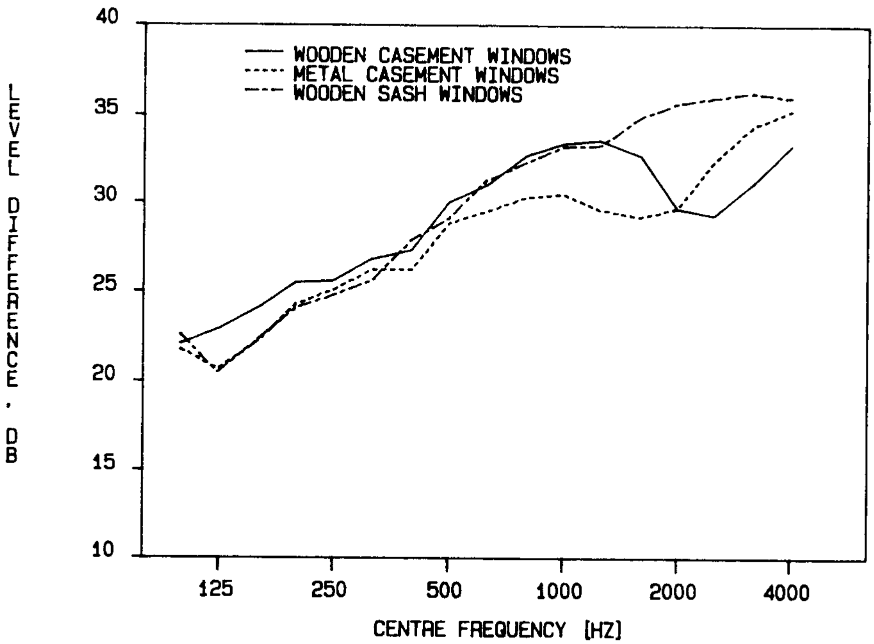

Figure 1.Level Differences for domestic windows with three different types of frame.

The immediate thought that this is the coincidence effect for the glass must be rejected as all the windows had the same thickness of glass for which the critical frequency would be around 4000Hz. Further investigations on casement windows showed that this effect can be explained on the basis of the frame acting as a Helholtz Resonator with the body of the resonator being the air trapped in the frame and the neck being a small slit or gap around the window which can occur when the window is closed tightly but not sealed [4]. Figure 2 shows the noise reduction measured for one metal casement window in four different conditions and it can be seen that as slight gap around the frame increases so does the frequency of the dip. This is in accordance with the predictions based on the theory of a Helmholtz Resonator. These results highlight the importance of the design of the window frame. The importance of the mounting of the glass within the frame has been shown by Utley and Fletcher [5] where a resilient mounting such as neoprene was found to give better sound insulation than conventional mounting.

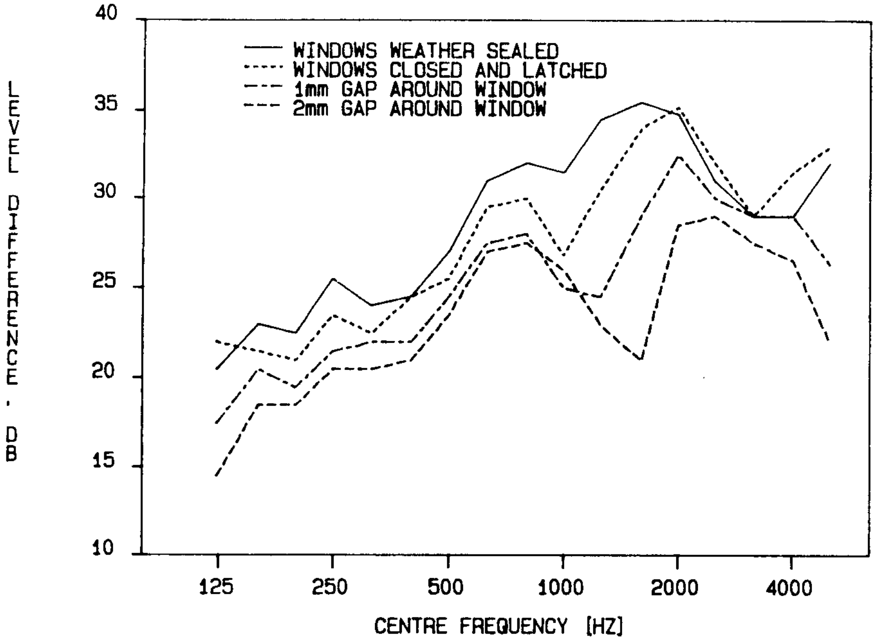

Figure 2.Level Differences for a metal casement window with various sealings

APPLICATION OF LABORATORY DATA

As there is only limited information available on the traffic noise insulation windows it is often necessary to use laboratory data to estimate the performance. In laboratory tests for sound insulation, the test partition is placed between two reverberant rooms. The level differences, for each frequency, between the values in the source room and in the receiving room are corrected for absorption in the receiving room and the size of the test specimen and the sound transmission loss determined. Even if tests of this nature are performed on windows (as opposed to glazing in a fixed frame) the results obtained are not necessarily indicative of ther performance of the windows when they are installed in a facade and exposed to road traffic noise.

A comparison between laboratory and field measurements by Taibo et al [6] included some measurements on facades (concrete panels and windows) and these showed that when the field tests were carried out in accordance with ISO R140/IV using loudspeaker generated noise the results were systematically lower than those achieved in laboratory tests. For the weighted sound reduction index this differernce was of the order of 2 while for the values at each frequency the differences were greater in the coincidence region and greater for constructions with higher sound insulation.

For road traffic noise reduction there is a further complication as the sound field striking the facade is quite different from that produced by a fixed loudspeaker. A specially constructed experimental building [7] located adjacent to a road with heavy traffic flow has been used for a series of measurements of a variety of windows in a number of different types of walls. For some windows comparisons were made between the noise reduction measured using road traffic noise as the source and using loudspeaker generated noise. These results consistently showed that the noise reduction measured using the traffic noise was less than for the loudspeaker generated noise.

CONCLUSIONS

The traffic noise reduction to be expected from typical domestic windows is very difficult to estimate. Measurements on a number of similar windows have shown a wide range of values. Even when room and window characteristics are taken into account this range was not reduced. The importance of considering the window and its frame is highlighted by the finding of dips in the performance spectra which can be explained by a study of resonator effects in the framing. Estimates based on laboratory data are likely to indicate greater traffic noise reduction than will be achieved in practice.

ACKNOWLEDGEMENT

Some of the work reported in this paper was undertaken while the author was an attached worker at the Building Research Establishment, U.K.

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A PROGRAM FOR A PROGRAMMABLE CALCULATOR FOR THE ESTIMATION OF TRAFFIC NOISE BY THE U.K. C.O.R.T.N. PROCEDURE.

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A particular problem for traffic noise workers is the mechanics of estimating the level of traffic noise at a site. The CORTN procedure is most generally accepted by State Road Authorities for use in Australia. The procedure is described in Refs (1) and (2).

Typically, and particularly for the freeway type situation, estimated noise levels are required as follows:

(a) At many locations and at multiple floor heights.

(b) Separate estimations (which are combined) are required for each road segment or carriageway.

(c) Investigation of alternative noise attenuation configurations is required.

Under these conditions, manual computation may not be feasible, however the investigation may not be sufficiently large to justify purchase or development of the necessary software.

The program described below has been used for traffic noise level estimations by the Department of Main Roads New South Wales for some years now. It is considered to be superior to other similar Australian programs known to the author in the following respects:

(a) It can process partial, multiple and/or sloping noise barriers;

(b) the treatment of attenuation over soft ground is developed for Australian conditions.

A program for the Texas Tl 59 is listed in Appendix 2. However the program is also described in some detail in Appendix 1 so that it could be easily rewritten in BASIC or another computer language, and/or some variant of the CORTN model incorporated.

The program estimates L10 (18 hrs) in dBA. This is defined as the average value of L10 for the 18 hrs 6 a.m. to 12 midnight for an average weekday.

Appendix 3 consists of sample calculations on a computation form. The remainder of this paper consists of comments regarding experience of use of the program.

The Department proposes to carry out a noise measurement program, to evaluate the performance of this model in late 1985.

A PROGRAM FOR A PROGRAMMABLE CALCULATOR FOR THE ESTIMATION OF TRAFFIC NOISE BY THE U.K. C.O.R.T.N. PROCEDURE.

COMMENTS ABOUT D.M.R. EXPERIENCE

1. The Department of Main Roads New South Wales, gives particular consideration to attenuation measures at properties where the noise level (L10, 18hrs) is measured or estimated to rise by at least 2 dBA to over 68 dBA. This closely follows British practice.

2. It has been found good practice to uniformly quote all estimated noise levels to 0.1 dBA. Although the procedure is not this accurate, the effect of a small change (e.g. an 0.3m change in a noise barrier height) can be discriminated with sufficient precision. Quoting to 1.0 dB(A) would introduce further uncertainty, particularly for noise level differences.

3. A common situation is along a road to be widened where the 2dBA rise may be exceeded, typically at a roadside house or church. Generally 4 or more lanes should be treated as 2 carriageways, otherwise the estimate of the noise level rise is likely to be unrealistic. The U.K. manuals would model all traffic as being between the two nearest lanes.

4. Similarly, deeming the intervening ground to be "all paved" or "all soft ground" can lead to unrealistic noise level differences. The "soft ground co-efficient" was therefore introduced into the program.

5. For soft ground attenuation, Refs (1) and (2) introduce a hypothetical observer height (hl) which is related to the average height above the ground (hs) of the observers' sight line ($h^1 + 0.5 = 2h_s$). In the program, the mean height of the sight line is obtained from survey data and entered directly. At 65 dBA or more, soft ground attenuation is usually not important.

6. For 2 or more lanes, the noise line should be placed 3.5 m behind the nearest traffic lane edge for all carriageways. (7m in front of the far edge was found to be troublesome and less realistic).

7. Having located the "noise line" the pavement edge line is not used again in the calculations.

8. The opposite facade correction does not apply to typical Australian residential development.

9. At some sensitive locations and where a barrier segment and/or the road segment behind it is highly skew to the listening point, the input data may need to be carefully considered. The CORTN procedure is not specific for this situation. One technique is to rotate the road segment and barrier about the intersection point of the bisector of their subtended angle and to increase the subtended angle accordingly.

A PROGRAM FOR A PROGRAMMABLE CALCULATOR FOR THE ESTIMATION OF TRAFFIC NOISE BY THE U.K. C.O.R.T.N. PROCEDURE.

ESTIMATED AND MEASURED NOISE LEVELS

Measured noise levels are more reliable than estimated noise levels, however, L10 (18 hrs) requires a noise measurement to be of 18 hours minimum duration. Reference (1) lists two techniques which can make the use of noise measurements more generally feasible.

(i) Paragraph 54 describes how a noise measurement can be adjusted, using the CORTN model to calculate the noise level change due to changes in the traffic volume, content and speed. This technique can be extended to incorporate moderate changes in site geometry such as along a widened road. The "before" and "after" noise levels are estimated and the difference applied to the measured noise level.

(ii) Paragraph 48 describes a technique whereby an L10 (18hr) reading at one site can be extended to many sites subjected to noise from the same traffic stream. At least 2 - 15 minute simultaneous readings are taken at each other site and the resultant noise level differences applied to the single L10 (18hr) reading.

The individual 15 minute readings should be at least 1 hour apart. If the resultant L10 (18 hr) measurements differ significantly then additional 15 minute readings can be taken at other times of day. If possible the permanent microphone should be left in place for more than one day, the average L10 (18hr) reading adopted, and weekend noise levels recorded.

REFERENCES

[1] Calculation of Road Traffic Noise U.K. Department of the Environment Welsh Office H.M.S.O.

[2] Predicting Road Traffic Noise. U.K.D.E. Building Research Establishment Report M5 H.M.S.O. This is a later, more convenient manual.

ACKNOWLEDGEMENTS

The author acknowledges the assistance of the Department of Main Roads, N.S.W. and individual officers in preparing this paper. The views expressed in this paper do not necessarily represent those of the Department.

1. KEY A. The "Roadside" Noise Level (L_R, 10 m from the nearest traffic lane edge) is estimated from the 18 hr traffic volume (Q), % heavy vehicles (1.5T tonne min, P), average vehicle speed (V in kph), and gradient (G in %).

L_R = 10 log Q + 28.1	Traffic Volume
+ 10 log (1 + 5 P/V)	Heavy Vehicles
+ 33 log (500/V + V + 40) - 66.8	Speed
+ 0.2G	Gradient (For 1-way downhill G=0)
+ 0.1G for existing situations	

2. KEY B. Distance (Ld) and "Soft Ground" Attenuation (Ls) are estimated from the traffic noise line co-ordinates (dr, hr = pavement level), the observer floor or ground co-ordinates (do, ho) the average sight line height (hs) which is described below and the "soft ground" co-efficient (s, which is stipulated to be 0.0 or 1.0, however the program will calculate for intermediate values).

(i) The plan distance (d_p) and the slope distance (d_s), from the traffic noise line (0.5 m above pavement) to the observer (1.5m high) are calculated.
$dp = do - dr$.
$d_s = (dp^2 + (ho - h_r + 1)^2)\ 0.5$.

(ii) Previous barrier calculations are erased.

(iii) Distance and Soft Ground Attenuation is calculated $L_d = -10 \log (d_s - 13.5)$
$L_s = 10 \log (1-S (1-((6h_s - 1.5)/dp)\ 0.52))$.
If $L_s > 0$, $L_s = 0$.

3. KEY C. Barrier Penetration. The Barrier distance is checked and the distance (B) is estimated that the barrier penetrates the "sight line". This allows the geometric data to be checked and is required for Step D below.

$B = h_b - h_o - 1.5 + (h_o - h_r + 1) \times (d_o - d_b)/(d_o - d_r)$

4. KEY D. Barrier Calculations

(i) The extra path length is calculated
$EPL(m) - = ((d_o - d_b)^2 + (h_b - h_o - 1.5)^2)\ 0.5$
$((d_b - d_r -)^2 + (h_o - h_r - 0.5)^2) 0.5 - ds$.

(ii) Barrier Attenuation (LB, dBA)
t = log (EPL). If t <-4, L_b = - 5.0.

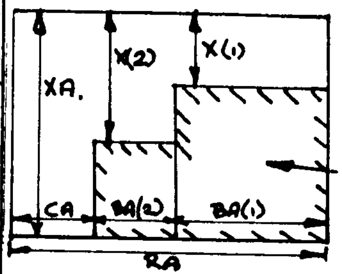
FOR B > 0 (Shadow zone)
If x <-3, L_b = -5.0 otherwise
$L_b = -15.4 - 8.26t - 2.787t^2 - .831t^3 - .198t^4 + .1539t^5 + .12248t^6 + .02175t^7$.
If L_b < - 20 L_b = -20 If L_b> - 5.0 L_b =-5.0

FOR B < 0 (Illuminated zone) If x > 0, L_b = 0 otherwise.
$L_b = - .109t - .815t^2 + .479t^3 + .3284t^4 + .04385t^5$.

5. KEYS E, A1 Total Attenuation
The effect of each barrier is accumulated (Step E) and the total attenuation calculated (Step A1).

RA and BA(N) are the effective subtended angles at the observer for the road segment and the noise barriers respectively. Each barrier angle must completely overlap the road angle but not another barrier angle.

If $L_s < L_b$ the barrier is neglected. The clear view angle (CA), which is displayed will indicate whether this has occurred, and can check that an incorrect key order has not occurred. CA is never negative.



CA= RA - Sum (BA(N))

X(N)=InvLog(L_b/10)
XA= InvLog(L_s/10)
(L_b,L_s<0;X(N),XA <1)

Noise energy blocked by barrier.

Total Attenuation.

L_a=F + L_d + 10 log (XAxCA/180+Sum(BA(N) x X(N)).
= F + L_d + the unhatched area.
F is an arbitrary correction normally 0.0 or the facade correction (+2.5).
For another barrier, repeat Steps C to A1 after entering the altered barrier data.

6. KEY B1. The road segment noise level is calculated:
$L_k = L_R + L_A$

7. KEY C1. Total Noise Level. The noise level of each road segment is accumulated.
L_T = 10 log (Inv log (L_T/10)+Inv log (L_n/10))

8. Key D1. The contents of all memories is printed, in order to check the input data and/or for record purposes.

9. Key E1. New Observer Location. The total noise level register is zeroized. (L_T = 0).

U.K.D.E. (CORTN) PROCEDURE FOR ESTIMATING TRAFFIC NOISE LEVELS. LISTING OF PROGRAMME FOR THE TEXAS TI59 PROGRAMMABLE CALCULATOR

```
000  76 LBL
001  11 A
002  57 ENG
003  60 DEG
004  43 RCL
005  13 13
006  28 LOG
007  65 ×
008  01 1
009  00 0
010  85 +
011  02 2
012  08 8
013  93 .
014  01 1
015  95 =
016  42 STO
017  27 27
018  53 (
019  05 5
020  00 0
021  00 0
022  55 ÷
023  43 RCL
024  16 16
025  85 +
026  43 RCL
027  16 16
028  85 +
029  04 4
030  00 0
031  54 )
032  28 LOG
033  65 ×
034  03 3
035  03 3
036  85 +
037  53 (
038  43 RCL
039  14 14
040  65 ×
041  05 5
042  55 ÷
043  43 RCL
044  16 16
045  85 +
046  01 1
047  54 )
048  28 LOG
049  65 ×
050  01 1
051  00 0
052  75 -
053  06 6
054  08 8
055  93 .
056  08 8
057  95 =
058  42 STO
059  28 28
060  00 0
061  32 X:T
062  43 RCL
063  15 15
064  77 GE
065  33 X²
066  00 0
067  76 LBL
068  33 X²
069  65 ×
070  93 .
071  01 1
072  65 ×
073  53 (
074  43 RCL
075  17 17
076  85 +
077  02 2
078  54 )
079  95 =
090  42 STO
081  10 10
082  85 +
083  43 RCL
084  28 28
085  85 +
086  43 RCL
087  27 27
088  95 =
089  42 STO
090  01 01
091  91 R/S
092  76 LBL
093  12 B
094  43 RCL
095  19 19
096  75 -
097  43 RCL
098  11 11
099  95 =
100  42 STO
101  10 10
102  33 X²
103  85 +
104  53 (
105  43 RCL
106  20 20
107  75 -
108  43 RCL
109  12 12
110  85 +
111  01 1
112  54 )
113  33 X²
114  95 =
115  34 √X
116  42 STO
117  28 28
118  43 RCL
119  19 19
120  42 STO
121  05 05
122  00 0
123  42 STO
124  29 29
125  43 RCL
126  28 28
127  55 ÷
128  01 1
129  03 3
130  93 .
131  05 5
132  95 =
133  28 LOG
134  65 ×
135  01 1
136  00 0
137  94 +/-
138  95 =
139  42 STO
140  27 27
141  42 STO
142  02 02
143  53 (
144  53 (
145  53 (
146  43 RCL
147  22 22
148  65 ×
149  06 6
150  75 -
151  01 1
152  93 .
153  05 5
154  54 )
155  55 ÷
156  43 RCL
157  10 10
158  54 )
159  45 Y^X
160  93 .
161  05 5
162  02 2
163  65 ×
164  43 RCL
165  21 21
166  85 +
167  01 1
168  75 -
169  43 RCL
170  21 21
171  54 )
172  28 LOG
173  65 ×
174  01 1
175  00 0
176  95 =
177  77 GE
178  28 LOG
179  44 SUM
180  02 02
181  76 LBL
182  28 LOG
183  43 RCL
184  02 02
185  91 R/S
186  76 LBL
187  13 C
188  43 RCL
189  24 24
190  67 EQ
191  38 SIN
192  43 RCL
193  19 19
194  75 -
195  43 RCL
196  25 25
197  95 =
198  77 GE
199  30 TAN
200  76 LBL
201  38 SIN
202  00 0
203  42 STO
204  24 24
205  61 GTO
206  35 1/X
207  76 LBL
208  30 TAN
209  43 RCL
210  26 26
211  75 -
212  43 RCL
213  20 20
214  75 -
215  01 1
216  93 .
217  05 5
218  85 +
219  53 (
220  43 RCL
221  20 20
222  75 -
223  43 RCL
224  12 12
225  85 +
226  01 1
227  54 )
228  65 ×
229  53 (
230  43 RCL
231  19 19
232  75 -
233  43 RCL
234  25 25
235  54 )
236  55 ÷
237  53 (
238  43 RCL
239  19 19
240  75 -
241  43 RCL
242  11 11
243  54 )
244  95 =
245  42 STO
246  03 03
247  76 LBL
248  35 1/X
249  91 R/S
250  76 LBL
251  14 D
252  43 RCL
253  24 24
254  67 EQ
255  88 DMS
256  53 (
257  43 RCL
258  19 19
259  75 -
260  43 RCL
261  25 25
262  54 )
263  33 X²
264  85 +
265  53 (
266  43 RCL
267  26 26
268  75 -
269  43 RCL
270  20 20
271  75 -
272  01 1
273  93 .
274  05 5
275  54 )
276  33 X²
277  95 =
278  34 √X
279  85 +
280  53 (
281  53 (
282  43 RCL
283  25 25
284  75 -
285  43 RCL
286  11 11
287  54 )
288  33 X²
289  85 +
290  53 (
291  43 RCL
292  26 26
293  75 -
294  43 RCL
295  12 12
296  75 -
297  93 .
298  05 5
299  54 )
300  33 X²
301  54 )
302  34 √X
303  75 -
304  43 RCL
305  28 28
306  95 =
307  76 LBL
308  88 DMS
309  42 STO
310  10 10
311  43 RCL
312  24 24
313  67 EQ
314  44 SUM
315  43 RCL
316  10 10
317  28 LOG
318  42 STO
319  06 06
320  85 +
321  04 4
322  95 =
323  77 GE
324  43 RCL
325  05 5
326  94 +/-
327  42 STO
328  04 04
329  61 GTO
330  39 COS
331  76 LBL
332  43 RCL
333  43 RCL
334  03 03
335  94 +/-
336  77 GE
337  81 RST
338  43 RCL
339  06 06
340  85 +
341  03 3
342  95 =
343  77 GE
344  45 Y^X
345  05 5
346  94 +/-
347  42 STO
348  04 04
349  61 GTO
350  39 COS
351  76 LBL
352  45 [illegible]
353  [illegible]
354  [illegible]
355  [illegible]
356  43 RCL
357  06 06
358  33 X²
359  65
360  93 .
361  00 0
362  02 2
363  01 1
364  07 7
365  05 5
366  85 +
367  43 RCL
368  06 06
369  65 ×
370  93 .
371  01 1
372  02 2
373  02 2
374  04 4
375  08 8
376  85 +
377  93 .
378  01 1
379  05 5
390  03 3
381  09 9
382  54 )
383  65 ×
384  43 RCL
385  06 06
386  33 X²
387  75 -
388  93 .
389  01 1
390  09 9
391  08 8
392  65 ×
393  43 RCL
394  06 06
395  75 -
396  93 .
397  08 8
398  03 3
399  01 1
400  54 )
401  65 ×
402  43 RCL
403  06 06
404  33 X²
405  75 -
406  02 2
407  93 .
408  07 7
409  08 8
410  07 7
411  65
412  43 RCL
413  06 06
414  75 -
415  09 9
416  93 .
417  02 2
418  06 6
419  54
420  65 ×
421  43 RCL
422  06 06
423  75 -
424  01 1
425  05 5
426  93 .
427  04 4
429  95 =
429  42 STO
430  04 04
431  85 +
432  05 5
433  95 =
434  94 +/-
435  77 GE
436  42 STO
437  05 5
438  94 +/-
439  42 STO
440  04 04
441  76 LBL
442  42 STO
443  43 RCL
444  04 04
445  85 +
446  02 2
447  00 0
448  95 =
449  77 GE
450  39 COS
451  02 2
452  00 0
453  94 +/-
454  42 STO
455  04 04
456  61 GTO
457  39 COS
458  76 LBL
459  81 RST
460  43 RCL
461  06 06
462  77 GE
463  44 SUM
464  53 (
465  53 (
466  43 RCL
467  06 06
468  33 X²
469  65 ×
470  93 .
471  00 0
472  04 4
473  03 3
474  [illegible]
475  05 5
476  85 +
477  43 RCL
478  06 06
479  65
480  93 .
481  03 3
482  02 2
483  09 9
484  04 4
485  85 +
486  93 .
487  04 4
488  07 7
489  09 9
490  54 )
491  65 ×
492  43 RCL
493  06 06
494  33 X²
495  75 -
496  93 .
497  09 9
498  01 1
499  05 5
500  65 ×
501  43 RCL
502  06 06
503  85 +
504  93 .
505  01 1
506  00 0
507  09 9
508  54 )
509  65
510  43 RCL
511  06 06
512  95 =
513  42 STO
514  04 04
515  61 GTO
516  39 COS
517  76 LBL
518  44 SUM
519  00 0
520  42 STO
521  04 04
522  76 LBL
523  39 COS
524  43 RCL
525  04 04
526  91 R/S
527  76 LBL
528  15 E
529  43 RCL
530  02 02
531  75 -
532  43 RCL
533  [illegible]
534  75 -
535  43 RCL
536  04 04
537  95 =
538  94 +/-
539  77 GE
540  [illegible]
541  43 RCL
542  04 04
543  22 INV
544  28 LOG
545  45 Y^X
546  93 .
547  01 1
549  65 ×
549  43 RCL
550  24 24
551  55 ÷
552  01 1
553  08 8
554  00 0
555  95 =
556  44 SUM
557  29 29
558  43 RCL
559  24 24
560  94 +/-
561  44 SUM
562  05 05
563  76 LBL
564  89 π
565  43 RCL
566  05 05
567  91 R/S
568  76 LBL
569  16 A'
570  43 RCL
571  23 23
572  85 +
573  01 1
574  00 0
575  65 ×
576  53 (
577  43 RCL
578  05 05
579  55 ÷
580  01 1
581  08 8
582  00 0
583  65
584  43 RCL
585  02 02
586  22 INV
587  28 LOG
588  45 Y^X
589  93 .
590  01 1
591  85 +
592  43 RCL
593  29 29
594  65
595  43 RCL
596  27 27
597  22 INV
598  28 LOG
599  45
600  93 .
601  01 1
602  54
603  28 LOG
604  95 =
605  42 STO
606  06 06
607  91 R/S
608  76 LBL
609  17 B'
610  43 RCL
611  06 06
612  85 +
613  43 RCL
614  01 01
615  95 =
616  42 STO
617  07 07
618  91 R/S
619  76 LBL
620  18 C'
621  43 RCL
622  07 07
623  22 INV
624  28 LOG
625  45 Y^X
626  93 .
627  01 1
628  85 +
629  43 RCL
630  00 00
631  22 INV
632  28 LOG
633  45
634  93 .
635  01 1
636  95 =
637  28 LOG
638  65 ×
639  01 1
640  00 0
641  95 =
642  42 STO
643  00 00
644  91 R/S
645  76 LBL
646  19 D'
647  00 0
648  22 INV
649  90 LST
650  98 ADV
651  98 ADV
652  91 R/S
653  76 LBL
654  10 E'
655  00 0
656  42 STO
657  00 00
658  91 R/S
```

APPENDIX C: SAMPLE CALCULATION

WORKSHEET FOR TRAFFIC NOISE ESTIMATION (UKDE PROCEDURE) USING THE TI59 PROGRAMMABLE CALCULATOR

Location: A-B Freeway. Proposed Link X-Y **Job No:**

No. of Lanes **Pavt. Type:** Worked Example

Field Results: L_{10} **(dBA, L10/1 hr or 18 hrs)**

Memory No. Description of Data.	1st Carriageway 1st bar.	1st Carriageway 2nd bar.	2nd Carriageway 1st bar.	2nd Carriageway 2nd bar.		
Roadway Data.						
*11. Distance (m) Sound Line to plan C.L.	10		-10			
12. R.L. (m) Pavt. at Sound Line	20					
13. Daily Traffic Vol.(18hr) or Hourly Volume x 20.4	20.4 x 1000					
14. % Heavy Vcls. (1.5 tn.min.)	6					
15. Gradient (%, 1way d'hill-ve)	-5		+5			
16. Average speed (k.p.h.)	100					
17. Speed predicted (0.0); Actual or Speed Limit (1.0)	0					
Observer Data.						
18. Angle (deg) of Road Segment at Observer.	170					
19. Dist. (m) Obs. to Plan C.L.	130					
20. Ground or floor RL at Obs (m).	69.0					
21. Ratio of Vegetated Ground Cover (0-1.0)	1					
22. Av. Height (m) of Sight Line.	4.0					
23. Total Noise Corrections. (dBA; Facade plus others).	0					
Barrier Data.						
24. Subtended Angle (deg) at Obs. (0=No barrier)	45	90	45	90		
*25. Distance (m) to Plan C.L.	70					
26. RL (m) at Top of Barrier	45.6	48.5	45.6	48.5		
Calculated Data.						
A01 Roadside Noise Level (13.5 m from Sound Line; L10, dBA)	74.86	-13.61	75.86			
B02 Distance Attenuation (dBA)	-13.61		-14.55			
C03 Depth of Barrier Intrusion (m)	0.10	+3.00	-3.57	-.57		
D04 Attenuation of Barrier (dBA)	-5.00	-9.66	-.75	-4.17		
E05 Clear View Angle (Deg)	125	35	170	80		
A'06 New Attenuation (dBA)	-14.16	-16.52	-14.80	-14.82		
B'07 Noise Level - Road Segment (L10, dBA)		58.34		61.04		
C'00 Noise Level - Total (L10,dBA)		(58.34)		62.91		

*Negative if the plan CL is between the Observer and the Sound Line or barrier.
Key D' to print the above data; key E' at each new observer point.

