THE ECONOMICS

OF

NOISE CONTROL

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THE ECONOMICS OF NOISE CONTROL

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AUSTRALIAN ACOUSTICAL SOCIETY
(Inc. NSW)

ANNUAL CONFERENCE

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TANUNDA S.A.

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THE ECONOMICS OF NOISE CONTROL

AUSTRALIAN ACOUSTICAL SOCIETY
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PROGRAMME (Contd)

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THE ECONOMICS OF CONTROLLING NOISE AT THE SOURCE

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1. INTRODUCTION

During the past two decades, public and private organizations around the world have attempted to control environmental and occupational noise exposure by various means and with varying degrees of success. In the United States, regulation has been the primary stimulus for reducing noise levels. Throughout this period several states and hundreds of municipalities developed noise ordinances for purposes of environmental noise abatement. Environmental noise control became a focused national concern with the passage of the Noise Control Act of 1972. Occupational noise exposure limits had been specified in 1969 by the Walsh Healy Public Contracts Act and were subsequently embodied in the Occupational Safety and Health Act of 1970. Similarly, the Federal Coal Mine Safety and Health Act of 1969 addressed the issue of noise control in coal mines and was superseded by the Federal Mine Safety and Health Act of 1977, which applies to mines in general. The regulations issued under these statutes have been partially effective in fostering the development of some new quieter products and the installation of retrofit control devices.

The U.S. public sector has also funded noise control research in selected areas. Some of these efforts have demonstrated substantial progress and accomplishments, particularly in transportation. Although many airport neighbors still believe strongly that they are exposed to unacceptably high noise levels, it is significant that present wide body DC-10 and L-1011 aircraft are about 10 to 15 EPNdB quieter than earlier 707s and DC8s. This noise reduction is an outgrowth of the application of more efficient high bypass turbofan engines to reduce jet noise and of nacelle liners to reduce fan noise. It is noteworthy that these aircraft and engines were developed by technologically sophisticated companies employing a large number of acoustical specialists. Although some of their research and development was sponsored internally, much of the progress made by these companies is attributable to millions of dollars in funding from NASA and other governmental agencies for technological development programs [1].

On the other hand, noise control progress in manufacturing and process industries has been less dramatic, for many reasons. Industrial machines vary enormously in design, function, and operation, are generally produced in limited quantity, and have a long useful life. As a consequence, the cost of noise control must be amortized over relatively few units, and replacement of noisy old machines with quieter new units is often slow and of little immediately perceived impact. Much of this machinery is manufactured by small- to medium-sized firms, few of which are prepared to hire and equip a group of noise control engineers. Moreover, the United States has not had a program to assist broadly in funding the development of industrial machinery noise control technology. Thus, instead of being able to design machinery to be quiet at the outset, manufacturers and users have tended to add noise treatment to machines that are already built.

The consequences of treating existing machines, primarily through a retrofit program, have been investigated by Bruce, et al. for U.S. industries. His studies have shown that these treatments would affect 13 million production workers, of which approximately 4.5 million are exposed to 85 dBA or higher. It would cost $10 to 14 billion to bring American industry into compliance with a 90 dBA OSHA criterion* and $18 to 32 billion to reduce noise levels to an 85 dBA eight-hour equivalent level [2,3]. To place these figures in perspective, one should recog-

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*The OSHA noise standard uses the 5 dB per time doubling rule, or 95 dBA for 4 hours, etc.

nize that the total estimated costs of complying with a 90 dBA regulation in the durable goods industries would be 3-1/2 times as much as those industries spend in one year to abate air, water, and solid waste pollutants combined.

In a similar study Gibson and Norton [4] considered the costs and benefits of industrial noise control in Australia. They found that it could cost Australian industry $A246.1 million to install noise treatment to protect 417,040 production workers, of whom 20 to 26% are exposed to levels above 90 dBA for eight hours. The benefit to the industry is primarily a reduction in hearing compensation liability, which was at a theoretical level of $A131 million in 1975. However, actual annual payments for hearing impairment amount to only a few million Australian dollars.