Remarks.

A MATHEMATICAL MODEL OF THE ENVIRONMENTAL IMPACT OF TRAFFIC NOISE

C.M. Steele

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INTRODUCTION

This paper outlines a mathematical model of the environmental impact of traffic noise. The basic formulation is a convolution integral which admits of a precise study of traffic noise and also greatly simplifies the problem when compared with other older predictive methods in use in Australia, e.g. Ref. [1].

The intensity at an observer's location is the convolution integral of a source function with a Green's function which represents the consequence of the emergence of traffic from the source point. The sequence thereby computed may be analysed as required. The meaning of environmental impact is considered in relation to traffic noise; and the problems associated with excess attenuation of sound are considered.

THE SOURCE FUNCTIONS

Let x(t) represent the sound intensity at 1 metre of traffic emerging from a sufficiently remote source. Such a sufficiently remote source may be a mathematical artifice in that more remote traffic has no significant effect upon the sound pressure levels at points of interest.

In practical cases, x(t) is usually a periodic function of time with semi-constants. Let x(t) be sampled at regular intervals, giving N samples for one cycle, then

$$x(t) = \frac{1}{N}\sum_{n=0}^{N-1} F_{re}(n)\cos\left(\frac{2\pi nt}{N}\right) - F_{im}(n)\sin\left(\frac{2\pi nt}{N}\right) \qquad (1)$$

where $F_{re}(n)$ and $F_{im}(n)$ are semi-constants.

Let many sets of N 24 hour samples of x(t) be taken and a Fourier analysis of every set be made to determine the values of $F_{re}(n)$ and $F_{im}(n)$ for every such set. The distributions of $F_{re}(n)$ and $F_{im}(n)$ may then be determined. In practical cases, the sets so analysed may be taken on the same day of the week over many weeks. Alternatively, it may be sufficient to classify the semi-constants into normal week-days, Saturdays, Sundays and public holidays.

In simulating x(t), the computer generates pseudo-random numbers F_{re} and F_{im} according to the appropriate distribution, and proceeds to the computation according to equation (1).

Of course, x(t) need not have this form, nor need it be analytic or continuous. For fine analysis, vehicles may be treated individually, even treating the tyres, engines and exhausts separately if required.

THE GREEN'S FUNCTIONS

The Green's function at a given location, may be determined experimentally by letting a vehicle of sound power 1 pW at a given frequency emerge from the source point at time t = 0; and recording the resulting sound intensity, as a function of time, from $t = 0$ to $t = \infty$. Let $h(t)$ represent such a function. $h(t)$ and all it's derivatives are zero when $t < 0$.

It is not always practical or even possible to measure $h(t)$, so it may be convenient to represent it in terms of its more easily ascertained components.

Let
$$h(t) = \frac{W(t)Q(t)10^{Ae(t)}}{2\pi r(t)^2}. \tag{2}$$

where, $W(t)$ = a multiplier applied to 1 pW sound power at the source, to allow for changes due to speed, gradient etc.

$Q(t)$ = a directivity factor, allowing for the change in orientation of the vehicle as it proceeds along the road.

$r(t)$ = the distance between the vehicle and the observation point at time t.

$Ae(t)$ = the excess attenuation not accounted for by the other factors, dB.

It should be noted that the effect of vehicle speed along the road is implicit in the expression of all the above functions as functions of time rather than of distance and speed. It is, of course possible to express them this way and to introduce further functions giving the shape of the road, vehicle speed and a factor of W depending upon speed. The transformation may be accomplished using subroutines.

It is usual to consider Green's functions as solutions to differential equations with delta function sources. In the cases considered in this paper $h(t)$ need not be analytic and may be discontinuous.

THE CONVOLUTION INTEGRAL

Let the source function be approximated by a sequence of pulses, the strength of which is defined as the pulse area. Thus the strength at time τ is the area $x(\tau)\delta\tau$. The intensity measured by an observer at a given location at time t is $h(t-\tau)[x(\tau)\delta\tau]$. By superpositioning the sum of all such responses is -

$$y(t) = \sum h(t-\tau)x(\tau)\delta\tau.$$

In the limit, as $\delta\tau \to 0$,

$$y(t) \to \int_0^t x(\tau)h(t-\tau)d\tau. \tag{3}$$

Equation (3) may be solved using the trapezoidal rule;

$$y(t) \approx \frac{\Delta}{2}\left[x(0)h(t) + 2\sum_{k=1}^{m-1} x(k\Delta)h(t-k\Delta) + x(t)h(0)\right] \tag{4}$$

where Δ is the integration step size, and m is the number of divisions ($\Delta = \delta t \div m$).

<u>Accuracy</u>
The accuracy of the computed value of y depends upon the value assigned to m. Large m yield high accuracy, but also considerably extends the computation time. This is undesirable where solutions are required for a large number of observer locations. Fortunately, the form of the solution that is required is

$$L = 10\ \ell g\ y(t), \tag{5}$$

a form which does not require great accuracy in y.

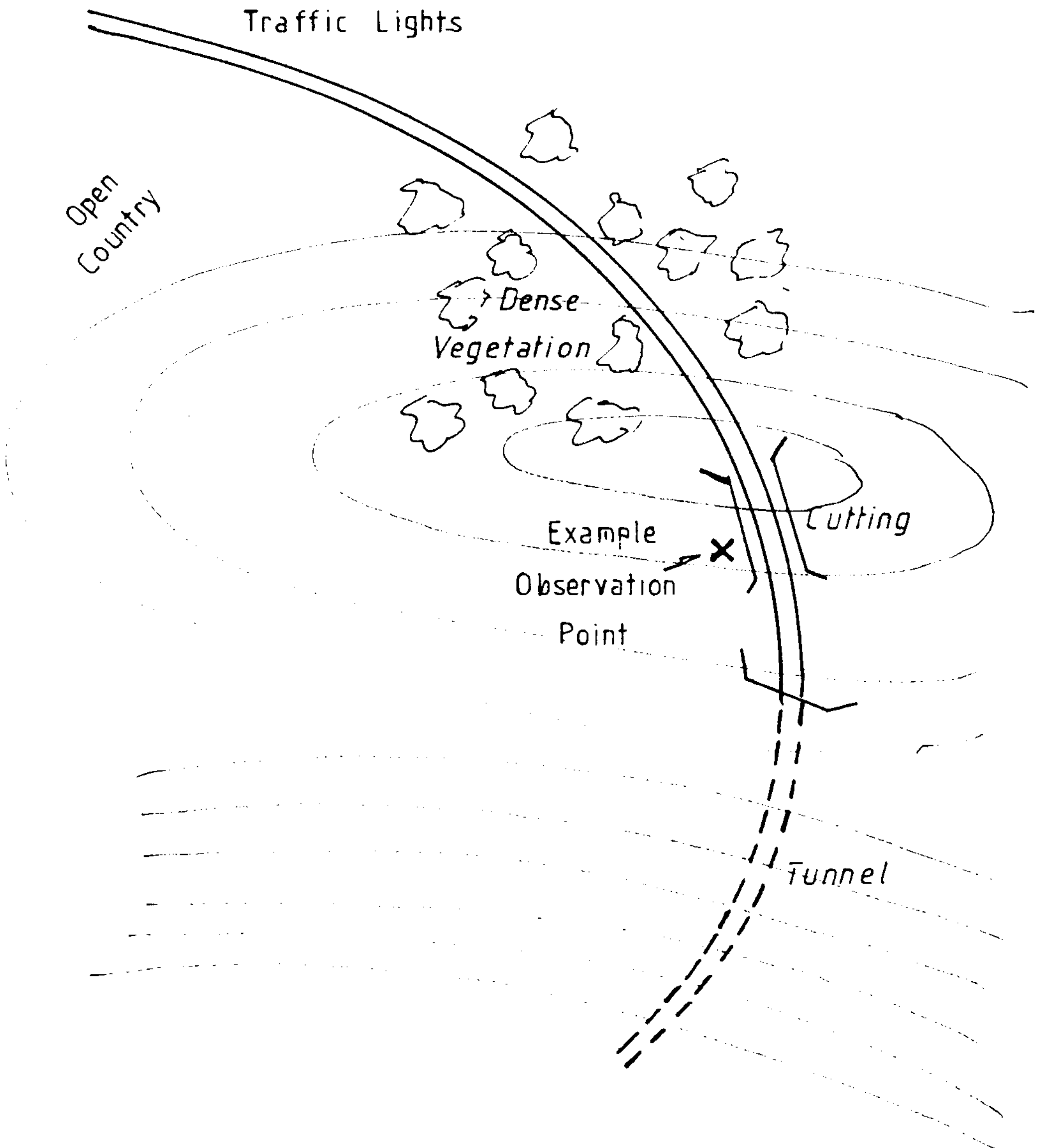

Figure .1. Diagram of Road in Example.

Consider the following example for the road shown in figure 1:-
Let x(t) be approximately represented thus -

n	$F_{re}(n)$	$F_{im}(n)$
0	1.35	0
1	3.94	-1.26
2	-1.06	-7.58
3	-1.06	7.58
4	3.94	1.26

and

$$W(t)Q(t) \approx 1 - \cdot 73t - \cdot 19t^2 + \cdot 73t^3 - \cdot 39t^4 + \cdot 10t^5 - \cdot 01t^6 + \cdot 001t^7$$

$$r(t) \approx 2.22 + \cdot 25t - 1\cdot 58t^2 + 0\cdot 91t^3 - \cdot 23t^4 + \cdot 03t^5 - \cdot 002t^6$$

$$Ae(t) \approx 25 - 63\cdot 4t + 133\cdot 5t^2 - 110\cdot 8t^3 + 43\cdot 7t^4 - 8\cdot 7t^5 + \cdot 87t^6 - \cdot 03t^7$$

$$h(t) = 0, \ t > 7$$

The integration using the trapezoidal rule yielded the following values of y(1) for corresponding values of m, the number of divisions in the integration:-

Table 1
Accuracy

m	y(1)
2	1.33
3	2.33
4	2.19
8	2.25
16	2.26
32	2.27

It can be seen that m = 3 gives an adequate solution when logarithms are to be taken. The first few values of 10 ℓg y(t) are given below:-

Table 2
Computed Results

t, min.	10 ℓg y(t),dB
1	3.7
2	5.3
3	19.8
4	31.0
5	30.0
6	37.9
7	37.0
8	34.0
9	35.8
10	35.8
11	38.8
12	38.3
13	36.2
14	37.4
15	37.4
16	39.7
17	39.3
18	37.3
:	:

Similar computations may be made for different frequencies, or alternatively data may be sufficiently well known for one sequence of, say, A-weighted calculations to suffice.

Usually traffic flows contain light and heavy vehicles travelling at different speeds and with different values of W and Q. The effect of this may be accounted for by separate calculations and superposition of the y(t) values obtained.

ENVIRONMENTAL IMPACT

The values given in table 2 form a time sequence, for the observer's location, which corresponds with a given time sequence at the source location.

As a first approximation, the environmental impact of the given traffic flows at the observer's location may be given by:-

$$L_{E.I.}(t) = 10\ \ell g \left[\frac{y(B)+y(t)}{y(B)}\right] \qquad (6)$$

where $10\ \ell g\ y(B)$ = background sound level.

The equivalent continuous level of the impact can then be calculated from the sequence represented by equation (6).

Loudness level computations are necessary if environmental impact statements are to give the public an idea of relative loudness levels. They are also required for accurate work. The Zwicker [2] procedure for non-diffuse sound is generally applicable to this representation of the results.

Interpolation

A distinction needs to be made between two problems which arise in the assessment of the acoustic environmental impact.

One problem is to assess the environmental impact resulting from a given or design set of Aes, for example, one may wish to ascertain the effect of a design temperature inversion, or some given wind profile. In such cases, all the values of Ae may be established in advance.

In the second problem, Ae is known (perhaps by measurement) for a number of critical locations, but not for all locations. Furthermore, it is desired to estimate the values of Ae for the other locations so as to calculate most likely sound levels there. Although it may be feasible to interpolate values of Ae, an alternative which greatly reduces the computation time is to interpolate the final values.

CONCLUSIONS

With automatic computing facilities, the methods of this paper are both accurate and simple. They may be applied to the determination of long-term effects or short-term effects, such as the effects of different schedules for traffic lights, etc. These methods apply equally to highway, rural or urban traffic; to road, rail and air traffic. The convolution integration, however, will find most use in road vehicle traffic noise analysis.

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DEVELOPMENT OF A COMPUTER-BASED TRAFFIC NOISE PREDICTION MODEL FOR APPLICATION TO URBAN PLANNING AND DESIGN

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INTRODUCTION

The National Capital Development Commission has the sole responsibility for planning, design and construction of Canberra. Central to its consideration of traffic noise has been the application of a predictive methodology with which to assess different development proposals. Until recently, the Commission has utilised a manual procedure developed by the United Kingdom Department of Environment for prediction of the 18 hour L10. The application of this manual procedure across a large number of diverse projects, and a range of design options, proved to be particularly inefficient. In order to improve both efficiency and accuracy, the Commission in late 1984 engaged the Australian Road Research Board to develop a computer-based predictive model based on the DOE procedure, but designed to provide flexibility in evaluating different problems in urban planning and design [1].

This latter feature was especially important for the Commission. It is manifest as a key element of the computer package, namely the ability to selectively and iteratively interact with the data base via terminal facilities.

The paper outlines in some detail the particular areas of application for the computer package, together with a specific example of its use. This is preceded, however, by an outline of the structure and procedures of the computer package as established by the Commission.

MODEL STRUCTURE

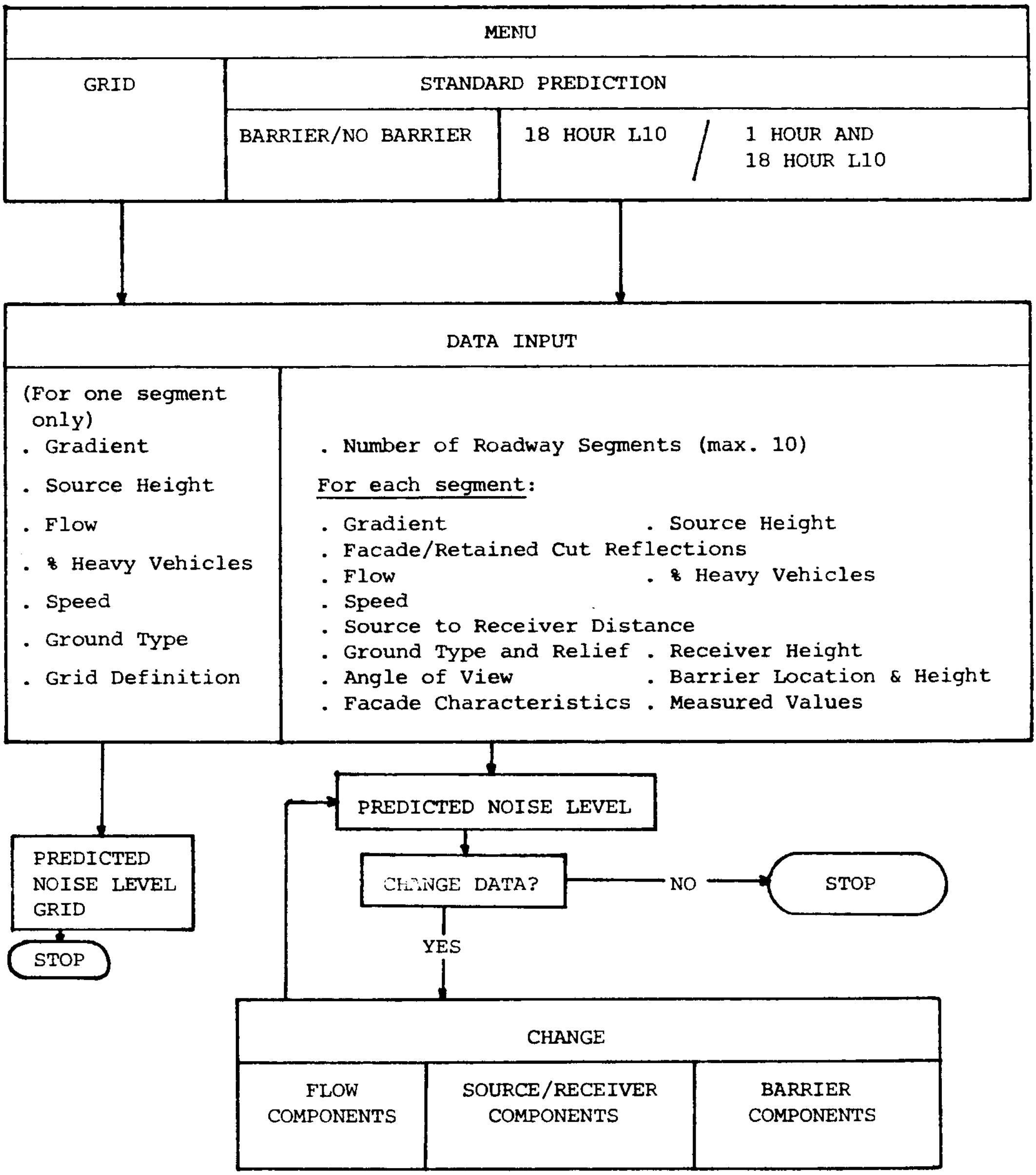
It is not intended in this paper to detail the various algorithms that make up the UK Department of Environment methodology on which the computer package is based. This is adequately described elsewhere [2].

Essentially, the UK Department of Environment methodology establishes a base noise level at the source, determined initially by traffic volume and corrected for features such as traffic speed, the percentage of heavy vehicles, road gradients or the presence of reflective surfaces. The noise level at the receiver may then be predicted by determining the attenuation of the base level due to the distance from the source to the receiver and the height of the receiver in relation to the source. Additional factors may also be taken into account such as whether the intervening space is 'soft, such as grassland, or 'hard' such as bitumen, and the effect of barriers, created for example, by cuts, mounding or walls.

Applying this methodology, the computer package established at the Commission is designed to allow a user to enter data via a terminal using a question and answer format and to obtain at the terminal a predicted noise level. In addition, however, the model includes the facility to then alter one or more of the data inputs, without having to re-enter <u>all</u> the data again. This allows the model to be used in an iterative manner.

The structure of the model is shown in Figure 1. The user is initially presented with a menu that requires a choice to be made between a standard

FIGURE 1. STRUCTURE OF THE PREDICTIVE MODEL



prediction and setting up a simple grid for production of noise contours. The vast majority of cases examined within the Commission require application of the standard prediction. Where this option is pursued, a choice is also available between predicting an 18 hour L10 value, or combining this with the prediction of 1 hour L10 values through the 18 hour period.

Execution of a standard prediction necessitates data input in a question and answer format. The data defines the number of segments to be considered, and the character of the noise source, the reception point, the relative spatial relationships of the source and reception point and the character of the space between the two.

In this sense, the model follows the basic content of the UK Department of Environment methodology. However, because of the Commission's interest in influencing or even undertaking house design in relation to traffic noise, the study brief required prediction of internal levels to be built into the computer package as an option. Where this option is taken up - for example, in establishing different designs of government housing - internal levels may be determined by user-definition of facade characteristics in terms of window-to-wall area ratios and whether windows are assumed open or closed.

Perhaps the most important facility from a planning/design viewpoint provided by the model is the ability to alter individual data inputs at the terminal without recoding a complete new data set. Initially, the user nominates whether or not changes are to be made within three broad data sets relating to FLOW components, SOURCE/RECEIVER components and BARRIER components. The parameters that fall within each of these data sets are summarised in Table 1.

TABLE 1. COMPOSITION OF DATA SETS ACCESSIBLE THROUGH THE CHANGE FUNCTION

	DATA SET		
	FLOW	SOURCE/RECEIVER	BARRIER
Parameters Accessible	. Traffic Volume . Percentage of Heavy Vehicles . Traffic Speed	. Distance Source to Receiver . Intervening Ground Type . Intervening Ground Relief . Height of Receiver . Angle of View	. Distance from Barrier to Receiver . Height of Barrier

Where the user has indicated that changes to a particular data set need to be made, the specific data items that are to be altered within that set are then identified. For each of these items, the model presents the value currently held in the data bank and requests the user to nominate the replacement value. The model then computes a new predicted noise level on the basis of the revised data. This process may be repeated as many times as the user requires. For each test the data input and the computed noise levels are stored in a tabular format which may be examined at the terminal or sent to printer facilities if hard copy is required. An example of the output as it appears on the terminal is given below in Figure 2.

FIGURE 2. TYPICAL TERMINAL MODEL OUTPUT

```
L10(18HOUR) DB(A)
EXTERNAL PREDICTED            64.1
         MEASURED               .0
         CORRECTED            62.4
95% CONFIDENCE LIMITS
ON CORRECTED VALUES           57.4 TO 67.4

INTERNAL PREDICTED VALUES - CORRECTED
W/W 1:8 PART OPEN WINDOW      41.9
W/W 1:4 PART OPEN WINDOW      43.9
W/W 1:2 PART OPEN WINDOW      46.9
```

As can be seen, the output includes for external areas:

- a predicted level, which is the direct result of the predictive methodology;
- a corrected level, based on an adjustment to the predicted level determined by ARRB for the model's application in Australia;
- record of any measured values that may have been taken and inserted for comparative purposes; and
- 95% confidence limits, again based on the ARRB's assessment of the application of the original predictive methodology in Australia [3].

Where internal levels are predicted, the output lists the values derived for each of three facade types nominated by the user.

MODEL APPLICATION

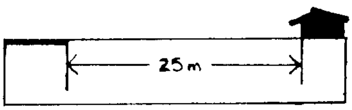
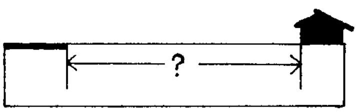
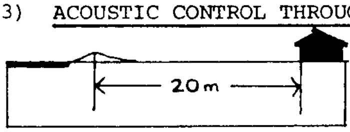
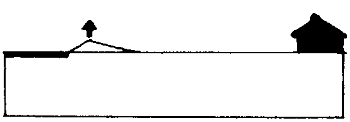
The model may be applied to a wide variety of situations where traffic noise is an important planning and design element. Typically, these may encompass the impact of new arterial roads in residential areas and the need for and design of acoustic barriers. Alternatively, the objective may be to determine the appropriate location and design of proposed housing near an existing major road. In this case, the model may be applied to examining matters of detailed design relating to courtyard walls, unit height and orientation and facade design. For the purposes of this paper, however, it is the first of these situations that will be used to demonstrate the model's application.

The example used envisages assessing the implications of locating a new major arterial road near existing detached housing. The problem is in essence to ensure that the Commission's guideline of 65 dBA is not exceeded, and the analysis begins by assessing an initial design against this value. The subsequent steps in the assessment are summarised in Figure 3.

The problem of reducing noise levels was addressed in terms of either increasing setback distances or constructing acoustic mounds. In the former case, the CHANGE facility was used to access the SOURCE/RECEIVER data set within which the effect of different noise source-to-receiver distances could be tested. This was done until the noise level predicted met the guidelines at a setback distance of 65 metres.

The second option of using acoustic mounds necessitated defining both the appropriate location and height of a mound which would achieve the guideline. This was done by using the CHANGE facility to access the BARRIER data set and insert initial values for these two factors. The CHANGE facility is then used

FIGURE 3. MODEL APPLICATION: ASSESSING THE IMPACT OF A MAJOR ARTERIAL ROAD ON EXISTING HOUSING

DESCRIPTION	PREDICTED LEVEL
(1) INITIAL SITUATION  For existing housing, insert data for an initial situation with the proposed road carrying 30,000 vpd 25m from housing	70 dBA
(2) ACOUSTIC CONTROL THROUGH SETBACK  With the above data bank in place, use the CHANGE facility to access SOURCE/RECEIVER data set and test the effect of increasing the distance noise source to receiver: 35m 65m	 68 dBA 65 dBA
(3) ACOUSTIC CONTROL THROUGH MOUNDING  Use CHANGE facility to access SOURCE/RECEIVER data set and restore original distance from road to house to 25m, then access BARRIER data set and test initial mound location and height. Distance Barrier to Receiver = 20m Barrier Height = 1m	68 dBA
 Use CHANGE facility to access BARRIER data set and for the above barrier location test increasing barrier heights: 1.5m 2.0m	 66 dBA 64 dBA

to insert new values for the mound height within the BARRIER data set until the guideline is met.

CONCLUDING REMARKS

The principal purpose of this paper has been to broadly describe a computer-based model based on a recognised predictive methodology but set up in such a way as to be readily usable by designers for whom traffic noise must be integrated into project development on a routine basis. This is achieved by emphasising the interactive character of the model, in particular the ability to rapidly test the effect of changing selected items within the data base. Use of the model within the Commission in recent months has already demonstrated the significant improvement it bestows in both the efficiency and accuracy of noise evaluations.

ACKNOWLEDGMENTS

The authors wish to thank the National Capital Development Commission for permission to present this paper. The views expressed are those of the authors and are not necessarily endorsed by the Commission.

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INTEGRATING TRAFFIC NOISE INTO URBAN PLANNING AND DESIGN: AN EVALUATION OF OPPORTUNITY AND PERFORMANCE

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INTRODUCTION

Because of the breadth of its responsibilities the National Capital Development Commission is potentially able to exert considerable infludence on the consideration of traffic noise during urban planning. The Commission is responsible in its entirety for the planning, development and construction of Canberra as Australia's National Capital. As such, it may integrate traffic noise into the planning of new roads, the character of residential sub-divisions and the design of housing.

The purpose of this paper is not, however, to simply outline the opportunity available to the Commission. Rather, it is intended as a critical analysis of the consideration of traffic noise within a corporate planning and development framework. It is directed at improving the understanding of the various factors that determine the ability to control traffic noise; factors that for convenience may be considered in terms of the technical basis for noise assessment and control and the planning process within which it exists.

OPPORTUNITIES

Commission Planning and Development Powers

By an Act of the Australian Parliament, the Commission has statutory responsibility for the planning, development and construction of Canberra. As such, it is the sole organisation that engages in these activities in the ACT. In practical terms, this centralisation of responsibility permits greater co-ordination in the planning and construction of the different elements of urban infrastructure.

This control is enhanced by all land in the Australian Capital Territory being owned by the Crown and occupied through leasehold tenure. As such, there is no freehold title.

The Commission is responsible for determining the strategic direction of metropolitan growth and then for designing the urban infrastructure to achieve that goal. The latter involves the structure of new towns, the nature of residential subdivisions, the location and design of major roads and the location of commercial and institutional centres. With the exception of private-sector development of specific property, the Commission is responsible also for land servicing and road construction, as well as for construction of government housing. Private sector development is controlled through imposition of lease and development conditions.

Clearly such a situation bestows considerable benefits. It allows, during the planning phase, the systematic consideration of all the elements that constitute the traffic noise problem. It facilitates the influence of housing design by the private sector in the vicinity of traffic noise, and in the case of government housing, presents the specific opportunity to apply acoustic protection principles to actual house design.

Commission Urban Design Philosophy

Canberra's metropolitan growth in the last twenty years has reflected the underlying principle of developing separate new towns, each supporting a major employment centre, yet closely linked via a system of high-grade peripheral freeways. The disaggregation of employment centres and the ability to route high-volume inter-city traffic away from residential areas have obvious benefits from a noise viewpoint. Within new towns, similar principles have been applied that enhance the ability to reduce traffic noise intrusion.

Most significant amongst these is the separation created between residential areas and major traffic routes by the adoption of a well-defined road hierarchy. This separation assists construction of effective barriers since it constrains direct access from adjacent housing. Definition of road corridors as a formal land use also ensures reservation of areas within which road design and acoustic protection can proceed unconstrained by other activities.

Institutional Character and Process

Commission Composition and Structure. The composition and division of responsibilities in the Commission reflect its comprehensive control over planning and construction. It displays an arrangement of town planning, architecture, engineering, construction and programme management in a line arrangement of planning, design and construction.

Involvement in traffic noise varies. Engineering Division, for example, includes the Environment Section which has overall responsibility for noise and Transport Branch, responsible for design and construction of arterial roads. Traffic noise is also considered by the Planning Division in subdivision layouts and release of development sites to the private sector, and by Architecture Division in the design of government housing.

Within this framework, the Environment Section is responsible for developing the Commission's technical base in traffic noise. This involves remaining up to date with scientific information on the one hand, and providing advice on traffic noise to other groups within the Commission on the other. This advice is premised on traffic noise guidelines and involves assessing particular projects - including roads, subdivisions and housing - for their ability to meet these guidelines.

Commission Planning Processes. Incorporation within the Commission of different groups influencing traffic noise is clearly advantageous, but also raises the problem of co-ordination. For this reason, considerable emphasis is attached to the involvement of all interested parties during project formulation, including a feedback link from construction to planning and design. Commission agreement must be sought at key points throughout the planning, design and construction phases, and potential conflicts in objectives evaluated prior to seeking Commission endorsement.

The planning process as it relates to noise must be considered in terms of the three principal elements, namely, the road, the development site, and the housing. The relationship between these three is brought together, at least in general terms, through Commission policy and Development Plans. These are non-statutory, and set out the physical relationship between major road corridors and adjoining land uses. In areas such as new towns, all these elements may be considered together in the planning stage, even if subsequently construction occurs at different times. In older areas of Canberra, Policy and Development Plans for new or re-developed sites must take the existing road system as given.

The design and construction of major roads is administered by the Commission. In contrast, influence over the location and character of adjoining housing is limited.

For detached standard housing, for example, traffic noise may significantly influence the planner's decision about the overall location of the subdivision, but have little bearing on the character of the housing subsequently constructed by the private sector. Several exceptions exist, however. For sites identified for townhouse development, for example, the Commission may incorporate in development conditions limits on unit heights or requirements for courtyard walls. For government housing, the consideration of traffic noise may extend through site selection and definition to encompass unit layout and design as well.

PERFORMANCE

Components of Success or Failure

The breadth of the Commission's powers has very positive spin-offs in the field of traffic noise. Many examples exist where measures taken to control traffic noise intrusion are very successful. It may be argued, however, that success or failure should not be judged solely on the criteria of whether or not measures have been taken to control noise and whether or not they have been effective.

Several other criteria must be considered as well. Poor performance can be considered to exist, for example, where excessive investment occurs in noise control or where existing noise protection is subsequently under-utilised or compromised by development. Overall, we are concerned with two broad components; those that relate to cost-effectiveness in the provision of noise control and efficiency in its subsequent use. The following section examines the factors that determine the degree to which these occur.

Factors Affecting Performance

Four broad components may be identified that influence performance. These are:

- the status afforded noise issues at a corporate level;
- the quality of the technical base for evaluation;
- the institutional processes that effect integration and co-ordination; and
- the attitude and control of the private sector.

Corporate Status of Noise. Within any organisation, the importance attached to traffic noise as a corporate objective significantly affects the ability to implement detailed noise controls. Recent experience emphasises the important distinction that may be drawn, however, between accepting guidelines at a working level and supporting their "elevation" to corporate status. The latter is seen by those affected by the guidelines as reducing flexibility in an area traditionally viewed as increasing costs and constraining developments.

In effect, Commission acceptance of guidelines has been premised on the specific exclusion of noise from the corporate policy arena and operation of the guidelines as one of a number of factors to be considered in the planning and design process.

Nevertheless, gaining formal acceptance by the Commission of noise guidelines must, in the context of earlier attempts, be seen as a success. Its benefits extend beyond having the weight of formal acceptance to the educational spinoff that has arisen during the process of having the guidelines accepted. On the other hand, failure to gain recognition of a traffic noise policy in any form is a very clear statement that priority is to be given to retaining flexibility.

Quality of Technical Base. The Commission is not a research organisation and therefore relies greatly on remaining up to date with current technical practice in the fields of noise measurement, development of planning guidelines and application of analytical techniques.

The Commission's guidelines are as follows:

DEVELOPMENT TYPE	LOCATION	18 HOUR L10 (dBA)
Standard Detached Housing	Building Line	65
Medium Density Housing	Private outside space	65
	Internal	45

Several comments can be made. The level of 65dBA for detached housing was first adopted in 1974 and drew heavily on experience in the United Kingdom. Those set down for medium-density housing were formulated in the late 1970's, but have only recently been accepted by the Commission. This has not been a straightforward exercise. The reluctance to formally ratify the guidelines is significant given strong evidence that the guidelines should be further reduced to a maximum level of 60dBA.

Achievement of the guidelines is greatly influenced by the degree to which affected groups in the Commission perceive their application in a constructive light. For this reason, considerable effort is being put into producing a schematic design manual for achieving the guidelines. In practical terms, however, it has been the introduction of a computer-based predictive model which can readily evaluate detailed design changes that has most significantly improved the "visibility" of noise as an issue. A perceived improvement in the degree of sophistication and an ability to respond rapidly have proved to have excellent advertising potential. There is no doubt that, for a multi-disciplinary group such as the Commission, effort given to translating the technical base into a useable format for designers is particularly productive.

Institutional Attitudes and Processes. Existing procedures rely to a significant degree for their effectiveness on the awareness and understanding that individuals have for traffic noise. Consequently, an onus is placed on the Environment Section to both scrutinise other Divisions' programmes and to educate. Given this situation, and the prominence given to the Commission's development rather than planning role, it is understandable that cases arise where acoustic protection is inadequate. As an urban developer, maximising block or unit turnoff while controlling costs is a primary objective and a strong pressure against implementing necessary noise controls. In other situations, the cause may simplay be a failure to seek advice.

It is interesting, however, that examples of poor cost-effectiveness exist where acoustic controls are implemented that are either excessive or unwarranted. These situations may arise where mounds are built along new arterial roads, without taking into account the specific physical relationship between source and receiver. This may occur where for design reasons, mound heights are standardised or where nearest residences are so far from the road as to derive minimal benefit when compared to the effect of distance.

In many cases, construction of arterial roads and adjacent subdivisions may not occur at the same time. From the viewpoint of controlling traffic noise, this exacerbates the problem of achieving co-ordination already posed by responsibility for these activites being split between Divisions. Examples exist where mounding built during road construction may be subsequently compromised by housing development that overlooks the mounds without compensating acoustic controls incorporated in unit design.

Role of the Private Sector. Limits exist on the degree to which the Commission can oblige private developers to take traffic noise into account. Experience suggests, however, that private developers are not particularly disposed to incorporate into dwellings adjacent to major roads sophisticated measures for noise control.

Guidelines for detached housing stipulate levels for external areas only. This reflects the fact that the Commission's design and siting policies do not enable control over the acoustic performance of a particular dwelling. It is, in essence, up to the developer to recognise the need for architectural controls to meet acceptable internal levels of noise.

Because the Commission is able to stipulate development conditions when releasing a site for multiple-unit medium-density development, this form of housing offers more potential for controlling developers. For example, development may have height restrictions imposed or may have to include courtyard walls. Controls do not extend, however, to unit design, so that developers cannot be obliged to adopt facade controls such as closed windows or double-glazing. This has proved to be an important limitation given the release of large numbers of sites adjacent to major roads for multi-storey townhouse or flat development. It has highlighted the need to ensure the availability of advisory information to developers at an early stage in design.

CONCLUDING REMARKS

There is no doubt that the issues raised in this paper will be familiar to those concerned with applying traffic noise control in a planning, design or development control organisation. In this sense, many of the problems identified will not be new. The Commission overall has been very successful in dealing with traffic noise, a reflection of bringing to bear the considerable potential for co-ordination inherent in the ACT planning system. Constraints on this potential do exist, however, and it is important that they are recognised. The paper has highlighted the need to recognise the influence on performance of not just the quality of the technical base, but corporate processes and professional attitudes as well.

ACKNOWLEDGEMENT

The author wishes to thank the National Capital Development Commission for permission to present this paper. The views expressed are those of the author alone.

CONTRIBUTED PAPERS

STREAM B

MOTOR VEHICLE NOISE

EXHAUST SYSTEM MANUFACTURING FOR A QUIETER ENVIRONMENT

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INTRODUCTION

In keeping with the sophisticated design of modern high performance engines the techniques of exhaust system design have also advanced. It is no longer a trial and error approach but a highly scientific exercise to design a system to meet all criteria.

Basically the requirements of an exhaust system are:
1. To provide the means of dispersing the waste fumes and gases from the engine without impairment to the vehicle's performance.
2. To achieve this efficiently and economically with due regard to society's and legislative requirements on noise.
3. To provide the user with a unit of reasonable life expectancy.

Each vehicle manufacturer provides a basic model with numerous optional power packs, transmissions etc., in order to satisfy customer needs. This means that an exhaust system has to be provided for each model or option, however the variants can be slight.

When the manufacturer has decided upon the engine configuration for a model release, the muffler design then has the following criteria given to him for the proposed exhaust system:

Capacity of the engine and expected power output.
Maximum back pressure allowable.
No resonance throughout the total revolution range.
General package details. These include pipe sizes, muffler sizes, clearance problems etc.
The system to comply with all the Australian Design Rules and State requirements.
The best system for the least amount of money.

No exhaust system or muffler can be designed on paper, nor will a muffler which is acceptable on one 6 cylinder engine be acceptable on a different 6 cylinder engine.

Knowing the engine capacity, pipe sizes and package details the designer calculates the size of the muffler. The calculated size is compatible with ground and body clearances, then a sample is made.

From this point on, the success of the design follows three established procedures or phases. Each is important and dependent on each other.

Phase One:
An engine dynamometer is used allowing the engine to be operated on a "No Load or Controlled Load Conditions". Engine pipe or pipes having the same diameter and length as the proposed system are fitted and a test muffler installed. By means of a dual valve system, two mufflers can be tested at the same time under identical conditions. Temperature gradients, firing frequencies, sound emission, engine output and system back pressure are studied, analysed and evaluated and the necessary design changes are made to the prototype system.

Phase Two:
The prototype system is fitted to a vehicle and a rigorous test programme is undertaken. This programme can be carried out using "on road" testing or simulated road conditions by a chassis dynamometer. Vehicle performance and system backpressure are again recorded. Body resonance, vibration and exhaust noise are analysed and evaluated. Sophisticated accoustical measuring, recording and analysing equipment are used.

Phase Three:
As a result of phases one and two, functional systems are made and fitted to a vehicle for prove-out by designer and customer. This involves town and country driving and the durability testing on car company proving grounds where final acceptance on performance and durability is made.

Here, like many other parts of a modern motor car, exhaust system durability is a continuing challenge. Corrosion resistance is an equally important factor as is mechanical strength. The recent proliferation of models and/or engine combinations has enlarged the problem. In normal combustion of fuel, acids are formed and include such corrosive agents as sulphuric, hydrochloric, sulphurous and hydrobromic acids. Driving habits and environmental conditions play a big part in the life span of an exhaust system. It is an established fact that the exhaust system life is inversely proportional to the mileage - the longer the trip the higher the operating temperature and therefore a reduced level of attack by corrosion mixtures.

Since the advent of the automobile as a means of transport, considerable research and development has gone into the improvement, performance and life of the exhaust systems. There still remains the fact that exhaust systems for the silenced road car cannot be designed beforehand. There is no text book or mathematical formula to give a guaranteed result. At all times, theory, background knowledge and the use of modern analytical equipment blend together to develop the system. However, we are getting closer. The introduction of CAD CAM, Computer Assisted Design and Computer Assisted Manufacture, have improved our performance in this area.

The Customer Model:
As is the case with many components which go to make up a motor vehicle, the exhaust system is, by necessity, a compromise brought about by the requirement to satisfy a number of conditions, which to some extent, are in direct conflict.

In both the design and manufacture of an exhaust system or exhaust component, the conditions, that is, the performance, fitment reliability, durability and appearance requirements must be determined, specified and satisfied.

Essentially the conditions to which we are referring are illuminated in what we call the "Customer Model". A typical customer model of an exhaust system is shown on Fig.1.

Manufacturing:
Although most of the conditions described in the customer model are design-related, achieving the intent of product design by ensuring all model conditions are met is the responsibility of manufacturing. In order to satisfy the customer model, a prerequisite of manufacturing must be the thorough planning out of process inputs such as methods, equipment and tooling together with process controls to ensure conformance.

FIG.1

CUSTOMER MODEL

PERFORMANCE

- Possess noise attenuation properties when fitted to the un-modified, designated vehicle, legal noise limits are met.
- Exhaust noise should meet the subjective approval of the vehicle's occupance under normal driving conditions.
- Exhaust gas leaks should not be audible, internall or externally.
- Exhaust noise should increase linearly with engine speed.
- Vehicle floor surface temperature should not exceed 50°C.
- Muffler should have adequate ground clearance.
- Vehicle must be free of vibration as senced in the vehicle body and seat.
- Should result in a minimum reduction in engine performance (<5%).

FITMENT

- Should be easily fitted, without special tools.
- When fitted correctly should not rattle or foul other parts of the vehicle under normal operation.

RELIABILITY

- Exhaust components should not rattle internally burst or fail mechanically under normal operation conditions.
- Exhaust components should not cause blockage or exhibit any reduction in noise attenuation during normal in-service life.

DURABILITY

- Engine pipes should have a service life of 5 years (75,000km).
- Muffler and tail pipe should have a service life of 2-4 years.

APPEARANCE

- The product must be rust free, no dents or damage.
- The outlet of the system should be compatible with the rear of the vehicle.
- The system or component must look the same as the one it's replacing.

- MUST BE READILY AVAILABLE.
- MUST BE REASONABLY PRICED.

EXHAUST SYSTEM MANUFACTURING FOR A QUIETER ENVIRONMENT

Whilst the establishment of a manufacturing process, through the development of a method and the preparation of tooling is virtually a "one off" activity, control of manufacturing process to ensure the product conforms to specification (satisfies the customer model) is very much on going.

Quality Assurance:
In order to ensure conformance of the manufactured product a "Process Control Plan" must be developed.

Tolerances and controls based on outcome measurements at the point of manufacture together with independent monitoring consideration are formally developed and recorded on the "Process Control Plan". The Process Control Plan places a strong emphasis on the measurement and control of process outcomes at the point where they are created, it serves to identify applications for statistical process control which are subsequently developed and implemented. Means by which defects are prevented are identified on the plan and supplemented by "Point Charts" so that those people who are controlling the processes such as operators, tool setters and leading hands know the requirement. The plan shows who is in control of the process, the means by which the outcome is assured and the method and by whom the process is monitored.

Quality monitoring and product performance testing is carried out in accordance with requirements specified in the Process Control Plan. Reliability and durability performance test methods and frequencies are developed to meet product requirements.

A quality control system, such as one that meets the requirements of Australian Standard AS1821, with definitive control procedures is vital in a quality and cost effective manufacturing operations. Areas such as employee involvement and good communications must become a discipline and be continually pursued.

Exhaust System Durability.
The area of most concern to an exhaust system designer and certainly one that troubles a vehicle owner is the durability of the product, which in the main, means its resistance to corrosion.

The exhaust system of a motor vehicle is exposed to two environments; externally to atmosphere and internally to exhaust and its combustion products.

External or atmospheric corrosion is of little consequence due to our Australian climate, whereas internal corrosion is the exhaust manufacturer's biggest enemy. The internal surfaces of an exhaust system are exposed to a particularly corrosive environment.

Analysis of exhaust condensates have found three types of corrosive acids to be present:

1. Nitric Acid: Formed by atmospheric nitrogen taken into the engine and converted to various oxides of nitrogen.

2. Sulphuric or Sulphurous Acids: Occurring as a result of fuels and lubricating oils containing sulphur, which forms sulphur dioxide and trioxide, which in turn, combines with water vapour.

3. Hydrobromic Acid: To overcome the problem of the anti-knock additive, tetraethyl lead, forming a lead compound deposit in the combustion chamber, ethylene dibromide which is added to remove the lead via the exhaust,

promotes the formation of Hydrobromic Acid.

A recent study of exhaust condensates taken from a random sample of 26 in-service passenger vehicles (engines both hot and cold) showed a pH range of 3.2 to 7.2 with an average reading of 4.2. The pH for 4 cylinder engined cars was significantly lower with a range of 3.2 to 5.4 and an average of 3.8.

The temperature of the system is another vital factor governing internal corrosion, the dew point of exhaust gas is in the region of 95°C. Hence, if the ambient temperature, or the vehicle is used in such a way that the system never really becomes hot, the rate of corrosion is dramatically increased. The location of a muffler or resonator within the exhaust system makes a major contribution to corrosion resistance with regard to the temperature factor.

With the two factors which cause corrosion, composition of condensate and temperature, being under the control of the vehicle maker, the exhaust system manufacturer must apply his design skills to minimise their effects.

Corrosion generally begins at the rear of a system (the coolest part) and progressively moves forward. The most vulnerable parts being perforated or louvre tubes in the case of absorption type mufflers and end plates in mechanical or expansion type silencers.

To combat corrosion, designs and materials used in the best combinations are constantly being examined. Designs that ensure chambers within the muffler retain heat and evacuate condensates are essential. A safety margin that can permit absorption material to become depleted without affecting noise attenuation, together with mechanical strength properties that will allow internal components to corrode without leaving lose or failed joints to rattle or mufflers break and fall off in the street, must be employed.

As far as materials are concerned aluminised mild steel still exhibits the best properties for acid corrosion resistance, mechanical forming and welding for the manufacture of economical steel exhaust systems.

Our product is becoming more sophisticated caused by a variety of influences from the changes in engine technology to the advent of legislation, the most dramatic being the introduction of catalytic convertors in January 1986.

At the same time, our market is changing - gone are the days when 10 part numbers would cover 80% of the range required. We now have to look at supplying some 85 model types in passenger cars alone, add to this the product variants, a further 25 versions in station wagon and a further 70 passenger car derivatives and light commercial vehicles and you will begin the perceive the extent of the vehicle market. There is then the medium and heavy duty range of trucks. In actual fact, we cover some 861 model variants in our catalogue. The consequence of this market size, is a proliferation of manufacturers and product all competing for a share of a market which is only increasing marginally in volume.

With such competition self regulation is impossible. We can devote time to researching and developing new products, testing for back pressure, sound levels, with stationary and drive by testing, noise spectrum analysis to ensure no resonance in the range, only to have the products copied the following week in a low cost version, using fibreglass to attenuate the noise.

The low cost version is then sold, without the benefits of product testing, quality assurance procedures and eventually, fails.

To add insult to injury, twenty five percent of the market is covered by imported product, sourced from developing countries as far away as Brazil, to our neighbours, New Zealand and the Philippines. The insult comes in the form of 15% duty, the injury because the product is made to a specification which does not necessarily comply with the long term objectives of State legislation for noise levels.

Physical Distribution:
Our product reaches the consumer through a variety of outlets, essentially however, we supply to two main areas, the exhaust specialist and the Repco Merchant Group. The Repco Merchant Group in turn distributes through the various state systems to retail, trade, reseller and specialist to ensure the product is readily available.

Conclusion:
The future of the exhaust systems manufactured in Australia is dependent on the factors of:

*Economics of manufacture in a high labour cost environment.
*Access to appropriate materials, currently aluminised material is fully imported from Japan.
*Effects of on-costs such as Workers Compensation, Payroll Tax, shift penalties, and wage benefits.
*Limiting imports particularly from developing nations.
*Legislation on noise levels which could preclude current designs.
*Local manufacture of motor vehicles.

We in the manufacturing sector want to continue with the highest possible standards, however, the need to manufacture is being eroded and unless we have in-service enforcement of noise legislation and a government committed to improving the environment then we are a small voice in the country crying the very familiar protectionist measures.

THE ROLE AND RESPONSIBILITY OF THE MUFFLER FITTER IN MAINTAINING VEHICLE EXHAUST SYSTEMS

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INTRODUCTION

The Environment Protection Authority of Victoria (EPA) has a program of testing the noise levels of in-service motor vehicles. The aim of this program is to reduce the noise disturbance caused by individually noisy vehicles which are used on the road. These vehicles contribute significantly to the overall disturbance caused by traffic noise [1].

Vehicles which are observed by the Police or EPA officers are required to be presented at an EPA testing station for testing in accordance with procedures set out in Regulations made under the Environment Protection Act. These Regulations also prescribe maximum permissible noise levels for various classes of vehicles. The owners of vehicles which are required to be presented for testing are given at least two weeks in which to repair their vehicles' exhaust sytems. To this end the EPA advises people to take their vehicles to muffler fitting companies for checking and repairs. Muffler fitters are required by the Regulations to repair exhaust systems so they meet the limits.

The EPA also conducts roadside motor vehicle noise testing with the co-operation of the Victoria Police [2]. To supplement these programs the EPA also conducts a muffler fitter education and liaison program. This paper explains the reasons for the existence of the education and liaison program; the method of operation of the program is explained. The impact of the program and some case histories are analysed.

THE MUFFLER FITTER EDUCATION AND LIAISON PROGRAM

Why Have a Muffler Fitter Education Program?