Clearly, there appears to be little financial incentive for United States or Australian industries to undertake a comprehensive retrofit program for machinery noise control. The costs of the American program seem out of balance to most people when considering, subjectively at least, the benefits in reduced hearing damage. It is not surprising that the U.S. Occupational Safety and Health Administration has recently decided to emphasize hearing conservation programs in lieu of more stringent engineering controls of industrial noise. Similarly, in Australia, actual expenditures for hearing disability are such a small fraction of the costs of remedial treatment of noisy equipment that it is more economical for industry to invest limited financial resources in alternative ventures and continue to pay disability compensation.

It is tempting to hypothesize from the above examples, and from general experience, that designing machines and equipment to be quiet is likely to be far more economical than quieting machines through retrofit treatment. The objective of this paper is to examine this hypothesis in some quantitative detail. First, from the perspective of the manufacturer and user of noisy products, we consider the economics of noise control embodied in machines or equipment as part of the initial design. This consideration will help illustrate the nature of the problem of actually developing and producing quieter products. Then, to illustrate the technical component of a solution to the noise problem, we consider alternative noise control strategies and, for a number of specific cases, evaluate their relative costs. We discuss partial financial solutions in the conclusions section of this paper.

2. ECONOMICS OF NOISE CONTROL

The general economic issues and relationships associated with noise control (or most forms of pollution abatement) are vast. They can be viewed at the micro level in terms of costs, benefits, and profitability for firms or industries operating under a variety of regulatory or market forces. Noise control can even be evaluated at a macro level, accounting for impacts of noise control on employment, inflation rates, and so forth. A study for the U.S. EPA evaluated a possible multibillion dollar truck noise reduction program in such terms [5]. At both levels it is important to consider whether noise and its control is an issue relevant only to the manufacturer and user or whether there are effects on third parties. When the noise of products (e.g., aircraft) affects primarily third parties, rather than the buyer or seller, noise reduction is usually sought through a regulatory process. When the noise of products (e.g., dishwashers) affects the buyer, incentives exist for manufacturers to quiet their products and for buyers to pay a premium for this feature.

The scope of the economic aspects of noise control addressed in this paper is more modest. Here we are concerned with the economics of source noise control from two perspectives: the equipment manufacturer and the equipment buyer or user. Each incurs costs, and often savings, because of noise control. It is important to understand how each party evaluates the economic factors affecting their decisions to produce or acquire quiet products and how such evaluations might lead to alternative forms of noise abatement.

The Manufacturer

When a product manufacturer conducts a noise control program, either because of regulatory requirements or perceived marketplace demand, it must address a number of factors that will be instrumental in determining the success of the product and, ultimately, the long term competitive position of the manufacturer itself. We will consider here two very important factors: the time and magnitude of the financial investment and the expected return.

The sequence of expenditures and revenues incurred by the manufacturer usually follows a classic life cycle cost pattern. This pattern begins with a research and development program, particularly when it is not entirely clear to the manufacturer how best to achieve a given amount of noise reduction. After a better understanding of the noise generation process is acquired and various treatments are explored, one or more prototype systems may be built and evaluated under actual service conditions in an operational testing program. There are further engineering expenditures as designs are modified and used as the basis for manufacturing. Once final production designs are generated, assembly line tooling is prepared, and product marketing may even begin. Finally, quiet products enter the manufacturing cycle and are distributed to customers. Only after quiet products emerge from this process and are purchased and paid for will the manufacturer begin to experience any revenues to offset the preceding expenditures to bring the quieted product to market.

It is generally accepted that future expenditures or earnings have less value to a company (or an individual) than current cash flows. The reason is twofold. First, currently available funds can be invested at a reasonable rate of return so that they will grow in value over the years ahead. For example, a dollar invested now in an instrument that accrues interest at a 10% annual rate will be worth \$1.61 at the end of 5 years. Conversely, the present value, i.e., the value today, of \$1.00 received 5 years from now is 1/1.61 = \$0.62. Second, uncertainty about the future adds a further discount to future cash flows.

To evaluate a stream of costs and revenues over a period of years in terms of a single number, it is common practice to compute its net present value (NPV) as

$$\text{NPV} = \sum_{i=0}^{N} \frac{R_i - C_i}{(1+D)^i} \quad , \tag{1}$$

where R_i are the revenues received in year i, C_i are costs incurred in year i, D is a discount rate, and N is the number of years for which the investment applies. The value of D varies among industries and represents the rate of return normally expected for a variety of alternative investment opportunities. A discount rate of 20% is often used for planning purposes in the transportation industry and will be used in the examples that follow.