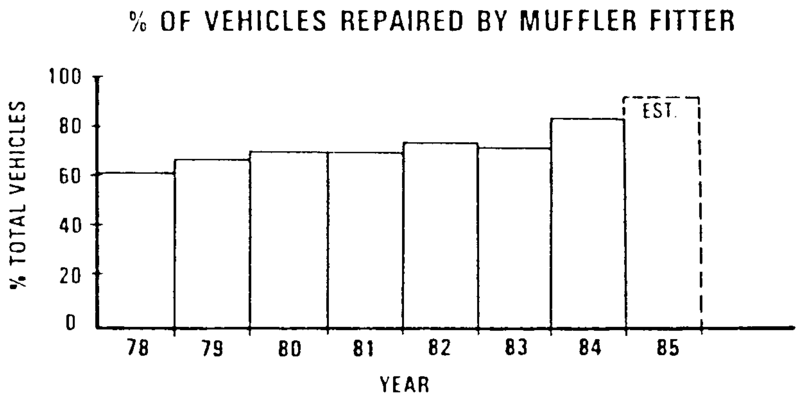
The EPA advises any person who is required to present a vehicle for a noise test at a testing station to take the vehicle to a muffler fitter for checking and possible repair prior to testing. The public's acceptance of this advice is well illustrated by Figure 1 which indicates the percentage of vehicles which are repaired by muffler fitters prior to testing. In 1983 the EPA commenced testing in country areas where little publicity had been given to the program, resulting in a decrease in the number repaired in that year.

In 1983 the EPA conducted a survey of the vehicles called in for testing in the metropolitan area and found that 15% of the vehicles repaired by commercial muffler fitters were still excessively noisy. As a result of this survey EPA initiated a formal muffler fitter education and liaison program. An informal program had operated previously.

The Aims of the Program

The program aims to reduce the number of vehicles repaired by muffler fitters which fail to meet the prescribed permissible levels by increasing muffler fitter awareness of the motor vehicle noise testing procedures and making muffler fitters aware of their responsibilities under the Regulations. The Motor Vehicle Noise Regulation make it an offence for a person to fit an exhaust system which does not comply with noise limits.

FIGURE 1



Method of Operation

The muffler fitter education program is a way of disseminating information to the muffler fitting industry through company visits, seminars and provision of printed testing information.

Early in 1984 the EPA supplied every muffler fitter in the state with a copy of the simplified testing procedures. These procedures are designed to allow muffler fitters to conduct accurate noise tests. Fitters are advised to aim for a level at least 2dBA below the appropriate limit. In addition to this information Technical Officers from the Noise Control Branch of EPA visit the premises of individual muffler fitters. These visits may be of a routine nature, or they may be as a result of a vehicle failing after having an exhaust system fitted by the company. The visiting officers check the muffler fitters sound level meter and tachometer for obvious faults. If the store does not have the equipment the officers advise the manager on the types of equipment available and the names of the companies who supply that equipment. The officers will also check that the manager and/or the staff are conversant with the testing procedures. If the staff of the store do not have a copy of the procedures, the visiting officer will supply the simplified testing procedures and demonstrate the correct testing method. The staff of the muffler fitting store are also given a telephone number for the Noise Control Branch where they can obtain information and/or advice should they require it. The muffler fitters are also made aware of their responsibilities under the Regulations and the possibility of prosecution for breaches of the Regulations. The EPA visits typically 100 to 150 muffler fitters throughout the state each year.

Case Histories

The following cases illustrate the success this type of program can have.

In 1983 a muffler fitter in Melbourne's northern suburbs fitted a number of exhaust systems to vehicles which were due for testing by the EPA. Some of these vehicles subsequently failed to meet the prescribed limit. Following consultation with officers of the EPA and several visits to the premises, the company changed from fitting basically modified exhaust systems to fitting systems which were more standard in layout and started conducting noise tests on all vehicles that were suspected of being noisy. The fitter also reviewed the quality of the mufflers he was fitting and changed to a better quality product. As a result of this change in operation this company has not since fitted an exhaust system which has failed to comply with the Regulations, when tested.

In 1984 a company in Melbourne's eastern suburbs fitted an exhaust system to a vehicle which when tested by the EPA was in excess of the maximum permissible limit. An investigation by EPA found that the company was not being thorough in checking vehicles before they left the premises. As a result of liaison with the manager that company is now more diligent when fitting exhaust systems and testing vehicle noise levels. This company has not fitted an exhaust system which contravened the Regulations since that time.

The manager of a western suburbs company was quite hostile toward the EPA when initially approached as he believed the EPA was interfering in his business. However as a result of discussions with officers of the Noise Control Branch he changed his mind and purchased good quality equipment with which he now conducts motor vehicle noise tests. This company is now one of the most reliable muffler fitters in Melbourne, and regularly uses EPA services to ensure it conducts accurate tests.

It should also be noted that there are a number of muffler fitting companies throughout Victoria which from the date of first contact have been most co-operative and have not fitted any vehicles recently which have failed a noise test conducted by the EPA.

When the Program Fails

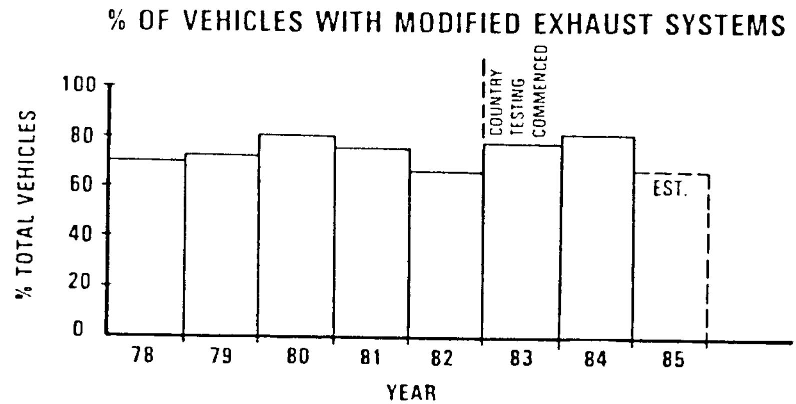
There are some companies who for one reason or another have not or will not accept the advice and assistance offered to them by the EPA through the program. These companies in general continue to fit exhaust systems which obviously do not comply with the Regulations. In cases such as this the EPA uses the powers it has under the Environment Protection Act to take action against these companies for breaches of the Regulations. To date the EPA has successfully prosecuted three companies, and a number of other companies currently face possible prosecution. It is not the EPA's policy to prosecute every breach of the Regulations, but only those cases where the failure margin is large or breaches continue to occur despite all the efforts of the EPA.

Occasionally Magistrates have instructed the EPA to investigate the performance of particular muffler fitting companies in cases where owners of noisy vehicles are being prosecuted.

Indicators that the Program is Having an Effect

As a result of the motor vehicle noise testing program and the muffler fitter education program the percentage of vehicles fitted with extremely modified exhaust systems has been substantially reduced. In the first 6 months of 1985 no vehicle called in for a motor vehicle noise test has been fitted with "side-pipes" or "horn pipes". This contrasts with 8% of the vehicles tested in 1978 having these systems. Figure 2 shows the percentage of vehicles tested that were fitted with non-standard exhaust components. These systems include modified piping layouts, different tail pipes and mufflers fitted to the vehicle which were designed for other types of vehicles.

FIGURE 2



The education program is beginning to have an effect on the way in which muffler fitters fit exhaust system components to vehicles. As stated earlier in this paper, in 1983 15% of the vehicles which had been repaired by muffler fitters prior to EPA testing exceeded the maximum permissible noise level. In 1984 this figure dropped to 13% and in the first six months of 1985 the figure was down to 10%.

As a result of an investigation by EPA one particular type of muffler was redesigned by its manufacturer. EPA will continue to liaise with suppliers and manufacturers of exhaust system components should it become apparent that particular mufflers require redesign.

There are also a number of muffler fitters who advertise that they will conduct free motor vehicle noise tests for members of the public [3], [4]. Muffler fitters throughout the state are now seeing the advantages of conducting motor vehicle noise tests.

The Future Roles and Responsibilities of Muffler Fitters in Victoria

The EPA will continue to liaise with the muffler fitting industry through seminars, company visits and information bulletins.

Muffler fitting stores will continue to be places where the public can obtain accurate advice on exhaust system repair and replacement, and places where the public can obtain reasonably accurate noise level assessments of their vehicles.

In the future muffler fitters responsibilities under the Regulations will be more rigorously enforced. Muffler fitters will still have a significant role to play in the repair and maintenance of vehicle exhaust systems.

THE ROLE AND RESPONSIBILITY OF THE MUFFLER FITTER IN MAINTAINING VEHICLE EXHAUST SYSTEMS

The EPA is currently examining the possibility of establishing approved motor vehicle noise testing stations. Some of these stations will be muffler fitting outlets. These stations will have a formal role in the control of noise from individual noisy vehicles in Victoria.

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TECHNIQUES FOR STUDYING MUFFLER PERFORMANCE

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INTRODUCTION

The design of mufflers for motor vehicles has traditionally been trial and error based. This is still the main method used throughout the world. In this way all sorts of known muffler types may be tested on a particular vehicle and the best type selected for "fine tuning". Various derivatives of this final type, differing only slightly, will then be tested on the vehicle and the final design will be selected on the basis of desired noise level and character, back pressure and estimated manufacturing cost. In this trial and error design process, mufflers using different acoustical principles will be tested, although the designer need not know and usually does not know anything about the acoustical events occurring. Designers can become very skilled in quickly specifying mufflers, aided with years of trial and error experience.

There are significant trends, however, to apply a scientific approach to muffler design. In earlier times such efforts usually followed initiatives from scientists and engineers knowledgeable in acoustics. Mathematical models were prepared which were very limited in their applicability due either to the poor handling of the noise source, or the inability to describe non-linear events or, of course, reliance upon inflexible tables and graphs in the days before computers. A well known example is the N.A.C.A. report by Davis *et. al.* published in 1954 [1]. The theoretical considerations therein were valuable, but mufflers designed and tested on an operating engine performed badly, relative to calculated expectations.

With the advent of the computer and the rapidly reducing cost of very complex calculations, interest in mathematical modelling has been generated within a few muffler manufacturing companies throughout the world. Computer programs developed to date may not be automatically performing complete designs, however, they are increasingly valuable as design aids.

Most such mathematical models are based on a linear acoustic description of the exhaust system. Before considering this approach in detail, however, it is useful to consider the operation of the engine and the method of generation of the exhaust noise, as the adoption of particular methods of analysis then becomes clear.

Source of Exhaust Noise

Figure 1 shows an engine cylinder at a time early in the exhaust stroke, with the piston passing bottom dead centre and the exhaust valve beginning to open. As the pressure in the cylinder is much higher than in the exhaust duct there is a flow through the exhaust port. The unsteady nature of the flow then creates the system of propagating pressure waves in the exhaust system. The action of these, in turn, on the gas within the tailpipe outlet, gives rise to large fluctuations in the outlet velocity and hence radiated noise.

Exhaust Noise Modelling

The flow of gas in the exhaust system may be adequately considered as one-dimensional and so the events in the exhaust system may be described by analyses based on the equations for an unsteady, compressible, one-dimensional

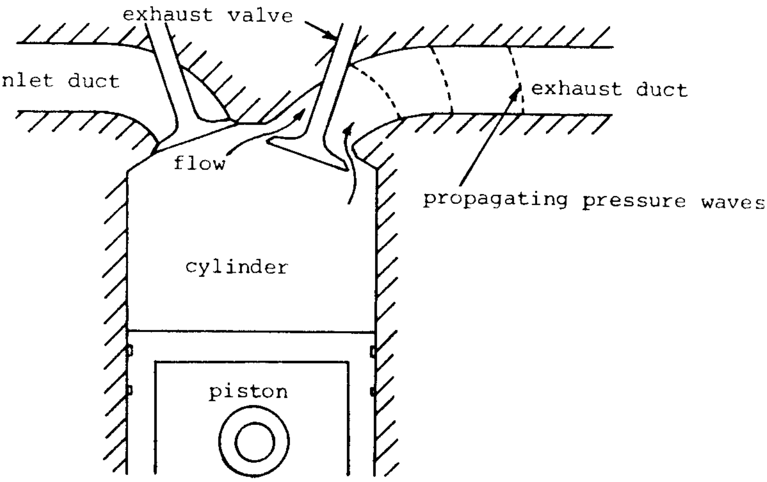


Fig.1 Gas Flow After Exhaust Port Opens

flow in a duct. For the flow in a duct with cross-sectional area A varying slowly in the axial (x) direction, these equations are, from for example, Benson *et. al.* [2] :

$$\text{continuity:} \quad \frac{\partial \rho}{\partial t} + \rho\frac{\partial u}{\partial x} + u\frac{\partial \rho}{\partial x} + \frac{\rho u}{A}\frac{dA}{dx} = 0 \tag{1}$$

$$\text{momentum:} \quad \frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + \frac{1}{\rho}\frac{\partial p}{\partial x} + F = 0 \tag{2}$$

where F is the wall friction

$$\text{energy:} \quad q\rho A dx = \frac{\partial}{\partial t}\left[\left(\rho A dx\right)\left(c_v T + \frac{u^2}{2}\right)\right] + \frac{\partial}{\partial x}\left[\left(\rho u A\right)\left(c_v T + \frac{p}{\rho} + \frac{u^2}{2}\right)\right] dx \tag{3}$$

By using particular numerical techniques, solutions to these equations may be obtained for $u(x,t)$, $p(x,t)$ etc. By matching such calculations of the unsteady flow in the duct to the flow from the engine cylinders, at one end, and to the conditions at the tailpipe outlet, at the other end of the exhaust system, a complete description of the unsteady flow throughout the exhaust system may be found and the radiated noise, for example, may be calculated. Such calculations have been carried out in exhaust noise studies, as reviewed by Jones [3], however they are very complex and greatly simplified methods are available.

LINEAR ACOUSTIC ANALYSIS OF EXHAUST SYSTEM

For a frictionless, adiabatic, one dimensional flow in a constant area duct the above equations may be simplified. By then assuming the flow is isentropic and using perturbation methods, the simplified forms of equations (1) and (2) may be combined to give the wave equation including flow as

$$\frac{\partial^2 p''}{\partial t^2} = (c^2 - U^2)\frac{\partial^2 p''}{\partial x^2} - 2U\frac{\partial^2 p''}{\partial x \partial t} \qquad (4)$$

where p'' is the instantaneous overall acoustic pressure, U is the mean flow velocity and c is sonic velocity based on static temperature. A solution of equation (4) in terms of harmonic waves is

$$p' = A_+ e^{j(\omega t - k_+ x)} + B_- e^{j(\omega t + k_- x)} \qquad (5)$$

where p' is the instantaneous acoustic pressure of frequency ω and k_+, k_-, the wavenumbers of positive and negative going waves, are

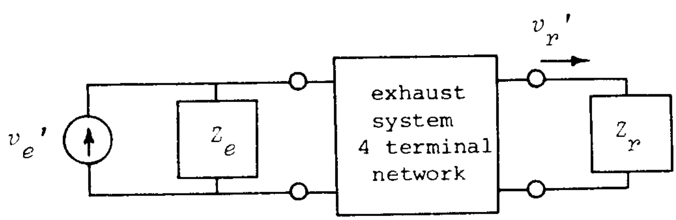
$$k_+ = \frac{k}{1+M}, \quad k_- = \frac{k}{1-M} \text{ for } k = \frac{\omega}{c} \qquad (6)$$

The analysis of the exhaust system is then straightforward as the acoustical performance may be studied at individual frequencies and general principles of linear analysis apply. In a linear model of the complete exhaust system the engine is assumed to be an acoustical source with certain strength and impedance, the exhaust system is a combination of passive acoustical elements and a particular termination impedance is assumed at the tailpipe outlet. For convenience the total system is then studied as an analogous electrical circuit as shown in figure 2.

Transmission Matrix Method

In figure 2 the combination of all the passive acoustical elements in the exhaust system is shown as a two port or four terminal network. This may conveniently be characterised by a 2 x 2 transmission matrix. The means of describing elements in this way is reviewed by Crocker [4].

The transmission matrix representation is advantageous as an individual element of the exhaust system may be represented by a particular matrix and, for a number of elements in series, the overall characteristics of the combined elements may be described by a single resultant 2 x 2 matrix. Thus the entire exhaust system may be described by only one 2 x 2 matrix, for which the values of the matrix elements are, in general, dependent on frequency.



v_e' strength of constant volume velocity source

Z_e engine source impedance

v_r' volume velocity at tailpipe outlet

Z_r radiation impedance at tailpipe outlet

Fig.2 Electrical Circuit Representation of Engine Exhaust System

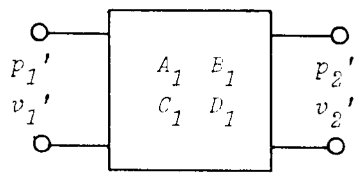
This method of element combination may be followed with the aid of figure 3. Here the acoustic pressure and volume velocity upstream of an element, p_1' and v_1', are related to the downstream values p_2' and v_2'. For the single element of figure 3(a) we have the matrix equation

$$\begin{bmatrix} p_1' \\ v_1' \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \begin{bmatrix} p_2' \\ v_2' \end{bmatrix} \tag{7}$$

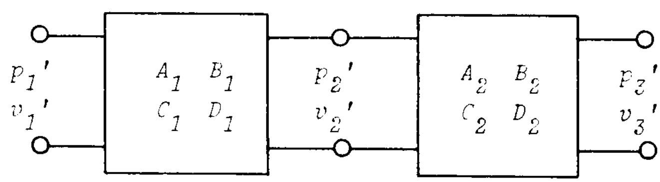
For two elements connected in line, as shown in figure 3(b) their four terminal networks are connected in cascade, and we have

$$\begin{bmatrix} p_1' \\ v_1' \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \begin{bmatrix} p_2' \\ v_2' \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix} \begin{bmatrix} p_3' \\ v_3' \end{bmatrix} \tag{8}$$

Thus a single resultant matrix follows from matrix multiplication.



(a) Single Four-Terminal Network



(b) Cascade Connection of Two Four-Terminal Networks

Fig.3 Four-Terminal Networks for Exhaust System Elements

The transmission matrices for a few simple elements, typically used in exhaust systems, are given below.

Straight Pipe with Uniform Temperature and a Mean Flow. From equation (5) the matrix elements may be shown to be:-

$$A = D = exp\left[-jk\ell\left(\frac{M}{1-M^2}\right)\right] cos\left(\frac{k\ell}{1-M^2}\right)$$

$$B = j\frac{\rho c}{S} \; exp\left[-jk\ell\left(\frac{M}{1-M^2}\right)\right] sin\left(\frac{k\ell}{1-M^2}\right)$$

$$C = j\frac{S}{\rho c} \; exp\left[-jk\ell\left(\frac{M}{1-M^2}\right)\right] \; sin\left(\frac{k\ell}{1-M^2}\right) \tag{9}$$

where ρ, c are the static values of density and sonic velocity, S is cross-sectional area and ℓ is the pipe length.

Step Change in Area. If the sound pressures are assumed the same across the junction and if volume velocity is assumed to be conserved, the transmission matrix is then a unit matrix. Thus the transmission matrix is

$$\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \tag{10}$$

Similarly for a temperature interface or an interface between dissimilar gases the transmission matrix is a unit matrix.

Side-Branch Element. If volume velocity is assumed conserved at the three-way junction and acoustic pressure is assumed the same in each branch at the junction, the transmission matrix follows as

$$\begin{bmatrix} 1 & 0 \\ \frac{1}{Z_b} & 1 \end{bmatrix} \tag{11}$$

where Z_b is the impedance looking down the sidebranch.

Orifice. For an impedance Z, such as an orifice in series within the system, for which volume velocity is assumed the same on either side, the transmission matrix is given by

$$\begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix} \tag{12}$$

Thus, with varying degrees of difficulty, a transmission matrix may be derived for each type of exhaust system element, based on the particular assumptions made for that element, and the whole exhaust system may then be described by one overall matrix for a single analogous four terminal network.

Tailpipe Outlet

With linear theory, the conditions at the tailpipe outlet are accounted for by assuming a certain radiation impedance Z_r exists, as shown in figure 2. Of course Z_r is the ratio of acoustic pressure to volume velocity at the outlet, p_r'/v_r'. By expressing p_r' and v_r' in terms of components from the incident and the reflected waves it follows that

$$Z_r = \frac{\rho c}{S} \left[\frac{1-R(M)e^{-j2k\ell(M)}}{1+R(M)e^{-j2k\ell(M)}}\right] \tag{13}$$

where ρ, c are average static values inside the tailpipe, $R(M)$ is sound pressure reflection coefficient modulus as function of Mach number and $\ell(M)$ is the pipe end correction or effective extra pipe length.

From Levine and Schwinger [5], for $ka \to 0$, where a is tailpipe radius, for zero flow and where the gas in the tailpipe is the same as in the surroundings

$$R = 1 - \frac{1}{2}(ka)^2 \quad \text{and} \quad \frac{\ell}{a} = 0.6133 \tag{14}$$

which gives, from equation (13)

$$Z_r = \frac{\rho c}{S}\left[\frac{(ka)^2}{4} + 0.6133\ jka\right] \quad (15)$$

Source Characteristics

To complete the mathematical model of the entire exhaust system, as shown in figure 2 the noise source, that is the engine, must be represented as a source of constant volume velocity v_e' with a parallel source impedance Z_e. Depending on circumstances, the source may be adequately modelled as having a simplistic form for Z_e or alternatively a much more complicated form. For example, Z_e may be assumed infinity for a single cylinder engine or may be set to the impedance of the manifold volume capacitance for a multicylinder engine. Much research has recently been conducted into the nature of the sound source for linear acoustic models and is beyond detailed discussion here. This work is reviewed by Jones [3] and Crocker [4].

Performance Predictions

Once the entire exhaust system linear model is complete, that is when v_e', Z_e, Z_r as well as the matrix elements for the single overall transmission matrix describing the system are known, the radiated noise may be found. Assuming the tailpipe outlet radiates as a monopole the radiated sound pressure amplitude at distance r_o, $|p_{rad}'|$ is

$$|p_{rad}'| = \frac{\rho_{ao}\omega|v_r'|}{4\pi r_o} \quad (16)$$

where ρ_{ao} is the atmospheric density.

It is generally more common to compute insertion loss as then the actual level of the source strength does not need to be known. The insertion loss for one exhaust system relative to another may simply be based on a comparison between two values of $|p_{rad}'|$, obtained whilst using a constant assumed value of v_e' in the two exhaust system models. Thus

$$\text{Insertion Loss} = 20\ log_{10}\frac{|p_{rad_1}'|}{|p_{rad_2}'|}\ dB \quad (17)$$

Example of Computed Insertion Loss

To test calculations from a computer based exhaust system model developed at Hills Industries Ltd., comparisons were made with measurements of radiated exhaust noise obtained by G. P. Gilbert [6] using alternate exhaust systems on a single cylinder four stroke engine. The engine was a Villiers type C-12 412H of 120 cm^3 swept volume. Exhaust systems used were: (1) straight pipe 0.667m length, 0.020m diameter; (2) expansion chamber 0.667m length, 0.120m diameter between two straight pipes each 0.667m length, 0.020m diameter. The engine was run at 3000 r.p.m. with a generator as a load.

The expected silencing caused by using the exhaust system (2) with the expansion chamber, in place of exhaust system (1), the straight pipe, as computed is shown in figure 4 as a solid line. Data points obtained by subtracting measured values are shown individually plotted. For the analysis mean flow was neglected, but pipes were segmented with a number of temperature jumps to allow for measured gas temperature variations along the system. Also a more accurate value of Z_r was used, based on an improved value of R (see Jones [3]).

Clearly the analysis provides very good results regardless of the approximation of infinity for Z_e and the neglection of mean flow.

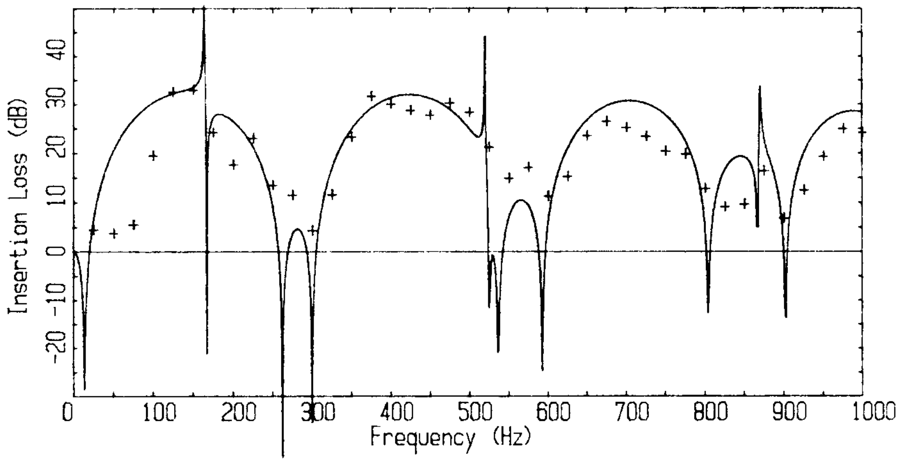


Fig.4 Measured vs Calculated Insertion Loss for Expansion Chamber on Single Cylinder Engine

CONCLUSION

With the steady advance in the development of mathematical models to describe events in engine exhaust systems, the days of muffler design being carried out using trial and error methods alone are drawing to a close. Computer based models that are being developed will, at least, be of great assistance in a design process incorporating trial and error, and at most will dominate the design process within the next decade.

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THE EFFECTS OF GROSS VEHICLE MASS VARIATIONS ON HEAVY VEHICLE NOISE EMISSION

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BACKGROUND

Recently, the National Association of Australian State Road Authorities (NAASRA) conducted a study of the regulations governing heavy vehicles and their operation on Australian roads. This study, entitled the Review of Road Vehicle Limits (RORVL), was primarily concerned with determining what would be the many effects of varying the mass and dimension limits that apply to heavy vehicles. One of these effects is noise emission, and RORVL awarded ARRB a research contract to determine, under typical Australian operating conditions, the effect of gross vehicle mass variations on heavy vehicle noise output. It is the intent of the present paper to document both the conduct and findings of this research.

To date much data are available concerning heavy vehicle noise emissions (NSW State Pollution Control Commission (1984), Broner and Mizzi (1980), ACSVD (1976), Kugler et al. (1976), Kennedy and Welbourne (1980)). However these data have tended to be collected under certification conditions such as those of ADR 28A (DoTA 1980). Furthermore, all of these data are categorised by parameters such as vehicle type, engine type or exhuast configuration. It is not possible to use existing data to investigate a noise/vehicle mass relationship.

In order to satisfy RORVL requirements, data were needed on the noise produced by a representative sample of heavy vehicles operating under typical Australian conditions while carrying a suitable range of loads. The operating conditions include constant speed situations encountered on freeways, urban arterials and other roads where traffic noise is likely to be significant. Also they include the acceleration conditions which typify many urban traffic situations. In addition, some information was required on heavy vehicle noise output under grade climbing conditions.

EXPERIMENTAL PROGRAM

A test program was established that involved a series of controlled test experiments conducted under appropriate operating conditions of constant speed, acceleration and grade climbing. A suitable range of five trucks was used and each vehicle was tested at all three operating conditions under three load configurations. Data collected were of the passby type with a microphone-vehicle trajectory distance of 15 m. Peak noise levels were recorded at the roadside using conventional, precision Bruel and Kjaer equipment while vehicle speed/time histories were monitored with the ARRB Vehicle Detector Data Acquisition System. This system employs an array of optical detectors located on the roadside, the outputs of which are recorded on magnetic cassette tape via a digital data logger. After subsequent processing on the ARRB CYBER Computer, vehicle speed/time histories are obtained. The test program was conducted during the week 4-7 December 1984 at the International Harvester Proving Ground located at Anglesea, Victoria.

In summary, the experimental program was as follows:

Test Details

Rigid trucks	2
Articulated trucks	3
Load condition/truck	3
Speeds (Passby)	50, 65, 80 km/h
Acceleration	0 to 50 km/h
Grade climb	15 km/h up 5% grade
Replications of each run	3

Vehicles and Loads

Vehicle	Description	Test Gross Masses (t)		
1	4 x 2 Rigid	14	15	16
2	6 x 4 Rigid	20.5	22.5	25
3	4 x 2 Prime Mover plus trailer	29	31	35
4	6 x 4 Prime Mover plus trailer	38.5	40.5	43.5
51	6 x 4 Prime Mover plus trailer	38.5	40.5	43.5

The objective was to test a range of vehicles which is typical of that in service at present. Note that these experiments were not designed to study the many factors such as engine performance and tyre/road interaction (Samuels 1982) that interact to generate vehicle noise. Vehicles 3, 4 and 5 differed only in prime mover, with one flat tray tandem axle trailer used throughout. Load was varied on all vehicles by means of steel blocks. Every vehicle was weighed at each load condition using a conventional, static, weighbridge. Table I presents further details of the vehicles.

DATA

A plot typical of the measured noise levels against constant speed for varying load is given in Fig I. The grade climbing data are given in Fig 2 along with the acceleration noise in Fig 3. The complete sets of data are documented in Samuels (1985) where it is also demonstrated that the reproducability of the data collected at Anglesea was good at less than 0.5 dB(A). It is apparent in Fig I that variations in Gross Vehicle Mass had little, if any, effect on the observed constant speed noise levels. For any particular truck there were no immediately obvious load related effects.

For the grade climbing data of Fig 2 a similar situation of load variations having minimal influence on noise was observed. Truck I was some 3 dB(a) quieter that the others but, given the nature of constant speed grade climbing, this observation is more likely to be a function of the mechanical design features of the trucks rather than their gross vehicle mass. Leaving aside this difference it was observed that, for each truck, the range of gross vehicle masses used could at the most account only for a small I dB(A) change in noise level. Such a change is negligible. If the Truck I discrepancy is load related, then comparison of the data for all five trucks indicates that the maximum range of noise levels due to this effect is a small 3 dB(A). In the more likely event of the

Truck I data being specificly vehicle related, then there were negligible variations of around I dB(A) that might be caused by load variations when the data for all trucks were considered together.

Under the acceleration conditions of Fig 3, each Truck tended to emit slightly less noise with increasing gross mass. As with the grade climbing data, these changes were in the order of a negligible I dB(A). Considering the acceleration noise data over all five trucks, a similar observation to that of Fig 2 arises. With Truck 5 excepted, there is no readily apparent effect of gross vehicle mass variation on the measured noise levels. The noise produced by Truck 5 is some 3 dB(A) less than that of the other four trucks and this, in a similar fashion to Truck I of Fig 2, is most likely an effect of parameters other than load. Overall it seems again that gross vehicle mass variation had a negligible effect on the observed acceleration noise levels.

STATISTICAL ANALYSIS

In order to quantify the experimental observations, a series of routine statistical analyses was conducted on the data using the SPSS Package on the ARRB CYBER Computer. Again these are documented fully in Samuels (1985). Initially, Analyses of Variance were performed to determine if parameters such as Speed (V) and Gross Vehicle Mass (M) influenced the measured data. Results of these analyses indicated, as expected, that Speed was a consistent factor influencing the constant speed data. For all three data types (constant speed, acceleration and grade climbing) the tendency was for the Analysis to indicate that Mass had an effect on the data, but that the statistical significance of this effect varied a little for the various vehicles and run types. In a couple of instances the Analysis indicated that Mass had no effect. When the data for all Trucks were aggregated by Run Type, Mass was found to have an effect on all three sets of data.

Since both Speed and Mass were shown by the Analyses of Variance to have some influence on the data, Regression Analyses were conducted to quantify these effects. Several Regression Equations were investigated and the best from a statistical (as measured by the Coefficient of Determination R_2) and an acoustical (in terms of being consistent with other observations of vehicle noise behaviour such as those of Samuels (1982)) point of view that was given in Eqn (I):

$$SPL = A + B \log M + C \log V \quad (1)$$

where SPL = Sound pressure level recorded during vehicle passby at 15 m adjacent to vehicle trajectory line (dB(A)).
M = Gross Vehicle Mass (t)
V = Vehicle speed (km/h)
A,B,C = Regression Coefficients

Results of the Regression Analyses using Eqn (I) are given in Table II. Note that for the grade climbing and the acceleration data, no Speed term was used in the Equation.

For the constant speed data, the generally high values of the Coefficient of

Determination, R^2, indicated that the equations were good descriptions of the measured data. As indicated by the narrow range of the Regression Coefficient C, the effect of Speed was consistent over the five trucks and also when the data for all trucks were aggregated. The effect of Mass was somewhat varied and might even be related to vehicle type. For the larger articulated Vehicles 4 and 5, a strong Mass effect was revealed by the Analysis. An apparent transition to quite the opposite for the smaller rigid vehicles is observed in Table II. Note that a negative Regression Coefficient indicates a decrease in noise level with increasing Mass. When aggregated over all vehicles the effect of Mass was small and of a similar order to that of Speed.

Similar observations were made for both the acceleration and the grade climbing data. In each case the Coefficients varied with vehicle and were small when the data for all vehicles were aggregated. All Coefficients were negative in the case of acceleration and this observation indicated that for all vehicles noise output decreased with increasing Mass. It is important to note that the R^2 values are generally lower for both the Analyses of the acceleration and grade climbing data than for that of the constant speed data, suggesting that the acceleration and grade climbing Regression Equation is note quite as robust as that for the latter case.

FURTHER COMMENTS

It appeared that variations in Gross Vehicle Mass had little effect on the noise produced under constant speed, grade climbing or acceleration conditions by a set of five trucks typical of those currently operating in Australia. Some possible, yet small, vehicle related effects were also observed in both the grade climbing and acceleration data. For each of the three operating conditions of constant speed, grade climbing and acceleration, the data are perhaps best considered further from two view points. These involve firstly the data aggregated over the five vehicles and secondly the data for each vehicle as appropriate.

In the constant speed case the Regression Coefficient of the Mass term (B in Eqn I) is a low 3.69 for the aggregated data. The implication of this finding may be examined by considering the changes in noise level determined by Eqn I in response to variations in Mass. By substitution into Eqn I it is found that a doubling of Mass leads again to a negligible 1.1 dB(A) increase in noise level. Note that the Standard Error of this increase estimate was 2.4 dB(A).)

When the constant speed data for each of the five vehicles are considered individually, it allows some specific effects of Mass to be isolated. In Table III, the Regression Equations for each vehicle have been applied to quantifying the changes in noise level associated with some appropriate variations in Mass. The specific values of Mass adopted in Table III are the extremes of the nominal values of the experimental design of the test program. In all cases of Table III, the changes in noise level are less than a small 2 dB(A).

For both the grade climbing and the acceleration data, a similar situation to that of the constant speed data arose. Considering the aggregated data, a doubling of Mass was calculated to increase the grade climbing noise by 2.3 dB(A) while decreasing the acceleration noise by 1.6 dB(A). Again these figures are small and may be neglected. Refering to Table III, the calculated effects of Mass on both the grade climbing and the acceleration noise for each vehicle are displayed. Consistently small and negligible values were obtained. It should be noted, however, that the regression based calculations in Table III are not as robust in the cases of both grade climbing and acceleration as in the case of constant speed. This situation merely reflects the generally lower values of the Coefficient of Determination R^2 achieved for the grade climbing and acceleration regressions compared to those of the constant speed regressions (refer to Table II).

These findings suggest that truck noise levels will not alter either practically or discernably in response to Mass changes such as those of Table III. Note that this conclusion is based on the assumption that the five trucks used in the test program represent a typical cross section of the Australian truck fleet. This assumption was felt reasonable since it was the basis on which RORVL approved the selection of vehicles for the test program.

CONCLUSIONS

The noise emitted by a set of five trucks was recorded under typical operating conditions of constant speed, acceleration and grade climbing. The gross vehicle mass of each truck was also varied at each condition. It was found that for each condition, gross vehicle mass variations had a negligible effect on noise emission. This conclusion applied both to the noise produced by each truck and to the range of noise levels obtained when the data for all trucks were aggregated.

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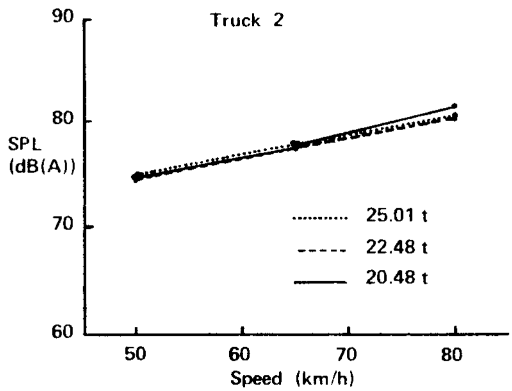

Fig 1. Typical constant speed data

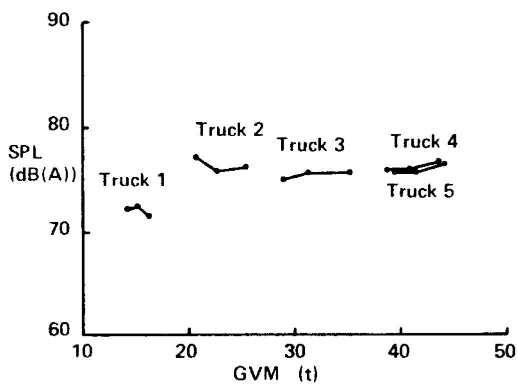

Fig 2. Grade climbing data

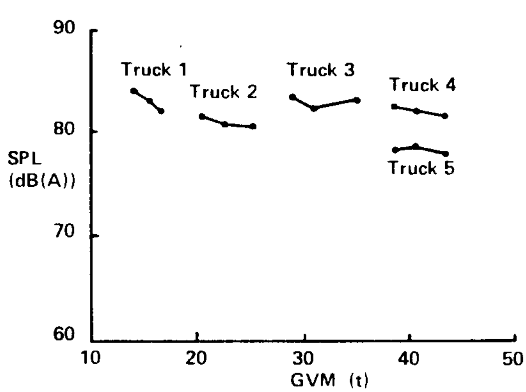

Fig 3. Acceleration data

Table I VEHICLE SPECIFICATIONS

Vehicle Number	Vehicle Type	Prime Mover Specifications			Test Gross Mass (t)		
		Manufacturer	Details	Engine	I.D.	Nominal	Actual
1	Rigid	Nissan	4 x 2 Cab over engine L H drive	6 cyl, 10 l Diesel	1 2 3	14.00 15.00 16.00	14.02 15.01 16.00
2	Rigid	I H	6 x 4 Cab over engine	6 cyl, 10 l Cummins LT250 Diesel	1 2 3	20.50 22.50 25.00	20.48 22.48 25.01
3	Articulated	I H	4 x 2 Cab over engine	6 cyl, 10 l Cummins LT250 Diesel	1 2 3	29.00 31.00 35.00	28.94 31.20 35.05
4	Articulated	Mercedes Benz	6 x 4 Cab over engine	OM 422LA, V8 Diesel	1 2 3	38.50 40.50 43.50	38.51 40.40 43.48
5	Articulated	Mack	6 x 4 Bonnetted	16.4 l, 440 HP, V8 Diesel	1 2 3	38.50 40.50 43.50	38.56 40.60 43.75

TABLE II REGRESSION ANALYSES

DATA	Vehicle	SPL + A + B log M + C log V A	B	C	R^2
Grade Climbing	All	64.1	7.59	-	0.55
	1	88.0	-13.70	-	0.32
	2	87.6	-8.36	-	0.27
	3	63.2	8.11	-	0.29
	4	41.4	21.40	-	0.77
	5	48.6	17.12	-	0.58
Acceleration	All	89.5	-5.43	-	0.25
	1	117.3	-29.0	-	0.76
	2	92.9	-8.81	-	0.66
	3	86.7	-2.36	-	0.02
	4	111.9	-18.5	-	0.51
	5	91.5	-8.10	-	0.17
Constant Speed	All	63.0	3.69	5.48	0.70
	1	84.3	-14.4	5.36	0.96
	2	70.8	-2.34	6.39	0.94
	3	61.5	4.17	4.79	0.99
	4	34.9	28.3	2.56	0.89
	5	18.9	29.6	8.31	0.80

TABLE III NOISE LEVEL VARIATIONS

SPL = A + B log M + C log V

Vehicle Number	Change in Mass (t)	Change in SPL (dB(A)) Constant Speed	Grade Climbing	Acceleration
1	14 to 16	-0.8	-0.8	-1.7
2	20.5 to 25	-0.2	-0.7	-0.8
3	29 to 35	+0.3	+0.7	-0.2
4	38.5 to 43.5	+1.5	+1.1	-1.0
5	38.5 to 43.5	+1.6	+0.9	-0.4

THE IMPACT OF TRUCK NOISE

R.T. Benbow

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The impact of truck noise on the acoustic amenity of residential areas is an environmental issue that remains unsolved in many surburban areas of Sydney. The immediate solutions available are essentially involved with town planning. Significantly different approaches to environmental planning of residential areas with adjacent traffic routes are required if the acoustic amenity of residents is to be preserved.

The many aspects associated with the impact of truck noise are illustrated by discussing three sites that depend on the use of trucks. (Only a brief summary is presented as slides will be extensively used during the conference).

The three examples to be used are :-

1. A quarry operating since 1965 and now surrounded by high density residential areas. Heavy trucks movements occur between 7.00am and 4.00pm.

2. A major source of concrete construction materials uses a large fleet of semi-trailers to transport these materials throughout metropolitan areas of Sydney. Until recently truck movements were along traffic routes relatively free of residences.

3. The proposed operation of a combined quarry and waste disposal depot has necessitated the prediction of the impact of truck movements. The existing traffic routes to the site do have residential areas along one or both sides of the roadway. Residences are built within 30 metres of the roadway.

   The effect of increased truck movements associated with the proposed operation of the depot on the L10 (1hr) and L10 (18 hr) noise levels has been assessed. The temporal distribution of truck movements is of significance both in successfully operating the depot and ameliorating the potential impact on the acoustic amenity at the residences.

   The use of the DOE method, the practical difficulties in ameliorating the impact and the noise control options available are discussed during the presentation of the paper.

THE IMPACT OF TRUCK NOISE

During this study, the relative increase in truck noise during the 15-20 year life of the waste depot was examined. The truck movements into a scheduled premises are controlled through the Noise Control Act. The gradual increase in traffic flow resulting from environmental planning of a local and regional nature will cause an increase in noise levels. The relative effects of truck movements and the gradual increase in traffic flows are examined using the calculation procedures of the DOE method.

DIESEL ENGINE NOISE UNDER ACCELERATION

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INTRODUCTION

The diesel engine is now the most common powerplant for medium and heavy goods vehicles. In general diesel engines emit more noise than gasoline engines mainly because of their combustion processes and it is the diesel engined vehicle which produces the peaks sound levels on our roads.

Most of the published works on engine noise [1,2,3] deal with engines which operate at steady full load conditions. Yet the noise regulations ISO R362, ADR 28A and SAE J366B prescribe driveby test under acceleration, and frequently it is the sound of an accelerating truck which causes the greatest community disturbance.

The aim of this paper is to promote a better understanding of the underlying engine parameters which control the noise during acceleration. To this purpose the combustion and fuel injection systems of three diesel engines are discussed together with their noise levels during acceleration.

DIESEL COMBUSTION PROCESS

A brief review of diesel engine combustion and their noise sources may be of help in understanding the remainder of the paper.

In diesel, i.e. compression ignition engines, fuel is injected and atomised during the compression process. The atomised fuel takes a certain time (ignition delay) to vaporise, mix with air and heat to auto ignition temperature. Thereafter ignition occurs and the subsequent pressure rise depends on the amount of fuel which is ready to ignite and burn at the time of ignition. Consequently a high injection rate or increased ignition delay usually leads to an increased rate of pressure rise.

Engine noise can be divided into combustion noise and mechanical noise. Combustion noise results from forces which act during the combustion process. The higher the rate of pressure rise, or the higher the peak pressure the higher the forces which excite the engine structure which in turn radiate the noise. Mechanical noise is usually reserved to the noise radiated from the structure due to inertia and other impulsive forces. In general the sound pressure level of an engine is a function of the bore, speed, peak pressure and rate of pressure rise.

RESULTS

In the following tests the engines were operated in semi anechoic chambers with microphones 1 m from the engines as per SAE J1074, and intake and exhaust were ducted out of the chamber.

Engine No. 1

This engine is a direct injection, turbocharged diesel engine with aftercooler and a common rail fuel system. The common rail fuel system differs from the more frequently used jerk pump in that the quantity of fuel injected is controlled by the rail pressure so that at a given engine speed the rate of fuel injection is proportional to the square root of the rail pressure. Direct injection (D.I.) means that the fuel is injected directly into the space above the piston as opposed to an indirect injection (I.D.I.) engine where the fuel is injected into a pre-chamber. Turbocharging increases the pressure and temperature of the air entering the engine and so increases the output by increasing the mass throughput. Aftercooling is used to increase the mass throughput even further by increasing the charge density.

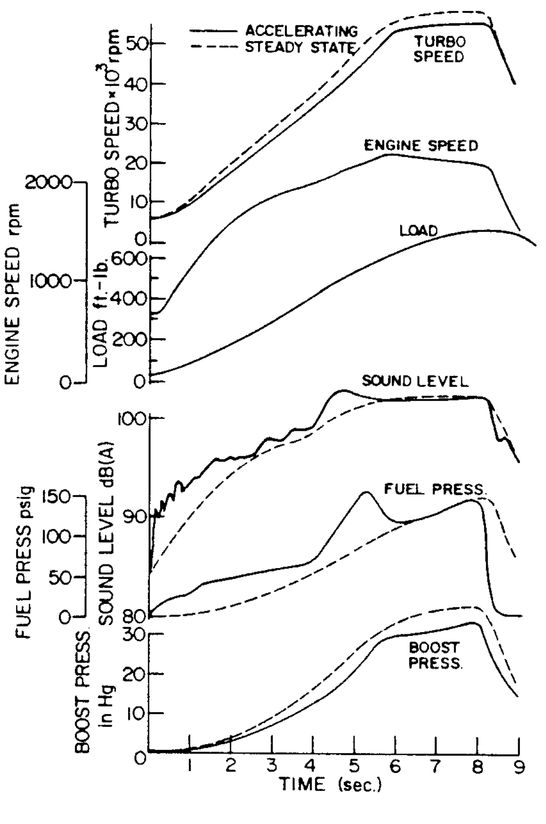

FIG. 1. STEADY AND ACC^{n} PARAMETERS FOR A TURBO DIESEL WITH RAIL FUEL SYSTEM

Fig. 1 shows a typical time variation of the important engine parameters, including the sound pressure level (SPL) at 1 m from the left hand side of the engine. The dashed lines represent the steady state values based on the same instantaneous load and speed. Points to note on this figure are:

(a) the difference in SPL between the accelerating and steady engine is largest during the first second of acceleration;
(b) the SPL differences are comparable with fuel rail pressure differences;
(c) turbo speed and hence turbo boost pressure have virtually no effect during the early accelerating phase;
(d) the steady state SPL has a similar time history as the accelerating engine speed.

Point (b) was tested further by plotting the SPL differences against $10 \log \sqrt{P_{FA}/P_{FS}}$ as shown in Fig. 2. The parameter on the abscissa comes from the fact that the rate of fuel injection is proportional to the square root of the fuel rail pressure and P_{FA} and P_{FS} are the rail pressures under accelerating and steady conditions respectively. The rate of fuel injection in turn directly influences the rate of combustion pressure rise which leads to the increased noise emission. This correlation is clearly evident in Fig. 2 and applies throughout the acceleration phase. Although the increase in SPL is greatest immediately after the start of acceleration the peak sound level for this engine occurs towards the end the accelerating period and this level is comparable with the steady SPL at rated load and speed. Further test results on this engine can be obtained from Ref. [4].

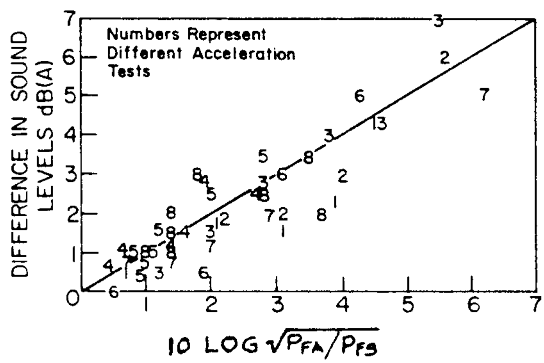

FIG. 2. COMPARISON BETWEEN MEASURED AND EXPECTED SPL DIFFERENCES

Engine No.2

This is a direct-injection, naturally aspirated engine with a jerk pump fuel injection system. The jerk jump differs from the common rail system in that the fuel quantity injected is dependent only on the effective stroke of the plunger shown in Fig. 3., and the rate of injection depends, to a first order, on the plunger speed i.e. engine speed.

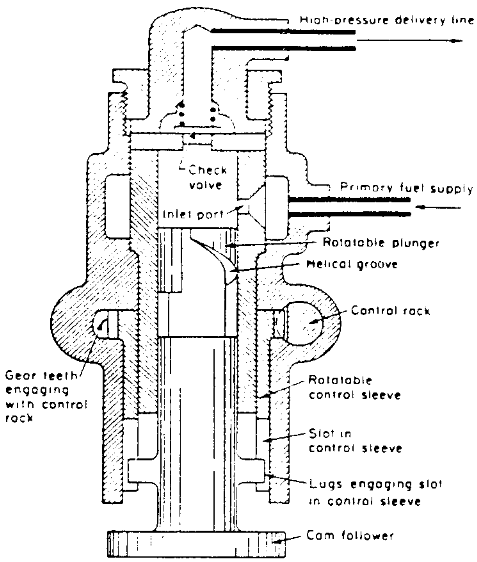

FIG. 3. JERK PUMP

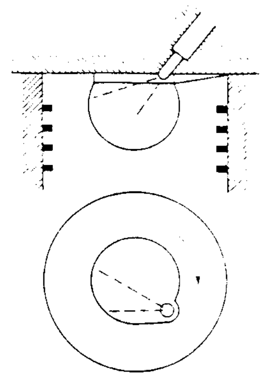

FIG. 5. MAN-M COMBUSTION SYSTEM

Fig. 4 shows a comparison of sound pressure levels between an accelerating engine and comparable steady operation. The left hand bar graphs apply immediately after the start of acceleration while those on the right refer to the end of the accelerating phase.