To illustrate the above concepts, consider the development and implementation of noise control for diesel trucks. Let us assume that a manufacturer produces 5000 trucks per year, for a 5-year period, after which the vehicle is redesigned and is replaced by a new product line.

For this example, the costs of noise control are derived from a project sponsored by the U.S. Environmental Protection Agency [6-13]. In this project, the noise emission levels of four current stock model heavy duty diesel trucks were reduced from an initial range of 77 to 82 dBA to final values of 72 to 73 dBA when measured at 50 ft with the trucks accelerating at full throttle past the microphone. Subsequent to the development and installation of the noise treatments, three of the trucks were tested operationally in fleets, accumulating a total of 230,000 miles.

Figure 1 illustrates the noise treatment applied to one of the vehicles. This treatment was similar to those applied to the other trucks in the program. The treatments involved the installation of a very effective exhaust silencing system, an enclosure for control of engine and transmission airborne noise, and (for two trucks) a pair of two-stage vibration isolators to reduce structureborne sound.

It cost EPA about $200,000 for research and development to reduce the noise of each truck to 72 dBA and about a dollar per mile to test it operationally. While this effort demonstrated technical feasibility, a manufacturer would probably put considerably more effort into development and operational testing to ensure that designs were reliable and efficient. While the costs for such efforts are speculative, it is the author's judgment that approximately $500,000 for R&D to develop treatment and $1M for operational testing of several trucks for a total of 1 million miles would probably be realistic. Thus the R&D and operational testing costs would be about $1.5M and might be spent during a 3-year period.

Tooling costs are estimated from manufacturing costs for enclosures and two-stage isolators. In the EPA program, the average estimated cost for these components was $558 per truck which includes a 19% markup for R&D and tooling. Thus total R&D and tooling costs for the 25,000 truck production is $2.23M. Subtracting $1.5M estimated above gives $0.73M for tooling.

In the EPA program further estimates determined that the incremental manufacturer's price for the noise treatment averaged $877 per vehicle. Since price is about 1.4 times manufacturing cost [6], the incremental estimated cost is $629 per truck. Thus, at a production rate of 5000 vehicles per year, a manufacturer will realize approximately $4.4M of incremental annual revenues at an extra cost of approximately $3.1M per year.

When these costs are projected over the life cycle of a product line, the cash flow appears as shown in Fig. 2. For about 3 years, a company invests a half million dollars annually in noise control R&D and operational testing. Assuming that it is able to develop a viable product, it may then spend 6 months in tooling for production. Thereafter, it produces a quieted product for about 5 years, after which the product may be obsolescent. If the company receives its first payment about 6 months after beginning to manufacture vehicles, the cash flow associated with this effort is positive only for the last 5 years of the cycle. For most of this period, annual revenues exceed expenditures by $1.255M. The cumulative expenditures and NPV* are also plotted in Fig. 2 as a function of time. The end point value of the NPV is approximately zero, even though the undiscounted profits (i.e., revenues less expenditures) are $4M.

As an alternative investment strategy, suppose a substantial amount of the technology of noise control could be sponsored by a third party, such as a central government. If this effort encompassed the first two years of R&D and testing, the results of which could be applied broadly across an industry, the manufacturer could tailor the outcome to its particular product lines. The NPV of the manufacturer's cash flow for this scenario, starting at the beginning of Year 3, is also illustrated in Fig. 2. It results in a positive value of about $1M, which is likely to be viewed favorably by a manufacturer.

Although a fair degree of approximation is embodied in some of the estimates used in the above example, it serves to illustrate some of the problems faced by a manufacturer in quieting a product. Substantial costs may be incurred initially in risky R&D efforts and only recovered at a discounted value in outlying years. An unfavorable NPV of the noise treatment serves as a disincentive to a manufacturer. This is particularly true when the treatment is not perceived as a substantive benefit to the user, who is rarely motivated to pay a premium to enhance the environment for third parties. However, this example also shows

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*The NPV calculation assumes a 20% discount rate.

how a public investment in noise control R&D can make the application of the R&D a more attractive prospect from the manufacturer's point of view.