Points to note are:

(a) the increase in sound level is 2-3 dB higher at the start of acceleration than at the end;
(b) the peak sound levels occur towards the end of acceleration;
(c) the more important engine parameters affecting the increased sound levels are:
  (i) injection begin;
  (ii) cooling water temperature;
  (iii) octane number;
  (iv) engine speed at the start of acceleration;
  (iv) engine load at the start of acceleration;

As explained above the rate of fuel injection with a jerk pump is primarily dependent on the engine speed. Consequently, as the rate of fuel injection increases the rate of pressure rise must also increase and this is responsible for the increased noise level. Point (c) (iv) verifies this. The other factors which affect SPL suggest the importance of combustion chamber temperature. Lower temperatures lead to increased ignition delay since $\tau = 0.44P^{-1.19}e^{(4650/T)}$

where τ = ignition delay (ms)
P = cylinder pressure (bar)
T = cylinder temperature (K)

This in turn leads to higher noise levels as explained earlier. Wall and air temperature measurements [5] support this theory and similar results can be found in Ref. [6]

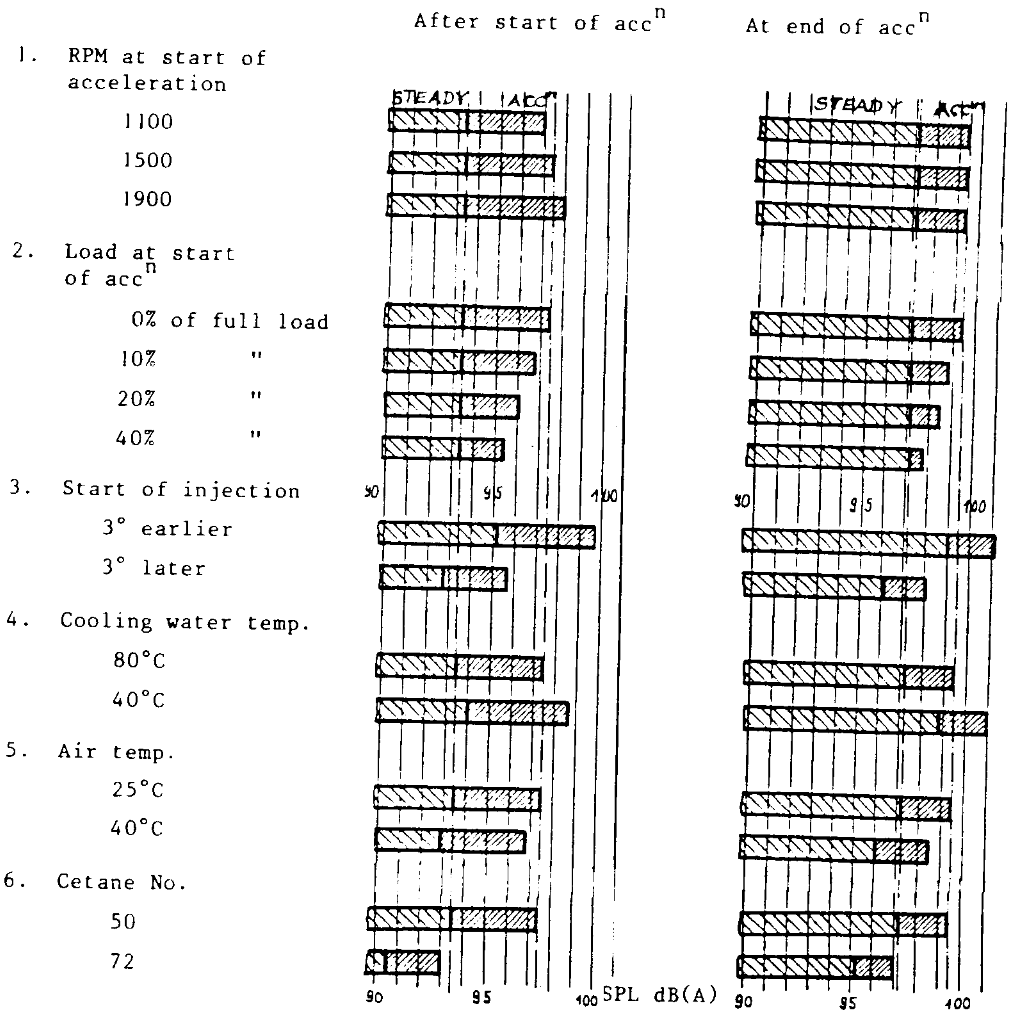

FIG. 4. STEADY AND ACCELERATING SPL FOR D.I. DIESEL

Engine No. 3

This engine is a direct injection, naturally aspirated engine with a jerk pump fuel system, similar to engine 2, but it has the MAN-M combustion process as shown in Fig. 5. The main difference between this process and that used in other engines is that the majority (80-85%) of the fuel is deliberately deposited as a film onto the inside of a bowl in the piston. Ignition occurs normally with only 10-15% of the fuel and thereafter the combustion is controlled by the rate of fuel vaporisation from the walls and the mixing process between fuel vapour and the air. Since the energy for vaporisation comes mainly from the flame the initial rate of pressure rise, i.e. combustion, is reduced and so is the noise level. In other words the fuel injection process and the ignition delay do not control the initial rate of pressure rise. In fact, in these engines, there is little difference between the SPL under acceleration and steady conditions as can be seen from Fig. 6.

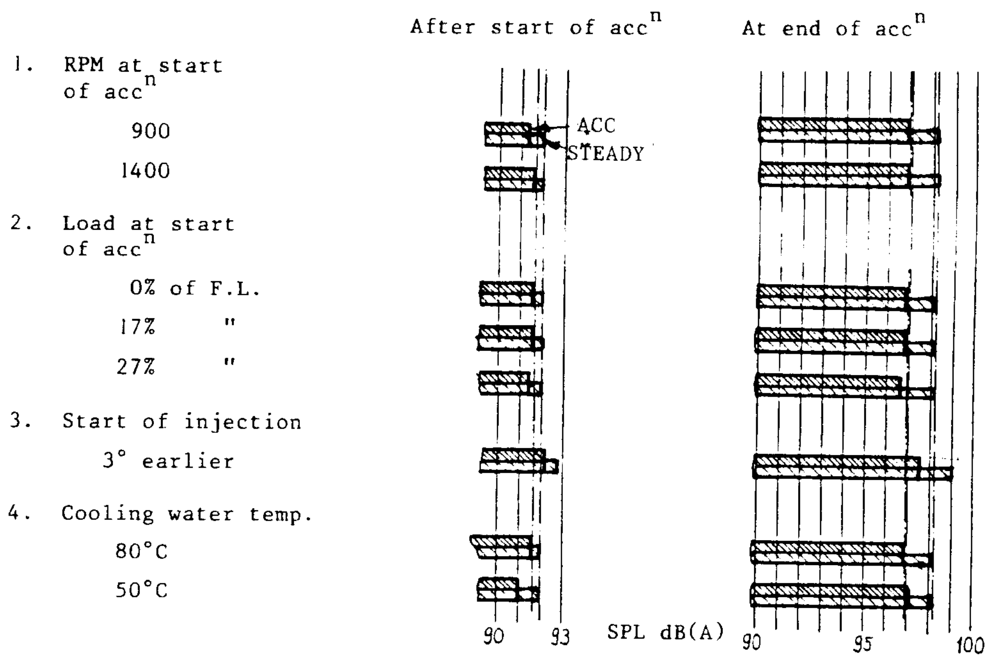

FIG. 6. STEADY AND ACCELERATING SPL FOR MAN-M ENGINE

DISCUSSION

From the above results it is clear that engine noise during acceleration comes from the combustion process, or more specifically, from the initial rate of pressure rise. With this knowledge one could anticipate the behaviour of combinations of combustion and fuel injection system. For example, an indirect injection engine should have comparable SPL to the MAN-M result. This is verified by Ref. [6]. Turbocharged engines with jerk pumps in general have smoother combustion at full load than naturally aspirated units and hence produce less noise. However, at part load they are frequently noisier than naturally aspirated engines and may even be noisier at part load than at full load due to high fuel flow rates and high peak pressures [2]. During acceleration the SPL immediately after the start of acceleration can also exceed the steady full load SPL [6].

CONCLUSION

It is hoped that an understanding of the engine parameters which control the noise under different operating conditions will help with noise control measures as well as with the specification of appropriate regulations and test procedures.

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INTERIOR NOISE LEVEL SCATTER IN MOTOR VEHICLES

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INTRODUCTION

A major problem of noise control in motor vehicles and other forms of transportation is the variability in the noise characteristics of nominally identical vehicles. Scatter ranges as high as 10 dB have been reported for four cylinder motor vehicles. Differences in noise levels of this magnitude are very substantial, and can lead to a situation where a percentage of cars are not acceptable to customers. It is necessary to understand noise scatter before a strategy to deal with it is implemented; this paper assesses noise scatter in terms of structural-acoustic characteristics of vehicles.

THE NATURE OF INTERIOR NOISE SCATTER

The variability observed in the dynamic response of motor vehicle structures is smallest at very low frequencies (up to 50 Hz). Measurements of modal frequencies, response amplitudes and loss factors are most reliably reproduced between nominally identical vehicles when the modes are essentially global. At higher frequencies, where modes are more localized and individual panel responses are more important, the spread of data is greater. Variations in panel response amplitudes higher than 100% are not unusual in the region of 100-200 Hz. The dominant cavity acoustic modes fall within this range, coinciding with the range of greatest noise level scatter in four cylinder vehicles.

There are numerous causes of scatter, and they can be divided into two broad categories: those of mechanical origin, and those of structural-acoustic origin. The latter are the prime interest of this paper but variability of mechanical origin will be briefly reviewed.

Many mechanical factors contribute to variability. They include differences in engine mount dynamic rate and damping, engine mount pre-load, engine mount assembly sequence, all of which influence the level of vibration transmitted to the body. Variations in driveshaft joint stiffness or friction have similar effects, as do variations in exhaust system mountings. While there are numerous mechanical factors which affect scatter, relative to structural-acoustic factors, they are easier to identify and control. Many of the causes of variability can be traced to mechanical differences, but it is when these causes have been exhausted as possibilities that sources of structural-acoustic origin need to be investigated.

Differences in the vibration levels of the engine are rarely found to be the cause of noise level scatter as the second order component of vibration, which dominates interior noise levels, is itself dominated by the forces generated by the reciprocating masses of the engine. There are negligible differences between reciprocating masses of nominally identical engines. Build quality determined by such items as crankshaft balance, bearing clearances, end-float, gear lash and radial run-out of shafts do influence vibration levels of engines, but they primarily influence the higher orders, half orders, or first order in the case of balance.

The usual procedure adopted to investigate noise level scatter is to firstly assess the degree of scatter [1] by measuring a representative sample of cars, perhaps five or more, and to select the best and the worst examples from the sample. Exhaustive tests are then done to characterize the dynamic differences between the two vehicles. The objective of these tests is to identify one or two significant differences between the vehicles, determine the causes of the differences, and introduce modifications which will reduce scatter. The tests will usually include vibration measurements on the powerplant; transmissibility measurements on powerplant mountings; modal analysis of the structure, or parts of the structure; and acoustic transfer functions (sound pressure level/force) between points on the structure and a microphone in the cabin.

Such programs of investigation and modification are not always fruitful, for example, when no significant common factors can be identified. In other cases, it has been found that, even when major differences have been readily identified, not all vehicles will respond to the modifications introduced. Such seemingly inexplicable behaviour is undoubtedly due to an inadequate model of the noise generation process.

Another troublesome manifestation of variability lies in the differences in acoustical behaviour between prototype and production vehicles [2]. It is also the authors' experience that hand-built prototypes are not always representative of mass-produced vehicles. This leads to considerable uncertainty about the acoustical environment that the customer will experience, and the noise control engineer is usually not content with the product until it is verified that production vehicles meet the acoustical objectives. Nominally identical prototype vehicles, which are essentially hand-built, also suffer the same variability problems as mass produced vehicles. The presence of noise level scatter and uncertainty about its sources considerably complicates the decision-making process when choosing between possible noise control treatments. A carefully planned and executed noise control program should make provision for the uncertainty associated with noise level scatter.

INTERPRETATION OF NOISE SCATTER IN TERMS OF STRUCTURAL-ACOUSTIC BEHAVIOUR

As part of an audit of production vehicles, noise traces of six nominally identical sedans were measured. All of the vehicles had four speed manual transmissions, and all were produced within a two-week period. Figure 1a shows the second order component of interior noise measured at the driver's left ear position, as well as the envelope of overall noise levels. In Figure 1b, structural-acoustic transfer functions are shown for the same vehicles. For these transfer functions, the output is the acoustic response at the driver's left ear position to an input force at the front of the right hand longitudinal member near a major engine mounting location. This particular excitation point was selected because previous studies had indicated that interior noise levels were sensitive to inputs at this point.

There is about 7 dB scatter in the overall noise levels near 4000 rpm, and there is a trend of increasing scatter with increasing engine speed. There is considerably more scatter in the second order component. The significant scatter occurs at the peaks in the second order component near 4000 rpm, with a lesser peak at 3000 rpm. These peaks correspond to peaks in the acoustic transfer functions in Figure 1b near 130 Hz and 95 Hz.

The noise traces show a double peak response near 4000 rpm, one at 3900 rpm and the other at 4200 rpm, and evidence of this behaviour can be seen in the acoustic transfer functions. One of the vehicles had no response at 3900 rpm, and another had very little response at 4200 rpm. Consequently, the scatter ranges in the second order curves at these speeds were about 15 dB and 12 dB respectively. At corresponding frequencies in the acoustic transfer functions about 11 dB of scatter is evident.

A rigid boundary two-dimensional finite element model of the cavity predicted normal modes at frequencies of 107 Hz, 140 Hz and 194 Hz. The transfer functions in Figure 1b have peaks at 95 Hz, 130 Hz and 190 Hz. The slightly lower measured frequencies are due to the effect of the flexible boundaries. Compact class sedans, by virtue of the size and shape of the cavity, typically have a major acoustic mode in the frequency range 120 Hz to 160 Hz. Coinciding with the cavity mode, they often have major second order noise periods in the engine speed range 3500 rpm to 5000 rpm. Furthermore, it is in the same range that greatest scatter of noise levels occurs, and this is the situation with the vehicles considered here.

Having established the importance of the structural-acoustic characteristics, it is now necessary to determine at which stage(s) of the energy flow path that the greatest sources of variability occur. Previous discussion has ruled out the engine, and prior experience with the vehicles has shown the engine mountings to be unimportant when properly assembled. The importance of the structural transmission path as a source of variability was tested by measuring mobility data at various points on the structure. Driving point mobility was measured on the right hand longitudinal member near the engine mount location, at the same excitation point as employed in the acoustic transfer functions. The transfer mobilities also used the same excitation point, but the responses were measured at different locations, one at the base of the 'A' pillar, the other on a stiffened floor panel. The points chosen for the mobility measurements are sketched in Figure 2a. The points were chosen as representing the various stages of the transmission path of vibration energy to the panels surrounding the cabin.

The scatter in the driving point mobility data is 3 dB near 130 Hz, and at the intermediate point near the base of the 'A' pillar it is also 3 dB. This indicates that the scatter is not inherent in the transmission path to the panels. However, at the measurement point on the front floor panel (actually measured on a light stiffener on the panel, the seat track mounting) the scatter is much greater, being about 15 dB. It is apparent that the major causes of scatter occur at the point of noise generation.

Evidence that the variable factors primarily influence the structural-acoustic behaviour of the vehicle is reinforced when the floor panel transfer mobility and acoustic transfer function data are compared for each individual vehicle. There exists a remarkable similarity between the shapes of the two curves in the range 100 to 150 Hz. Of course, other panels also participate in defining the shape of the acoustic transfer functions. Panel participation can be understood in terms of panel influence diagrams discussed in references [3] and [4]. The individual contributions from each panel can be plotted in a polar vector diagram and added vectorially to obtain the resultant sound pressure.

Obviously, the phase angles between the various vectors determine whether or not they cancel each other. In principle, a different vector diagram must be constructed for each point in the vehicle. However, at frequencies of interest here, below 200 Hz, the pressure distributions are sufficiently symmetrical about the vehicle longitudinal centre-line to require such diagrams only for the front and rear seat positions.

The vectorial approach is required because of the low modal densities of the cavity below 200 Hz. For the vehicle considered here, there are only five modes below 200 Hz. Modal densities of the structure are considerably higher and several hundred modes may exist below 200 Hz [5]. High acoustic modal densities enable the use of averaged acoustic properties over a frequency band to be employed to estimate interior noise levels, but low modal densities require the coupling between individual structural and cavity modes to be considered. Coupled structural-acoustic finite element models [6] have been recently developed to address this problem computationally. This mode-by-mode approach requires modal damping information, and because there is considerable uncertainty associated with structural damping in particular, a potential source of variability can be immediately identified.

SOURCES OF SCATTER

The sources of uncertainty can influence the natural frequencies and response amplitudes of the panels surrounding the cabin. When the modal density of the cavity acoustic field is low as in the present case, the natural frequencies of the panels are important if they allow the panels to couple with the cavity modes. Sources of uncertainty which influence panel response amplitude are important regardless of whether coupling occurs because high panel amplitudes can force large acoustic pressures at frequencies removed from the cavity modal frequencies. Nevertheless, the worst case occurs when substantial coupling exists.

It can be argued that because of the relatively high damping of cavity modes, large shifts in natural frequency are required to alter the magnitude of coupling. Large shifts in frequency require considerable variations in the parameters which affect frequency, and the source of this variability would be evident. Hence it is reasonable to expect that parameters which affect response amplitudes and phase relationships are more likely sources of variability.

Damping Uncertainty

Energy dissipation in a built-up structure such as the automobile is made up of internal material damping, damping due to structural joints, and radiation damping. The loss factor may be written as

$$\eta = \eta_m + \eta_j + \eta_r$$

where the subscripts m, j and r refer to material, joint and radiation damping respectively.

There is considerable uncertainty about damping, including both the mechanisms by which energy is dissipated, and the magnitudes of the loss factors. Material damping loss factors can usually only be quoted to within an order of magnitude accuracy. For example, η_m is quoted as being in the range 10^{-4} to 10^{-3} for steel.

Built-up structures which are manufactured by joining skins and frames by spot welds and rivets typically have much higher loss factors than monolithic structures. Loss factors η_j of the order of 10^{-2} are common. The mechanism of 'gas pumping' has been shown to be an important contributor to the damping of structural joints. Viscous forces are generated in air which is forced to move tangential to the plane of the plate by relative flexural motion between adjacent joint surfaces. However, this is essentially a high frequency mechanism, and at the low frequencies considered here, where the bending wavelengths are an order of magnitude higher than the spot weld spacings, 'gas pumping' is not a significant mechanism. There is considerable conjecture as to how jointed structures dissipate energy at low frequencies, and experimental data is scarce.

For lightly damped aluminium aircraft structures radiation damping predominates However for motor car structures, radiation damping is much lower than the structural damping component. High radiation damping of automotive structures is not desirable as significant acoustic energy is imparted to the cavity.

Nefske and Sung [5] in their structural-acoustic modelling of automobiles employed experimentally determined modal damping data, measured decay rates being approximately 100 dB/s. This corresponds to a loss factor of 0.028 (for panel resonance at 130 Hz.

The variance of the internally-radiated acoustic power can be shown to be, for high modal overlap of cavity modes, dependent on the modal density and loss factor: the variance decreases as modal density and loss factor increase. The dependence on modal density is to be expected because the tuning of individual cavity modes becomes important as modal density decreases. At frequencies below 200 Hz the modal density of automotive cavities is small.

Phase Angle Uncertainty

The contributions of individual panels to the total sound pressure at a point is determined by the phasing of the panel vibrations, as well as their response amplitudes. There is considerable variability in the phase angle response of nominally identical vehicles, and because the authors know of no published information on phase angle scatter, some data is presented here.

The phase angle between excitation and response is shown in Figure 3 for three vehicles. The data were recorded for a position on the front floor panel. The range 100-150 Hz was investigated as this encompasses the frequencies of greatest noise level scatter. In that range the phase angle of the floor pan (measured at the seat track) has a spread of 180°.

This high level of scatter is significant because of its influence on interior noise via the polar vector diagrams [6] of panel contributions. The scatter is so great that there is possibly no recognizably unique polar diagram for nominally identical vehicles, especially when the effects of damping scatter are included. It suggests that a probabilistic interpretation of the vector diagram is required in place of the usual deterministic approach. However, further work is required to obtain a better understanding of the causes and effects of phase angle scatter.

CONCLUSIONS

Scatter of structural-acoustic origin is far more difficult to control than the scatter which originates in mechanical sub-systems. Finite element models of the vehicle structure and the cavity, and which include coupling of the panels with the airspace, have recently been developed, and they may be used as a reliability model by which the sources of scatter can be investigated.

A review of the potential sources of variability indicates that only two appear to be significant: damping and phase angle. These parameters define the polar vector diagrams for determining the panel participation in the generation of noise at a point. The sources which affect coupling with the cavity mode via shifts in panel natural frequency are deemed to be of much lesser significance.

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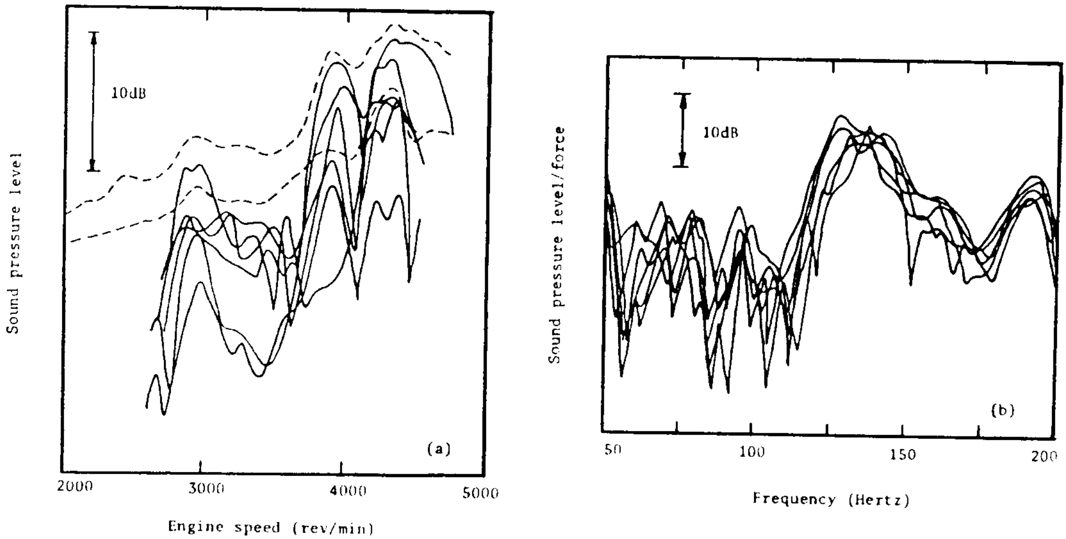


Figure 1. Scatter of interior noise levels in six nominally identical sedans. (a) Road recordings of second order noise. The dashed lines represent the envelope of total noise levels. (b) Acoustic transfer functions for the same vehicles.

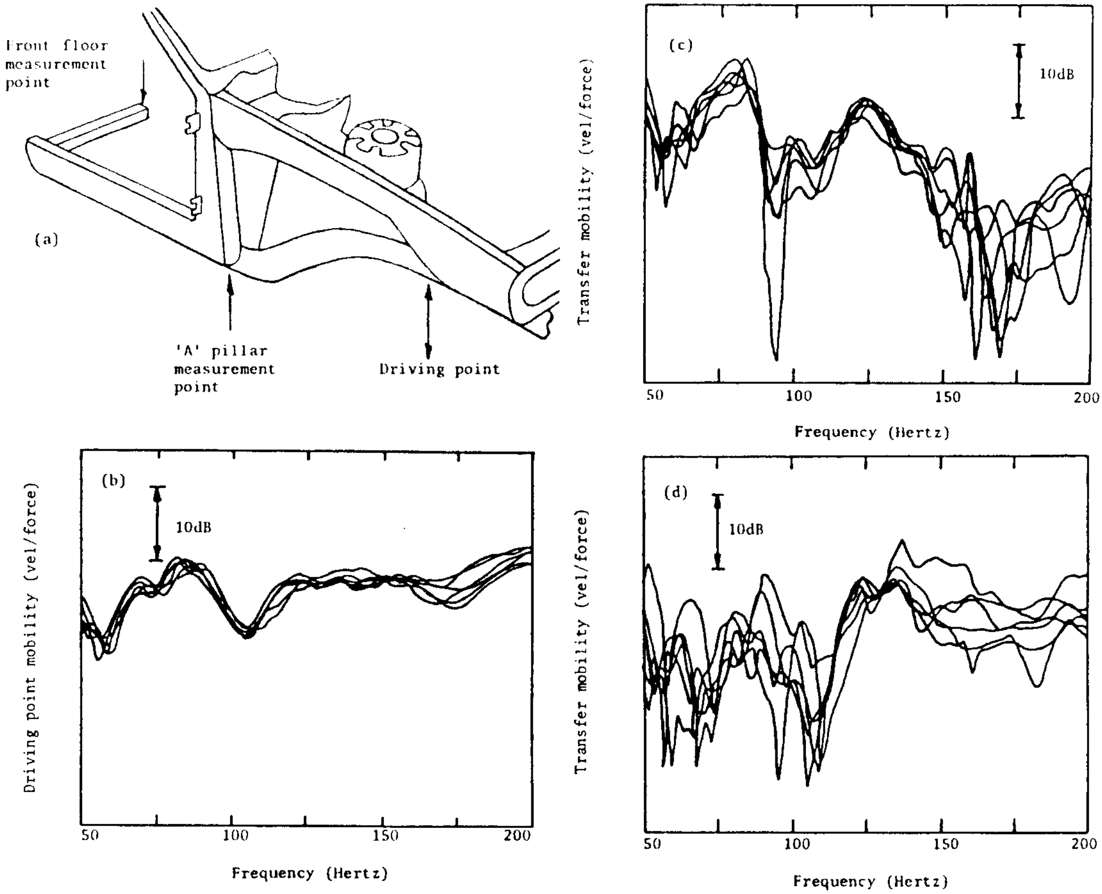
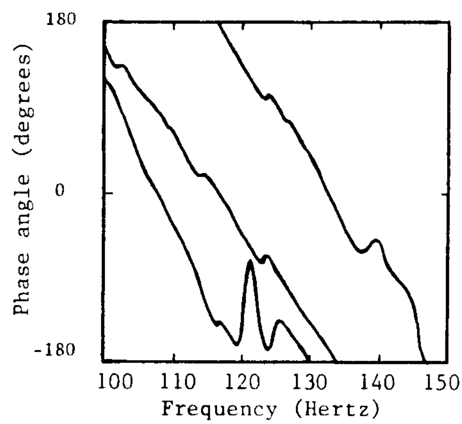


Figure 2. Mobility measurements. (a) Diagram of excitation and transfer measurement points; (b) driving point mobility. Transfer mobility measured (c) at the base of the 'A' pillar, and (d) at the front floor.

Figure 3. Phase angle scatter. Phase is measured between excitation and response of front floor panel for three vehicles.



PASSENGER CAR NOISE ON A CONCRETE BLOCK PAVEMENT

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BACKGROUND

It has been traditionally claimed that concrete block pavements provide potential road safety benefits because the vehicle noise on these pavements differs from that on asphaltic concrete pavements, thereby providing a stimulus to the driver (e.g. Hodgkinson and Morrish 1982). This advantage is seen as particularly relevant at low traffic speeds (up to 60 km/h) where the primary application of concrete block pavements lies. At higher speeds, adequate riding quality cannot be achieved on concrete block pavements (e.g. Lilley and Clark 1978; Lekso 1982) and therefore they are generally not adopted in these situations.

An extensive study of the design and performance of concrete block pavements has recently been undertaken at ARRB (Sharp and Armstrong 1985). Part of the study involved the noise generation properties of the pavement and this part is reported in the present paper. It was intended to establish both the magnitude and nature of the noise produced by the block pavement and, where possible, to relate these to comparable attributes of a smooth asphaltic concrete pavement.

ARRB STUDY

A concrete block pavement 90 m long and 4 m wide was constructed at ARRB. It was made up of shaped, 'hand sized' Unipave concrete blocks 80 mm thick laid in a herringbone pattern as shown in Fig. 1. The nominal plan dimensions of the blocks were 220 mm long by 110 mm wide and all edges were chamfered, with the chamfered area being approximately 10 per cent of the total plan area. This block pavement represents the type most commonly used in trafficked applications in Australia.

Roadside, passby noise data were collected under dry conditions (primarily for logistic reasons) as a test vehicle drove over the block pavement and over an adjacent smooth asphaltic concrete pavement. Data were collected at a microphone-vehicle trajectory distance of 15 m at vehicle speeds of 20 and 40 km/h. Four tyre types, of which two are shown in Fig. 2, were used for these tests: two sets of commercially-available tyres (Tyres 2 and 3), a set of patternless or 'slick' tyres (Tyre 1), and a set of experimental tyres (Tyre 6) that were moulded with tread patterns consisting of uniformly spaced lateral grooves. These tyres were part of a set of six used previously in Samuels (1982) in an extensive study of tyre/road noise generation. The test vehicle, a 1977 Ford Falcon XC Wagon, equipped with a 4.9 L V8 engine and four-speed manual gearbox, was originally selected as a reasonably typical example of the Australian passenger car population and it was also used in the tests described in Samuels (1982).

Also of interest was the noise generated inside a vehicle as it traversed the pavements. Interior noise levels were monitored as four cars drove over the concrete block pavement and adjacent asphaltic concrete pavement at speeds of 20 and 40 km/h. The first of these vehicles was that used for the previous tests, fitted with a commercially available set of tyres, while the remaining three vehicles were selected almost at random from the ARRB car park. Tyre type was not an experimental variable during these tests.

ROADSIDE NOISE

Linear and A-weighted driveby data collected on the concrete block and asphaltic concrete pavements are presented in Table I. Samples of these data are graphed in Fig. 3, along with similar data extracted from Samuels (1982). Inspecting first the Table I results it is apparent that there are only small differences between the overall noise levels produced by the concrete block pavement and those produced by the asphaltic concrete. It should be emphasised that the data of Table I were collected at low speeds of 20 and 40 km/h. At these low speeds, roadside noise tends to be influenced mainly by engine and exhaust noise sources, rather than by tyre/road interaction (Samuels 1982) and this may offer a first explanation of the Table I observations.

However, Sandberg (1979) has indicated that tyre/road interaction becomes the dominant source at around 30 km/h. Since the test data straddle this speed value, they must be considered to lie in a borderline area, thereby making precise interpretation difficult. This complexity may be resolved in part by frequency analysis techniques as exemplified in Fig. 4 for the experimental tyre case. On the smooth asphaltic concrete the spectrum is dominated by engine and exhaust related peaks at the lower frequencies (below 150 Hz) and a substantial, tyre-related peak at 420 Hz (Samuels 1982). Similar spectral components are also observed in the concrete block pavement curve, along with some additional low to mid frequency discrete peaks associated with the block pavement itself. In fact, these peaks are related directly to the passing frequency of the concrete block joints which, at 40 km/h, were calculated to occur at various frequencies between 75 Hz and 300 Hz. Although the two spectra of Fig. 4 are similar in overall level, they differ distinctly in spectral character. The two noise signals described by these spectra would, therefore, appear to a roadside listener as quite different. In fact the block pavement spectrum of Fig. 4 has quantified the low frequency 'thumping' sound usually associated with the passage of vehicles over such a pavement. Similar observations and conclusions were made regarding the spectra of the other data in Table I.

Returning to Fig. 3, only a small variation in noise level with speed is observed. Again, this may be explained in terms of the Fig. 4 spectra and in particular is most likely the result of the strong influence of the engine and exhaust components at these low speeds. The levels measured at ARRB are also shown in Fig. 3 to be consistent in terms of magnitude with those measured previously in Samuels (1982). The latter data noise levels decrease with decreasing speed and probably reach a lower limit or plateau at the lower speeds.

INTERIOR NOISE

Interior noise levels for each vehicle presented in Table II indicate that there are only small differences in the overall levels produced on the concrete block pavement compared with those on the asphaltic concrete pavement. The block pavement linear levels are consistently higher by around 2 dB at 20 km/h and 4 dB at 40 km/h than the asphaltic concrete pavement levels. Indeed, these levels exhibit greater between-vehicle variability on the concrete block pavement and this probably reflects the complex manner in which noise is transmitted from the tyre/road interface, through the vehicle structure and into the passenger cabin.

An important observation in Table II concerns the relative magnitudes of the linear and A-weighted noise levels. In all cases the A-weighted levels are some 37 to 41 dB lower than the linear levels, thereby indicating that the passenger cabin noise signatures are comprised of substantial low frequency components. Based on the earlier Fig. 4 data, it could reasonably be suggested that the concrete block pavement would generate primarily low frequency interior noise levels. However, considered alone, the A-weighted levels exhibit similar trends to those of the linear levels. Consequently, it would appear that the components of interior noise due to the concrete blocks have largely been masked by existing high levels of low frequency noise.

These results do not necessarily mean that vehicle passengers would not notice interior noise components associated with the concrete block pavement. As indicated previously, such components would probably comprise discrete frequency peaks which may well be readily noticed by vehicle occupants. Rather, the results suggest that the concrete block pavement had only a minor, possibly negligible, influence on the measured vehicle interior noise.

CONCLUDING REMARKS

A limited set of low speed experiments has suggested that the concrete block pavement at ARRB did not generate high levels of roadside noise. The noise levels generated were found to be very similar to those produced by an adjacent smooth asphaltic concrete pavement. However, the concrete block pavement did generate discrete peaks in the roadside noise frequency spectrum and these peaks would be readily noticed by roadside observers. For passengers inside a vehicle traversing the concrete block pavement at low speed, the noise associated with the pavement might only just be noticied. Much of the block pavement noise monitored inside four vehicles seemed to be masked by existing high levels of low frequency noise.

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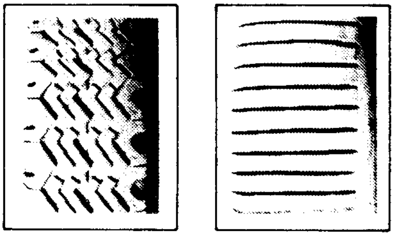
Fig 1. Section of the concrete block pavement tested at ARRB.



Tyre 4
Commercial

Tyre 6
Experimental

Fig 2. Two of the tyre types used in the tests.

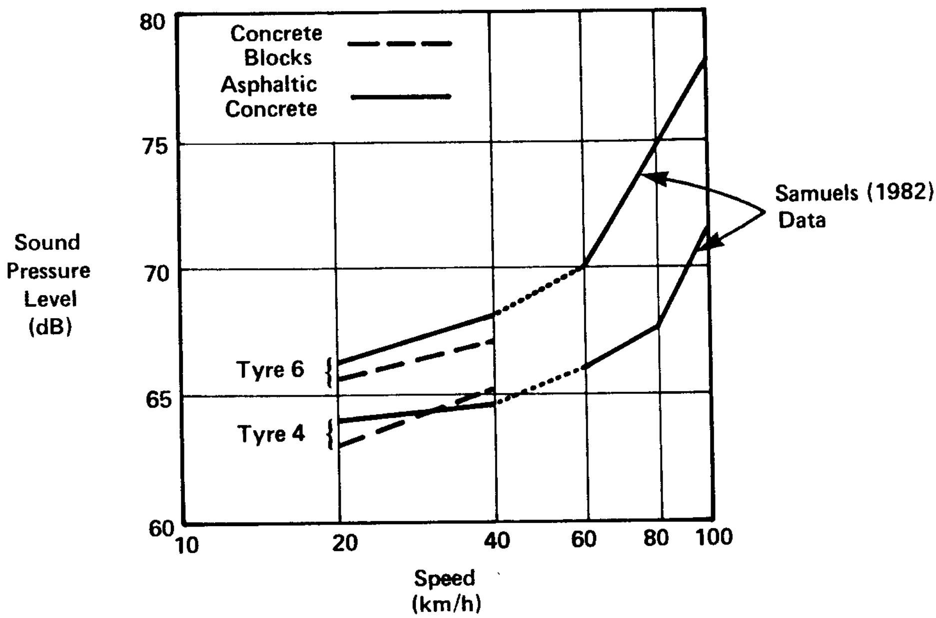


Fig 3. Driveby noise levels.

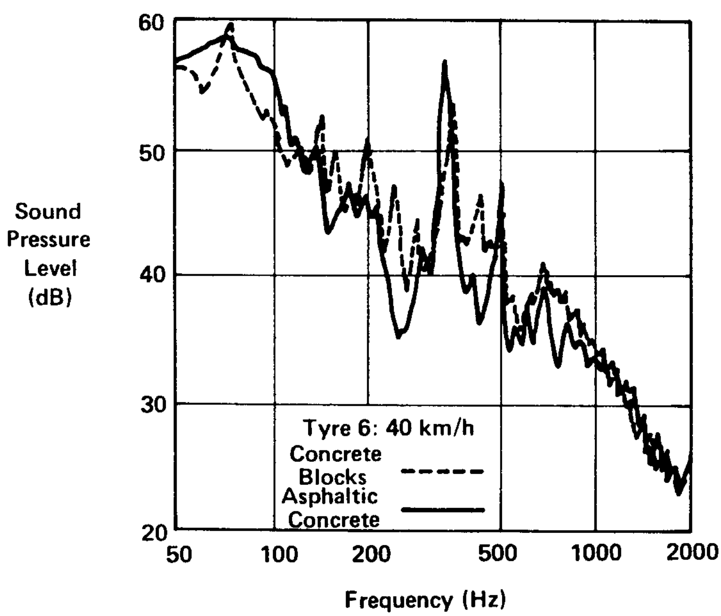


Fig 4. Driveby Spectra.

TABLE I DRIVEBY NOISE DATA
(measured at 15 m)

Data Type	Tyre	Concrete Blocks 20 km/h	Concrete Blocks 40 km/h	Asphaltic Concrete 20 km/h	Asphaltic Concrete 40 km/h
Linear (dB)	1	63.9	64.5	66.0	65.0
	2	65.5	65.0	66.8	66.7
	4	63.0	65.1	64.0	64.7
	6	65.6	67.0	66.3	68.1
A-Weighted (dB(A))	1	43.4	49.9	42.0	48.5
	2	44.3	50.6	42.1	51.1
	4	44.6	51.4	46.5	52.3
	6	46.0	54.7	51.0	57.1

TABLE II INTERIOR NOISE DATA

Data Type	Vehicle	Concrete Blocks 20 km/h	Concrete Blocks 40 km/h	Asphaltic Concrete 20 km/h	Asphaltic Concrete 40 km/h
Linear (dB)	1	99.0	105.0	97.0	101.0
	2	94.0	95.0	92.0	92.0
	3	97.0	103.0	95.0	99.0
	4	95.0	101.0	93.0	97.0
A-Weighted (dB(A))	1	62.0	64.0	58.0	60.0
	2	57.0	59.0	55.0	55.0
	3	60.0	64.0	56.0	61.0
	4	58.0	63.0	54.0	60.0

Vehicle 1 — Ford Falcon, Station Wagon
V8 motor, 4 speed manual transmission

Vehicle 2 — G.M. Commodore, Sedan
6 cylinder motor, 3 speed automatic transmission

Vehicle 3 — Ford Falcon, Station Wagon
6 cylinder motor, 3 speed automatic transmission

Vehicle 4 — Toyota Corona, Sedan
4 cylinder motor, 3 speed automatic transmission

A REVIEW OF THE CONTROL OF TRUCK NOISE USING A STATIONARY TEST

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INTRODUCTION

Noise from motor vehicles either individually or as aggregate traffic flow causes considerable annoyance to many people. The OECD in 1984 {1} affirmed that "motor vehicles are still the main source of noise discomfort in OECD countries", while a recent report from the Australian Environment Council {2} stated "Despite the introduction of a number of control measures, traffic noise remains a major environmental problem in Australia". In view of these concerns major decisions {3} have been, or are in the process of being, made in a number of overseas countries, such as those in the EEC, as to the future directions of motor vehicle controls. There are considerable pressures in Australia to reduce motor vehicle noise.

Trucks are a very important component of traffic noise but, even when new, they are permitted to be very much noisier than cars {4}. In-service, the differences in noise are likely to be even greater because trucks are more consistently operated at high engine speeds and under load with large throttle openings than cars or motorcycles. Effective control of truck noise in-service is thus a vital ingredient of any meaningful comprehensive noise reduction strategy. Particular emphasis is needed on the heavy trucks (i.e. those with gross vehicle mass (GVM) above 12 tonnes) due to their size as well as the fact that almost all of them are fitted with diesel engines, which are inherently noisier than petrol engines.

The 1.0 metre stationary close proximity test used in New South Wales seems to be a very effective tool for bringing about reductions in truck exhaust noise {5}. Over 5 years of experience has been gained in the application of this test. Although it is not possible to cover here many aspects of this experience it is the purpose of this paper to present the results of some recent survey work performed by the State Pollution Control Commission and to use these to attempt to assess the effectiveness of control of truck noise using a stationary noise test with fixed upper limits.

DEVELOPMENT OF THE 1.0 METRE STATIONARY NOISE TEST

The use of a stationary noise test for routine use in controlling on-road noise from motor vehicles was considered by various federal bodies in the mid 1970s. Following noise surveys of 556 commercial vehicles in New South Wales and 1197 in Victoria, noise limits for a 7.5 metre stationary test were established and adopted by the AEC in 1978 {6}. Limits were of necessity lenient as they applied retrospectively to all trucks and buses ever built.

The 7.5 metre test posed substantial problems for routine in-service control of noise because a very large area (45 metres square) was required, and such areas were difficult to find, while background noise sometimes interfered with the measurements.

To overcome these problems a "close-proximity" stationary test was developed with the microphone placed only 1 metre from the exhaust orifice. The simplicity of this test meant that vehicles could be stopped and tested at the side of the road thus causing a minimum of delay to the vehicle's driver.

In order to determine suitable noise limits, over 450 trucks were tested in this way in New South Wales. Vehicles over 12 tonnes with a vertical exhaust made during or before 1979 were found to have a mean noise level of 99.8 dB(A) and a standard deviation of 5.7 (based on 304 trucks tested) while those with a horizontal exhaust had a mean noise level of 104.2 dB(A) with a standard deviation of 6.3 dB (based on 59 trucks tested).

After considering the data and having discussions with the automotive industry, the AEC adopted in 1980 the 1.0 metre stationary test and related noise limits {7} which were subsequently adopted in the NSW Noise Control Regulation.

SURVEY AIMED AT INDIVIDUALLY NOISY TRUCKS

At selected locations total traffic flow over a set period was recorded. Any vehicles subjectively assessed to be noisy were selected for testing.
The criterion for selection was not whether the vehicle would fail the Regulation limit or not but whether it was considered to be excessively noisy. From a total traffic flow of 11927 vehicles 2900 (24.3%) were trucks of which 49 (1.7%) were thus assessed noisy. Table 1 shows the noise test results for these vehicles:

TABLE 1: ROAD SIDE SURVEY OF INDIVIDUALLY NOISY TRUCKS

Date of manufacture and gross vehicle mass	No. tested, exh. type. V=vertical* H=horizontal	Regulation limit dB(A)	Number failing {Ave. noise level dB(A)}	Number passing {Ave. noise level dB(A)}
Above 12t:				
pre 1/7/80	20V	105	10(108)	10(102)
	2H	109	1(110)	1(108)
1/7/80 - 83	4V	102	-	4(96)
post 1/7/83	2V	99	1(101)	1(98)
Subtotal of trucks > 12t.	28	-	12	16
Trucks ≤ 12t	5	Various	0	5(93)
TOTAL	33	-	12	21

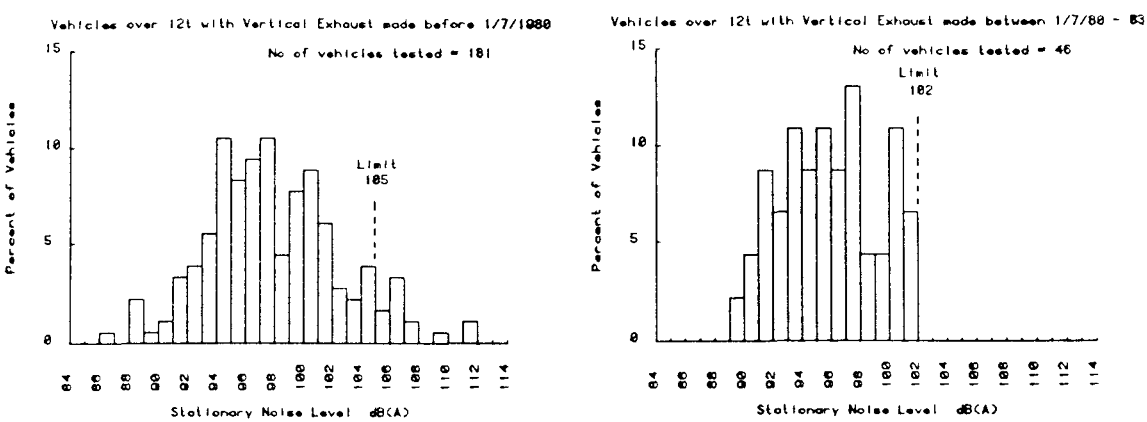
*Almost all vehicles made after 1/1/1976 must have vertical exhausts under the Clean Air Act. A vertical exhaust is defined as one where the outlet is greater than 1500 mm above the ground.

Overall 1.7% of all trucks were perceived to be outstandingly noisy. Based on the results of the 33 trucks (which are felt to be a representative random sub sample of the 49) it can be seen that more than 60% of these noisy trucks do not fail the Regulation limit; this indicates that the limits are inadequate for control of the "tall poppies" of the truck fleet. It is interesting to note that the average noise levels of the vehicles passing the noise test are only marginally below the Regulation limits, with all but two of the heavy trucks above 95 dB(A).

SURVEY FOR ASSESSING THE OVERALL POPULATION

Trucks were selected at random from the traffic stream at various locations such as Port Botany and on main highways at Wollongong and Berowra. The criterion here for vehicle selection was on the basis of an observer (located some distance from the test site and who could not hear the truck) picking the next large truck which came into view after the previous truck had been tested. Vehicle details were relayed to Commission officers further down the road who stopped and tested the truck.

Figures 1 & 2. TRUCK NOISE SURVEYS : 1983 - '85



The results for trucks with a gross vehicle mass (GVM) greater than 12 tonnes are shown in Figures 1 and 2, and in Table 2.

TABLE 2: ROADSIDE NOISE SURVEY OF RANDOMLY SELECTED TRUCKS GREATER THAN 12 TONNES

Period of manufacture	No. tested, exh. type	Ave. noise level dB(A)	Standard deviation dB	Reg. limit dB(A)
pre 1/7/80	181 V	98.6	4.8	105
	17 H	101.2	5.1	109
1/7/80 - 83	46 V	96.4	3.4	102
	0 H	-	-	106
post 1/7/83	8 V	94.1	4.0	99
	0 H	-	-	103

'For heavy trucks (that is those with a GVM greater than 12 tonnes) the mean noise levels have decreased substantially:

- the mean for trucks with horizontal exhausts made before 1/7/80 was 104.2 dB(A) in 1979 and 101.2 recently (Table 2). This decrease is significant (at the 95% level).
- similarly those with vertical exhausts made before 1/7/80 have decreased from 99.8 to 98.6 dB(A) (Table 2). This decrease is also significant (at the 95% level) and like that described above for trucks with horizontal exhaust could only be explained as a result of SPCC enforcement activities.

. average noise levels for trucks with vertical exhausts in each of the categories of manufacture dates have decreased steadily:

- pre 1/7/80 : 98.6 dB(A) vs a limit of 105

- 1/7/80 to 83 : 96.4 dB(A) vs a limit of 102; this decrease of 2.2 dB is significant at the 99% level, and could have occurred as a result of the introduction of ADR 28A as from 1/7/80 and/or due to SPCC enforcement activity.

- post 1/7/83 : 94.1 dB(A) vs a limit of 99; this further decrease of 2.3 dB is just significant at the 90% level and could only be due to the effect of the NSW Noise Control Regulation and the Commission's enforcement activity.

Referring to Fig 2, no trucks failed the limit of 102 but a fair percentage are only just under the limit. Fig. 1 shows that about 8.3% of trucks built before 1 July 1980 exceeded the specified noise limit, and appropriate action was taken on these vehicles under the Noise Control Regulations.

SURVEY OF PASS-BY NOISE

In a special survey carried out at Berowra, the pass-by noise level for every truck was recorded by placing the microphone at a position designed to give noise levels that could be compared with the limits in ADR 28A. The practical on-road differences in gear selection, speed and distance to the microphone (some vehicles were closer than 7.5 m, some further away) contributed to the scatter in the data. Over a period of 3 days, 687 pass-by noise measurements were recorded of which 309 applied to trucks above 12 tonnes; these results are shown in Figure 3 and have a mean of 85.6 dB(A) with a standard deviation of 3.0 dB. 78 of these vehicles were selected on a random basis (as described in the previous section) and tested for stationary noise; the pass-by noise levels for these trucks are shown in Figure 4 and have a mean of 85.9 dB(A) with a standard deviation of 3.7 dB(A). Comparing the two samples, there is neither a statistically significant difference (at the 95% level) between the two means nor the two standard deviations. Therefore the 78 trucks selected at random and stationary noise tested can be taken as being representative of the overall sample of 309 trucks.

Figures 3 & 4. BEROWRA TRUCK NOISE SURVEY

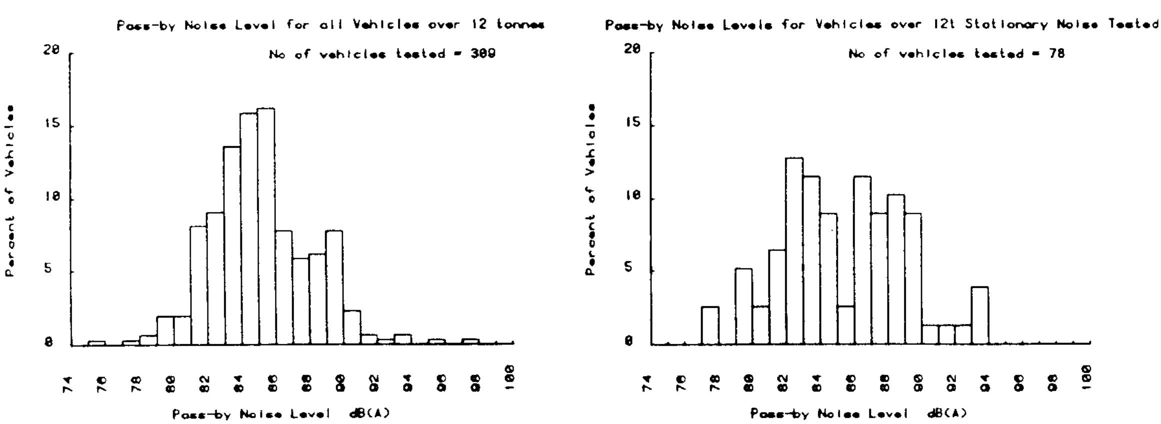


Figure 5. BEROWRA TRUCK NOISE SURVEY

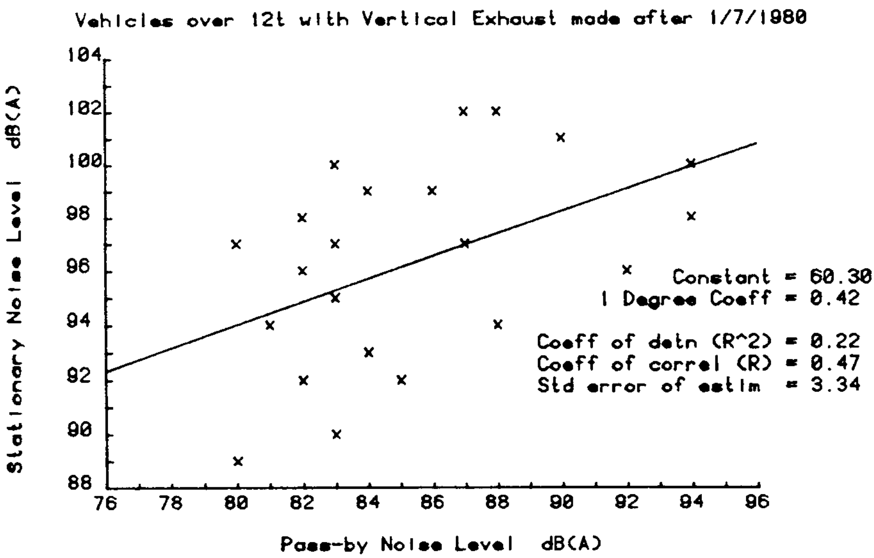


Figure 5 shows the stationary and pass-by noise levels for trucks greater than 12 tonnes built after the 1st July 1980. The mean and standard deviation for these 23 vehicles are 85.3 dB(A) and 4.1 dB respectively and are not statistically significantly different (at the 95% level) from the overall sample of 309 vehicles greater than 12 tonnes. From this it can be concluded that these samples are probably representative of the overall population of trucks.

The slope (0.42) of Fig. 5 differs significantly (at the 95% level) from a slope of zero. Therefore it can be said that stationary noise is definitely correlated with (real-on-road) pass-by noise. This is not unexpected considering that a Research Project by the AEC {5} showed a highly significant slope of 0.99 between drive-by levels according to the well-defined conditions of the ADR 28A test procedure and the stationary test levels.

It does therefore appear, because of this correlation, that the 99 dB(A) noise limit is at least partly effective in controlling on road drive-by noise levels. This is because exhaust noise is a dominant feature {8} of total vehicle noise.

CONCLUSION

The survey results outlined in this paper show:

- more than 60% of trucks assessed to be noisy did not fail the stationary noise test limits. This indicates that the various limits are far too lenient for effective control of excessively noisy trucks.
- mean noise levels for trucks have decreased substantially since the late 1970s partly due to the introduction of ADR 28A but mainly due to the stationary noise Regulation and SPCC's enforcement of it.
- stationary noise is correlated with pass-by noise (real-on-road) as well as ADR 28A drive-by noise and hence the 99 dB(A) noise limit contributes to the control of on-road drive-by noise.

REFERENCES

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{2} Australian Environment Council "A Reappraisal of Motor Vehicle Noise Controls in Australia", May 1985.

{3} Commission of the European Communities, "Proposal for a Council Directive amending Directive 70/157/EEC.", Report No. COM(83) 392 final, Brussels, 27 June 1983.

{4} Commonwealth Department of Transport, "Australian Design Rules 28 and 28A for Motor Vehicles Noise", July 1972 and March 1976 respectively.