A second example will show the importance of timing in the introduction of noise control in a product line. This example deals with both fixed and variable costs associated with helicopter noise control [14,15]. Fixed costs, which are invariate with production volume, encompass the research, development, test, and evaluation (RDT&E), and tooling expenditures. Variable costs, which are roughly proportional to number of units produced, relate to manufacturing, quality control, and distribution. The noise treatments for two aircraft, summarized in Table 1, involve rotor speed reduction and redesign for most of the modifications.

TABLE 1. NOISE TREATMENTS AND NOISE REDUCTION FOR TWO HELICOPTERS [14].

Helicopter Type	Modification	Noise Reduction From Baseline
Large Dual Rotor	1. Reduce rotor speed, change accessory gear drive	7 EPNdB
	2. Redesign rotors, flight controls, and transmission	10 EPNdB
	3. Slower new rotors	13 EPNdB
Small Single Rotor	1. Redesign slower tail rotor	3 EPNdB
	2. Redesign slower main rotor	6 EPNdB

Sales revenues* needed to offset development costs are estimated by the authors of that study, and plotted in Fig. 3. These

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*Sales revenues are the sum of the funds received from the sale of all aircraft.

graphs illustrate the magnitude of fixed and variable costs for different levels of noise treatment. The fixed costs in this industry are clearly substantial (owing in large measure to extremely stringent reliability requirements and concomitant testing efforts). For example, Mod 1 for the large dual rotor helicopter involves a rotor speed reduction, change in accessory gear drive, and change in vibration absorber tuning. The RDT&E costs of these changes would be about $2M but would not result in any additional costs per aircraft. On the other hand, the development of new main rotors for each helicopter (Mod 2) involves a fixed cost of the order of $40 to 50M. This cost is not only for the rotor but for modifications to transmissions and flight control systems required to power and control the slower turning rotors.

The primary point illustrated by this second example is that redesign of existing systems can have far-reaching impacts, often at great cost, and not always with obvious benefits. In Mod 2 for the heavy helicopter, it was necessary not only to reconfigure the rotor but to modify a well-developed flight control system and a transmission to be compatible with lower speed rotor operation. Thus there was a cascading effect in which one design change caused another design change, and so on. This extended redesign work, in effect, negated the value of much of the initial design and development effort. Thus, it is apparent that when noise control can be designed into a system initially, the incurrence of such repetitious costs can be avoided.

The User

Unlike the manufacturer, a user often is faced with two options: retrofit existing equipment or purchase new equipment. If he already owns a piece of equipment or if a quieted model is not offered by the manufacturer, he may have to install retrofit noise treatment on the equipment or in the area in which the equipment is used. As illustrated in Fig. 4, the retrofit process would begin with a design stage, or at least the selection of noise abatement equipment such as silencers or vibration isolators, depending on the nature of the equipment noise problem. The second stage involves the purchase and/or fabrication of treatment components and their installation. After this, the user may incur additional direct or indirect operating costs or savings for the life of the equipment. Direct operating costs would include fuel and maintenance, while indirect costs could accrue because of reduced productivity.

If a machine has been quieted by its manufacturer, the user simply pays a differential for the machine at the time of purchase and may incur additional operating costs over the life of the equipment. As illustrated in Fig. 4, the operating costs of an initially quieted machine may be less than for a retrofitted machine.

The principle associated with reducing to a single value a stream of costs incurred by an equipment user is the same as that for an equipment manufacturer. Namely, the net present value of all costs and revenues is computed using Eq. 1. Noise control often increases costs, resulting in a negative NPV. However, as we shall see in subsequent sections, noise control can sometimes reduce operating costs and result in a positive NPV or a savings to the user.