{5} Australian Environment Council, "A Comparison of Methods for Measuring the Noise of Individual Motor Vehicles", November 1983, revised January 1984, 174 pages.

{6} Australian Environment Council, "Technical Basis for Regulations for the Control of Noise from In-Service Motor Vehicles in Australia", February 1978.

{7} Australian Environment Council, "Technical Basis for Regulations for the Control of Noise from In-Service Motor Vehicles in Australia", February 1980.

{8} Meredith Rogers, Lex Stewart, "An Evaluation of Some Motor Vehicle Noise Test Procedures", Paper No 32, 1984 Australian Acoustical Society Conference.

A REVIEW OF THE CONTROL OF MOTOR CAR NOISE USING A STATIONARY TEST

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INTRODUCTION

In the early 1970's noise from motor vehicles became a matter of environmental concern, and the need to control this noise source came to be recognised.

The first two decisions in introducing more widely applicable noise controls on vehicles were taken in 1972 and 1976 to introduce Australian Design Rules (ADRs) 28 and 28A [1] which were based on EEC Directives [2]. These rules apply to new vehicles and are not practical tools for controlling the problem of individual vehicles that become excessively noisy while in-service, due either to deterioration of the exhaust system or to tampering, defined as the fitting of modified or non-standard components producing a noisier vehicle than was originally designed.

For control of in-service noise from vehicles a much simpler test was required. The stationary exhaust noise test from ISO standard 5130[3] was chosen, but without the deceleration mode, which gave less repeatability than was desired [4]. From widespread survey work mainly in Melbourne and Sydney a limit of 96 dB(A), to be applied retrospectively was deduced as an approximate discriminator between cars with grossly noisy exhaust systems and other cars. This limit and test procedure were then recommended to, and endorsed by, the Australian Environment council (AEC) in 1978 [5] and adopted into State Legislation.

As experience was gained in controlling in-service noise from cars in this way, it became evident that the 96 dB(A) limit was too lenient for effective control and that almost all cars when new had exhaust noise levels beneath 90 dB(A). In 1982 therefore, the AEC revised its Technical Basis for cars made after 1st January 1983 to meet a limit of 90 dB(A) and this was accordingly written into NSW legislation [6].

It was recently considered desirable to assess what improvements might have been effected by the State Pollution Control Commission's ongoing enforcement of Regulations and the introduction of the 90 dB(A) limit. To this end, a further survey of cars in Sydney along the same lines as the earlier surveys in 1976 was performed. 313 cars were tested, compared to 421 almost a decade ago.

The major purpose of this paper is to assess the results of these two surveys.

SURVEY METHODOLOGY

Sampling Procedure

The tests in both 1976 and 1985 were conducted at a number of major shopping centres in Sydney, selected because of their high turnover of cars together with the availability of appropriate testing areas. It is acknowledged that the samples of cars tested contain a bias towards female drivers and the "second" car. However it is felt that this bias was very similar in each survey and that valid comparisons can therefore be made.

Test Procedure

Cars presented for test were subjectively assessed as being noisy or non-noisy on approach to the site and a subsequent "rev-up". The exhaust system condition (standard or non standard, faulty or non faulty) was determined by visual inspection and driver interview. The stationary noise tests were then conducted in accordance with the NSW Regulation procedure[6].

The classification of a car into the "noisy" or "non-noisy" categories involved a subjective assessment by the testing officers. The interpretation as to whether an exhaust system was standard or non-standard and faulty or non-faulty also involved some judgements. There would therefore be some differences between the 1976 and 1985 surveys. Because the officers involved were both skilled in noise measurement and familiar with motor vehicle hardware, it is felt that the differences are small, or, if anything, tending to favour a marginal vehicle being assessed as noisy in 1985 but non-noisy in 1976. It is obviously impossible to backtrack and check these matters, so the following analyses are based on the assumption that the same criteria were used in 1976 as in 1985. Details of the survey statistics are not presented here, but are available from the Commission[7].

RESULTS

Average Noise Levels

The mean noise levels of some subsets of the data are presented in Table 1 below. Arithmetic averaging has been used.

TABLE 1: MEAN STATIONARY NOISE LEVELS OF CARS IN THE 1976 AND 1985 SURVEYS

SURVEY DATE	DATE OF VEHICLE MANUFACTURE	"NON-NOISY" dB(A)		"NOISY" dB(A)		TOTAL dB(A)	
1976:	all	86.5	s = 3.6 n = 381	98.2	s = 3.4 n = 40	87.6	s = 4.9 n = 421
1985:	all	86.5	s = 4.2 n = 287	93.9	s = 3.8 n = 26	87.1	s = 4.6 n = 313
1985:	pre 1/1/83	86.9	s = 4.0 n = 252	93.9	s = 3.8 n = 26	87.5	s = 4.5 n = 278
1985:	post 31/12/82	83.9	s = 4.4 n = 35	N/A	- -	83.9	s = 4.4 n = 35

Salient features of the data in Table 1 are as follows:

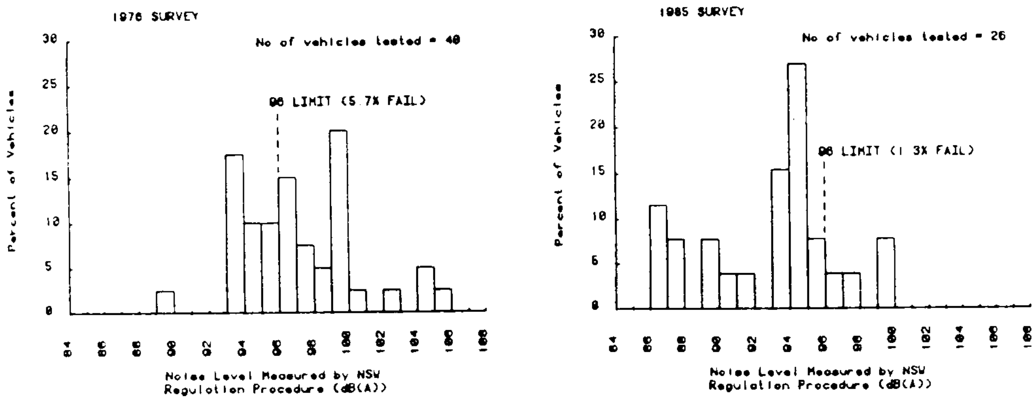
- The mean stationary noise level of the whole car fleet appears to have changed from 87.6 dB(A) in 1976 to 87.1 dB(A) in 1985, but this is not statistically significant (i.e. only at the 80% confidence level, rather than at the usual yardstick of 95%); this small change can be explained by significant changes in some sub-populations as described below.

- the mean noise level of "non-noisy" cars made before 1/1/83 has not changed (86.5 to 86.9 is not significant); this fact tends to support the view that the criteria used for assessment of noisiness (acknowledged above to have been subjective) were reasonably consistent.

- the mean noise level of "non-noisy" cars made after 1/1/83 is 83.9 dB(A). This differs highly significantly (99% confidence) from the mean noise level of 86.9 for the "non-noisy" cars in the 1985 survey made before this date. This improvement is most probably a direct result of the lower standard (90 dB(A)) applying to new cars. As more cars made after 1/1/83 are sold, with older ones being scrapped, the fleet average noise level can be expected to decrease further than the change from 87.6 to 87.1 dB(A) already achieved. If enforcement of the 90 dB(A) standard is reasonably thorough then this average will be down to close to 83.9 dB(A) by the year 1998. This would be a substantial gain for the environment.

- the mean noise level of "noisy" cars has changed significantly from 98.2 down to 93.9 dB(A); details are shown in Figure 1:

FIGURE 1: STATIONARY NOISE LEVELS ON ALL NOISY CARS



These changes are of substantial environmental benefit, as it has been established [8,9] there is a reasonable correlation between annoyance from vehicles on the road and their stationary noise levels. There could be three reasons for these improvements:

- ADR 28 (applying to cars made after 1/1/74) has brought about lower stationary noise levels as well as lower driveby levels. The 1976 survey was mostly composed of pre-ADR 28 cars, while few ADR 28A cars (made after 1/1/81) were included in the 1985 survey's pre-1/1/83 subset.

- enforcement action by the State Pollution Control Commission has been effective in culling out many cars with noise levels above 96 dB(A).

- an increased community awareness of noise control and the Commission's enforcement programme have led to consumers and mufflers fitters selecting quieter non-standard exhaust systems when initially fitted.

<u>Numbers of Cars and Failure Rates in Various Categories</u>

The table below presents the numbers of cars in each category and the numbers with noise levels in excess of 96 dB(A).

TABLE 2: COMPARISON OF CATEGORIES AND FAILURE RATES

			1976 SURVEY		1985 SURVEY(*)	
			CARS TESTED	CARS FAILING	CARS TESTED	CARS FAILING
Non Noisy	Standard	Non Faulty	356	1	253 (34)	3 (1)
" "	"	Faulty	11	0	8 (0)	0
" "	Non Std	Non Faulty	14	1	24 (1)	0
" "	"	Faulty	0	0	2 (0)	0
			381	2	287 (35)	3 (1)
Noisy	Standard	Non Faulty	17	10	3 (0)	0
"	"	Faulty	3	1	4 (0)	0
"	Non Std	Non Faulty	20	13	18 (0)	3
"	"	Faulty	0	0	1 (0)	1
			40	24	26 (0)	4
	TOTAL		421	26	313	7 (2)

(*) The numbers in brackets refer to the subsample of cars made on or after 1/1/83.

From these results it appears that:

- There are fewer "noisy" cars now than in 1976. The decrease from 9.5% (40/421) to 8.3% (26/313) is statistically significant at the 95% level. The three possible reasons for this beneficial trend are mentioned above.
- There are no"noisy" cars in the sub-sample of the 1985 survey made after 1/1/83. This is most probably explained by the fact that very few of these cars, aged between 0 and 2½ years, would have suffered significant muffler deterioration or have been tampered with.
- The proportions of faulty standard systems are very similar (11 + 3/421) compared to (8+4/313) and such a small difference might be explained by the slightly higher average age of the 1985 fleet (6.65 vs 5.94 yrs[10]).
- In 1976 the overall failure rate was 6.2% and almost all of these were classified as "noisy", whereas in 1985 the failure rate (at 96 dB(A)) was 2.2% with 1.3% or only about half of these being classified as "noisy". This shows a dramatic improvement in the numbers of these "noisy" vehicles. If this improvement applies to the whole fleet which has grown in NSW from 1,950,000 to 2,610,000 [10] then there are now 80,000 fewer "noisy" cars with noise levels above 96 dB(A) than there were in 1976.
- The "non-noisy" non-standard non-faulty category has risen quite strongly from 3% (14/421) to 7½% (24/313) indicating an increased prevalence of fitment of what may be termed "custom-made" exhaust systems; this same trend is reflected in the "noisy" non-standard category - up from 4.8% (20/421) to 6.1% (18+1/313).

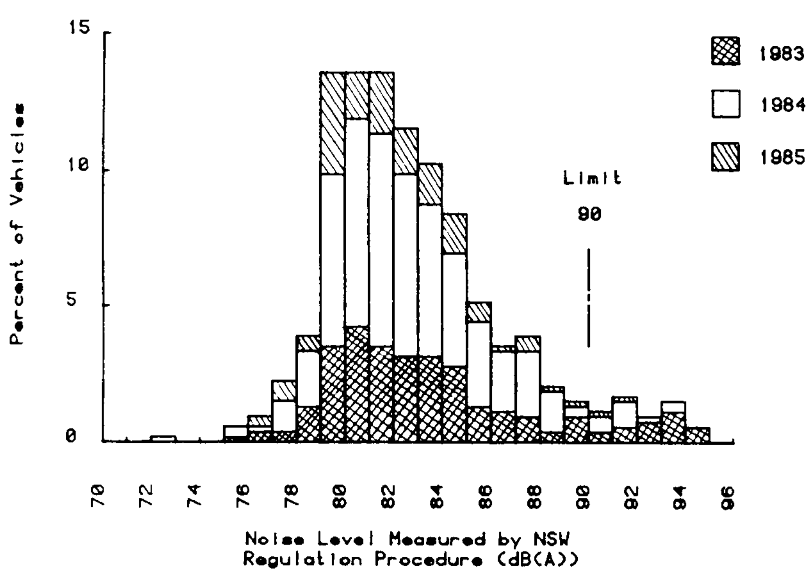
- The failure rate (at 96 dB(A) for "noisy" custom-made exhaust systems has dropped dramatically from 65% (13/20) to 17% (3/18). It appears that the Commission's enforcement programme, though modest due to limited resources has had substantial impact on the behaviour of this section of the muffler market. Even though these cars are still classified as "noisy", they are still a lot quieter (4.3 dB as shown above) than previously.

Deterioration

Apart from tampering, the other major factor that can lead to a vehicle becoming excessively noisy in-service is deterioration of the exhaust system. As the median age of cars is around 14 years [11], while their mufflers mostly last between 3 and 5 years [12], it is plain that the quality of replacement mufflers and the ways in which they deteriorate are important considerations.

Fortunately, it appears that deterioration is usually slightly negative - i.e. noise levels decrease with time - until gross failure occurs, at which stage most owners replace the muffler etc with a minimum of delay. This view is widely held in the automotive industry, and there are good theoretical grounds for assuming that deterioration follows this pattern in that the gradual buildup of deposits (carbon/lead particles etc) absorbs some acoustical energy until corrosion causes a hole to appear or a muffler baffle to collapse. The limited data available to the Commission support that view; part of this data is the sales-weighted testing on 548 new cars with mean 83.9 dB(A) and standard deviation of 3.7 dB. This sample was on a sales-weighted basis, except for a greater frequency of cars above 90 dBA). More of these cars were tested to obtain a broader basis for discussions with manufacturers, all of whom successfully fitted revised exhaust systems as well as making them available as the standard replacement parts. Even considering the few extra cars above 90 dB(A), this sample of new cars does not differ significantly from the data in Table 1 for in-service cars made after 1/1/83. If deterioration is important then it is certainly not evident in these data.

FIGURE 2: STATIONARY NOISE LEVELS OF NEW CARS MADE IN 1983, 1984 AND 1985.



CONCLUSIONS

1. There are fewer "noisy" cars now than in 1976, when 5.7% of in-service cars failed the proposed 96 dB(A) limit and were classified as "noisy". In 1985 this category comprised 1.3%.
2. The average stationary noise level of subjectively noisy cars has decreased from 98.2 to 93.9 dB(A), a very worthwhile gain.
3. Deterioration of stationary noise has not been demonstrated to occur to a significant extent.
4. More "custom-made" exhaust systems are now being fitted. Although some are still "noisy", they are a lot quieter than in 1976.
5. The introduction of the 90 dB(A) limit has had very significant benefits:
   - the mean stationary noisy level of "non noisy" cars made after 1/1/83 has decreased by 3.0 decibels compared to pre-1983 cars.
   - no "noisy" cars made after 1/1/83 were detected.
   - the fleet average stationary noise level by the year 2000, assuming continued enforcement of stationary controls, should be around 84 dB(A), compared to 87.6 in 1976, and 87.1 in 1985.

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A BRIEF ANALYSIS OF EIGHT YEARS OF MOTOR VEHICLE NOISE TESTING IN VICTORIA

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INTRODUCTION

In 1976 the Government of Victoria passed legislation which set exhaust noise limits for passenger cars used on public roads. The Environment Protection Authority (EPA) was given the responsibility for enforcing these limits, and testing began in August 1977. Noise limits for trucks, buses and motorcycles were introduced in 1978 and testing of those vehicles began in that year.

All vehicles tested by the EPA have been subjectively assessed as noisy by either an EPA inspector or a member of the Victoria Police. Subjective assessment of motor vehicle noise has been recommended by Kassler et al [1] as a highly effective means of detecting both excessively noisy vehicles and vehicles with defective exhaust systems. Until 1984 owners were required by a mailed notice to present their vehicles at an EPA testing station for a noise test. Since 1984, however, EPA has also been testing vehicles at the roadside with the assistance of the Victoria Police.

The EPA has now tested over 16,000 noisy vehicles. The current annual testing rate is approximately 3,000 per year.

Complete records of tests have been kept since 1977. These records have been analysed for the years 1978-1984 using a sample of 25% of the total number of vehicles tested in each year. The number of vehicles tested in 1977 was considered too small to be of significance in the analysis.

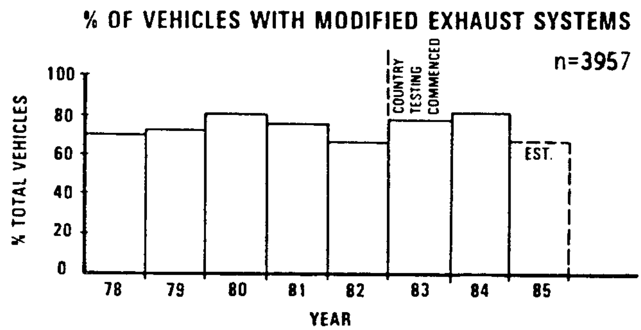
ANALYSIS OF EXHAUST SYSTEMS

Modified Exhausts

The great majority of noisy vehicles had modified exhaust systems fitted at the time of observation (Figure 1). (A modified exhaust is one which uses non-standard components or which has a non-standard layout). The proportion was increasing when controls were introduced, and reached a peak of 80% in 1980. The drop to 67% in 1982 is attributed to an increased awareness of the program by the public and the professional muffler fitters. It is worth noting that there is evidence, particularly in the case of motorcycles [2] that exhaust modifications may adversely affect engine performance.

In 1983 the EPA commenced testing in country areas, and it was immediately obvious that the proportion of vehicles with modified exhaust systems was much higher than in the metropolitan area. In Warragul, for example, the proportion was 95% of those tested. In Benalla, it was 91%, and in Shepparton 87%. As a result, the overall proportion jumped from 67% in 1982 to 79% in 1983. From a peak of 80% in 1984 it appears from figures for the first half of 1985 that the proportion is falling again. This is presumably due to the improved awareness of the program in country areas.

FIGURE 1



ANALYSIS OF THE AGES OF SUBJECTIVELY NOISY VEHICLES

Passenger Cars

An analysis of the ages of vehicles subjectively considered to be excessively noisy shows some interesting trends. The median age of noisy cars is steadily rising, from 6.6 years in 1978 to 10.5 years in 1984 (Figure 2a). A major factor contributing to this rise is the high proportion of noisy cars which are Holdens and Fords made in the period 1971 - 1974, particularly HQ Holdens. In 1978 HQ Holdens made up 28% of the noisy car population. In 1984 the proportion was still a surprising 17%. In contrast, 19% of noisy cars were less than 5 years old in 1978, but in 1984 the proportion had fallen to just 3%. One explanation for this trend may be that the older, pre-air emission control cars are cheaper, can be more easily modified, and were available with high performance engines.

Motorcycles

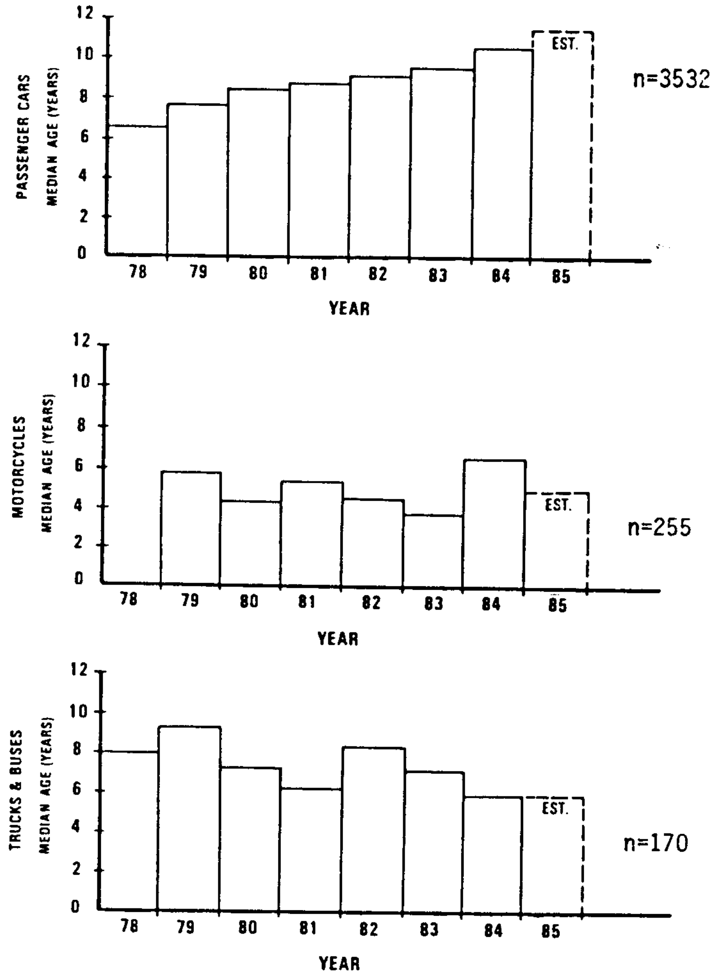
The median age of noisy motorcycles has remained fairly constant at around 5 years (Figure 2b). This is probably due to the relatively short lifespan of motorcycles [3] and the ease with which modifications can be made to engines and exhaust systems.

Heavy Diesel Trucks

The median age of heavy diesel trucks has dropped from 8 years in 1978 to 6.1 years in 1984 (Figure 2c). There is no immediately apparent reason why this drop should occur. The low median age may reflect the relatively short life-span of trucks.

FIGURE 2a-c

MEDIAN AGES OF VEHICLES TESTED



ANALYSIS OF THE NOISE LEVELS OF VEHICLES TESTED AT THE ROADSIDE

Figures 3a-c show the noise levels of all subjectively noisy cars, motorcycles and heavy diesel trucks tested at the roadside between October 1984 and June 1985. Vehicles were tested if they stood out as noisy in the general traffic stream. In other words, these are the 'tall poppies' in the traffic stream. These vehicles cause annoyance to the community far above that due to their contribution to bulk traffic noise levels, because their higher noise levels can cause significant sleep disturbance [4].

All cars tested were manufactured before 1 November 1983 and were therefore subject to a limit of 96 dBA. Similarly, all motorcycles tested had to meet a limit of 100 dBA and heavy trucks had a limit of 95 dBA.

Passenger Cars

Figure 3a shows that around 40% of all subjectively noisy cars actually passed the test. The obvious conclusion is that the 96 dBA limit does not reflect the subject assessment and that a lower limit is appropriate. The analysis indicates that the 90 dBA limit, introduced in Victoria for cars made on or after 1 November 1983, more accurately reflects the subjective assessment of noisiness at present. Only 5% of cars considered to be noisy fall below this level.

Heavy Diesel Trucks

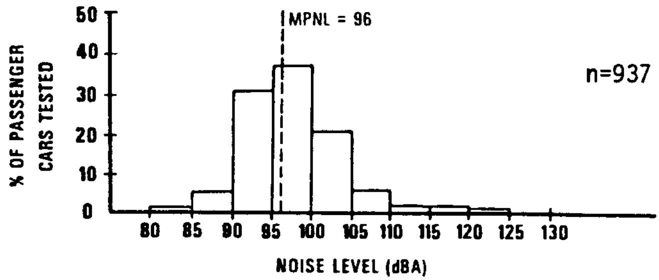
An alarming 86% of heavy diesel trucks assessed as being subjectively noisy fell below the 95 dBA maximum (Figure 3b). The implication is that 95 dBA is a totally inappropriate limit. If we accept the standard that the in-service limits should cause the same proportion of cars, motorcycles and trucks to fail, then a more appropriate limit for heavy diesel trucks would appear to be around 86 dBA. Clearly, a review of current heavy truck noise limits is needed.

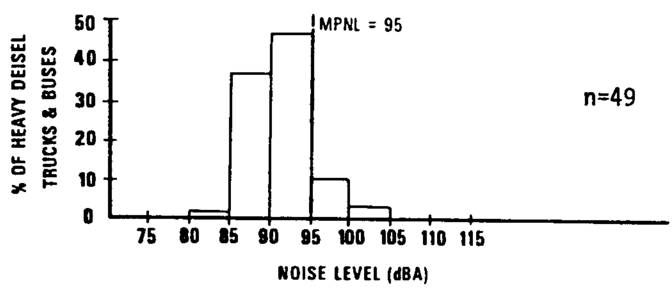
Motorcycles

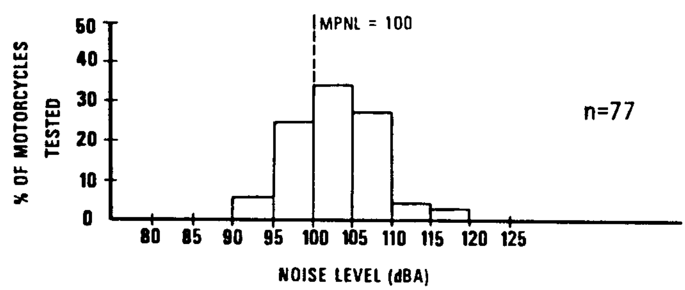
30% of motorcycles considered to be noisy fell below the 100 dBA limit, indicating that this level does not reflect the subjective assessment (Figure 3c). The 94 dBA limit, introduced in Victoria for motorcycles made on or after 1 March 1985, more accurately reflects the subjective assessment at present. Approximately 5% of subjectively noisy motorcycles would fall below this limit.

FIGURE 3 a-c

VEHICLE NOISE LEVELS — ROADSIDE TESTING







Discussion

Registration figures for recent years shows that the proportions of cars, trucks and motorcycles registered in Victoria are around 84%, 10% and 6%, respectively [5]. This indicates that the major contributors to bulk traffic noise levels will be cars. The contribution of trucks, motorcycles will be somewhat smaller. The justification for lowering bulk traffic noise levels has been well demonstrated [6]. In order to achieve this lowering, it would appear that the emphasis will need to be placed on cars and trucks. Lower levels for trucks can also be justified because they are already 'tall poppies' which cause annoyance because of their high individual noise levels. Although there is some justification for lowering motor cycle levels (approximately 5% of those judged subjectively noisy fall below the current limit), the need is not as pressing as for cars and trucks.

CONCLUSIONS

Most noisy vehicles are fitted with modified exhaust systems. Noisy passenger cars tend to be considerably older than noisy trucks or motorcycles. The median ages of passenger cars, trucks and motorcycles are currently around 11, 6 and 5 years respectively. There is a clear need to lower heavy diesel truck noise levels, but the need for lower motorcycle noise levels is less pressing.

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