In some cases, noise treatment is unlikely to affect operational performance but may affect operating costs. Truck noise control discussed earlier is a good example. In conducting operational tests, we found that the noise treatments did not affect the truck's payload or delivery schedule but had a small effect on fuel and maintenance costs. Table 2 illustrates these costs for the three trucks that were operationally tested [11-13]. The treatment costs identified as "normal" in the table are associated with inherent design factors such as added weight or restricted access to components requiring servicing. The abnormal costs relate to design deficiencies, such as the failure of latches and wear of enclosure components, which were largely cor-

TABLE 2. MAINTENANCE AND FUEL COSTS FOR THREE QUIETED HEAVY DUTY DIESEL TRUCKS [11-13].

	Ford CLT 9000	GMC Brigadier	IH F-4370
Miles Operated	107,201	86,865	35,778
Maintenance Cost ($)			
Non-Treatment Related	6,194	3,316	1,153
Treatment - Normal[1]	43	40	49
Treatment - Abnormal[2]	457	155	57
Total	6,694	3,511	1,259
Fuel Consumption ($)[3]			
Non-Treatment Related	28,659	16,995	7,300
Treatment Related[4]	20	8	49
Total	28,679	17,003	7,349
Annual Maintenance and Fuel Cost ($)[5]			
Non-Treatment Related	17,556	12,626	12,759
Treatment Related (Normal)	32(0.18%)	30 (.24%)	147 (1.16%)
Total	17,588	12,656	12,906

Notes:

1) For routine service of noise treatments.

2) For refabrication and reinstallation of prototype treatments.

3) Fuel priced at $1/gal.

4) Estimated from considerations of exhaust system backpressure and treatment weights.

5) Based on 54,000 mi/yr average utilization of heavy duty diesel trucks [5].

rected during the operational tests. The normal treatment-related costs range from 0.18% to 1.16% of total fuel and maintenance costs unrelated to vehicle treatment. Note that these incremental costs are an even smaller percentage of total vehicle operating costs, which include other major expenses such as drivers' compensation and insurance.

Table 3 presents the incremental prices of the quieted trucks (about 3% of total truck price) along with incremental operating costs. The NPV of the incremental operating cost, computed for a 5-year period and 20% discount rate, is generally small compared with the incremental price.

TABLE 3. INCREMENTAL NPV OF QUIETED TRUCKS.

	Ford CLT 9000	**GMC Brigadier**	**IH F-4370**
Incremental Price	$1309	$1174	$1302
Incremental Annual Operating Cost	32	30	147
NPV of Incremental Annual Operating Cost (20% Discount, 5 Yr)	96	90	440
NPV of Noise Treatment Costs	$1405	$1264	$1742

When equipment productivity is affected by noise treatment, operating costs are often given in terms of dollars per unit of production. Fixed costs are usually allocated over the life of the equipment, and variable operating costs are added. Thus, such nominally fixed costs as depreciation and insurance and variable costs as fuel, maintenance, and labor are all taken into account.

For the helicopter example discussed above, incremental operating costs resulting from noise control have been calculated in terms of dollars per seat mile [14,15]. The results, presented in Fig. 5, show some very interesting effects. For the large helicopter, noise control implemented in Mod 1 actually reduces operating costs. This is because rotor speed reduction conserves fuel and increases helicopter range. As additional noise reduction is sought, large fixed-cost increments associated with major component redesign result in increased values of depreciation which increase operating costs. For the small helicopter, operating costs increase rapidly. Each modification requires component redesign and an increase in depreciation costs that is large in comparison to the low initial price of the helicopter.

The truck and helicopter examples show some of the impacts of noise control on the user. Increased manufacturing costs are passed on, with a markup, as increased price. When allocated over equipment utilization, price increases can be thought of as increases in operating costs. However, the examples also show that noise control can decrease operating costs when equipment can be made to operate more efficiently and fuel consumption can be reduced. Mod 1 for the large helicopter is a concrete example of this effect, while truck data are still speculative. A clear strategy for noise control is to minimize incremental manufacturing costs, to benefit both the manufacturer and user, and to couple noise treatment with improved performance to reduce, rather than increase, operating costs.

3. COSTS OF ALTERNATIVE NOISE CONTROL STRATEGIES

While the above examples have illustrated some of the cost elements and issues associated with noise control, here we will explore how equipment manufacturers and users may employ various strategies to reduce noise emission levels at minimal cost. One of the most common practices is to integrate noise control technology into the design of a machine. This strategy often involves reducing noise-generating forces at their source, attenuating airborne sound by means of enclosures and silencers, and reducing structural vibrations with isolators and damping treatment. Alternatively, a stationary machine in a factory may be enclosed by means of heavy curtains or rigid panels, and reflecting surfaces in a building may be treated with sound-absorptive material. New processes may be found or existing processes may be automated. Operating changes may be instituted. Personnel exposure may be lessened through administrative changes involving rotation of equipment operator assignments or through the use of hearing protectors.

While all of these techniques are useful under certain circumstances, their economic evaluation would go well beyond the intended scope of this paper. This paper addresses design factors only and attempts to compare the economics of retrofit, integral design, and machinery operational factors. To illustrate this objective, we will consider a few cases relating to components and to a complete system.

The various machine design options for noise control are illustrated in Table 4. Here we identify three areas of control (source, structural path, airborne path) for four types of appli-

TABLE 4. ALTERNATIVE NOISE CONTROL OPTIONS FOR MACHINE DESIGN.

	New Equipment		Retrofit	
	Mechanical Design	Operational Control	Mechanical Design	Operational Control
Source				
Structural Path				
Airborne Path				

cations. These applications involve mechanical design or operational control for new equipment and for existing equipment that requires retrofit. It is important to make clear what is meant by each of the noise control areas.

- Source control involves the reduction of excitation forces or pressures that ultimately generate sound.
- Structural path control involves the reduction in vibrations along the mechanical path connecting the source with the surrounding air.
- Airborne path control involves the attenuation of sound transmitted through the air to a listener.
- Mechanical Design involves a change in the configuration of the machine without changing operating variables such as speed, torque, and power.
- Operational Control involves the change in operating variables which may necessitate secondary changes in design factors such as component strength.

As an example, consider the application of noise control to a gearbox. Source control could be achieved by reducing the time-varying component of gear mesh forces through the use of helical, instead of spur, gears or decreasing the pressure angle. Structural path control would include the application of damping material to the gearbox itself or the insertion of compliant couplings in input and output shafts. Airborne path control might be achieved by surrounding the gearbox with a sound-absorptive enclosure. Mechanical design would encompass all of these treatments, while operational control would be implemented by operating the gears at a lower speed.

To illustrate the costs of the alternative strategies identified in Table 4, we will evaluate three cases. The first two, electric motors and cooling fans, are illustrative of machinery component treatment, while the third, sewing machines, shows what can be accomplished for a complete system.

Case 1: Electric Motors

One of the most instructive examples of source control that can be applied to all four elements across the top row of Table 4 is electric motors. Noise levels for standard and quieted totally enclosed fan-cooled motors are presented in Fig. 6 for a range of horsepower and operating speeds. These data clearly show that for a given horsepower rating, noise emission levels are distributed within a 10 to 20 dBA range. Standard untreated high-speed motors are invariably the noisiest, while quieted motors operating at low speeds are the quietest.

Noise control is designed into motors through the combined use of high-temperature insulation and low-volume cooling fans. The insulation allows the motor to run hotter than normal, requiring less air flow to dissipate waste heat. The lower air flow and concomitantly lower head loss permit the use of smaller, quieter fans.

The impact of source mechanical design treatment on motor price is illustrated in Fig. 7 for two lines of motors. For the U-line it is apparent that 3 to 8 dBA of noise reduction can be obtained at about a 2% price premium. Data for the T-line show that anywhere from 2 to 13 dBA are achieved at an incremental price of up to 34%.

Noise abatement can also be achieved at the source by operational speed reduction with a price impact, such as that illustrated in Fig. 8. The data points designated by circles show that motors built to operate at 1800 instead of 3600 rpm cost about the same as 3600 hp motors but can be as many as 17 dBA quieter. Motors built to operate at 1200 rpm cost 15 to 80% more than 3600 rpm motors and are 2 to 17 dBA quieter. Of course, the ultimate cost impact associated with using a lower speed motor depends additionally on the configuration and costs of the system being driven by the motor.

Source retrofit could be accomplished on a machine by replacing a noisy motor with a quiet one. In practice, of course, this is rarely done because of the waste of scrapping a properly functioning motor to replace it with one that does not function any better. If one wished to carry out such a replacement, a motor of the same speed would generally be required for compatibility with the system being driven. To estimate the retrofit cost, we assume 2 hours of shop labor is required at $25 per hour, and add $50 to the incremental cost for the motors corresponding to Fig. 7. The result is that retrofit costs range from about 102% to 143% of the cost of the standard motor. These costs are 4 to 50 times the 2% to 34% incremental costs of building noise control into the motor in the first place.

To estimate the costs of quieting motors through structural and airborne path attenuation, an example may be taken from a project to quiet a portal bus used in underground mining [16]. Here, two 10-hp motors were quieted by 6.7 dBA through the application of a sound-absorptive enclosure and vibration isolation mounts. Table 5 illustrates the noise reduction realized for

TABLE 5. COSTS AND NOISE REDUCTION FOR TREATING TWO 10 HP DC MOTORS USED ON A PORTAL BUS.

	Noise Level - dBA			
	Untreated	Treated	Noise Incremental Reduction	Cost
Airborne	82.5	74	8.5	$100
Structureborne	81.0	76	5	63
Total	84.8	78.1	6.7	$163

each path and the corresponding costs. The total cost of this treatment is $163, which represents about a 5% increase over standard motors.

Table 6 summarizes the motor noise reduction and costs that can be obtained by pursuing different strategies. Clearly, source control of new equipment has the greatest economic poten-

TABLE 6. NOISE REDUCTION AND COST FOR ALTERNATIVE ELECTRIC MOTOR ABATEMENT STRATEGIES.

		New Equipment		Retrofit Mechanical Design
		Mechanical Design	Operational Control	
Source	Cost Noise Reduction	-2 to 34% 2 to 13 dBA	-12 to 80% 0 to 17 dBA	102 to 143% 2 to 13 dBA
Structural Path	Cost Noise Reduction	~2% 5 dBA		
Airborne Path	Cost Noise Reduction	~3% 8.5 dBA		

tial. A large number of motors embodying noise treatment or operated at low speed are available that cost about the same as noisier motors. Enclosing and vibration isolating motors appears to represent the second-best approach, while retrofitting noisy motors with quiet ones will generally be the most expensive course of action, owing primarily to the intrinsic value of the motor that is discarded.

Case 2: Cooling Fans

Another interesting example of source noise control by various techniques evolved during the development of truck noise control technology in support of U.S. motor vehicle regulatory activities. It became apparent that truck cooling fans were major noise sources and needed to be controlled. However, it was also observed that demand-actuated fans often operated less than 1% of the time for line haul tractors. When the fan drives were automatically disengaged by a thermostatically controlled clutch, the fan turned slowly, generated very low sound levels, and consumed almost no power. Accordingly, noise control was approached from the alternative perspectives of designing quieter fans to reduce noise levels and of using demand-actuated fans to eliminate the source of sound most of the time.

The results of various studies [5,17,18] are combined and illustrated in Table 7. These data illustrate several interesting phenomena. First, retrofit costs are about 3 to 7 times larger than new equipment costs. This is attributable to three factors.

TABLE 7. COSTS OF TRUCK FAN NOISE REDUCTION.

	New Equipment		Retrofit	
	Mechanical Design	Operational Control	Mechanical Design	Operational Control
Equipment Cost	$9	$ 168	$61	$ 569-718
Annual Operating Savings	-	810	-	810
NPV @ 20% Discount	-$9	$2254	-$61	$1704-1853

1) manufacturers just pay for the incremental cost of one product over another, whereas a user has to pay for the entire new component and often scraps the part it replaces;

2) manufacturers purchase components in large quantities and realize economies of scale through original equipment manufacturer discounts;

3) the labor required by a manufacturer to install a quiet part is often the same as for a noisy part, whereas the user must first expend labor to remove an existing component and then expend additional labor to install the new component.

Second, although operational control is initially far more expensive than mechanical design, the extra cost is more than offset by substantial fuel savings over a 5-year operating period.

Case 3: System

When noise control is designed into a system at the right time, the results can be favorable to the manufacturer and user. In fact, integral design of treatment, rather than conventional add-on treatments, is often the only feasible approach. Control of helicopter noise, discussed earlier, or of fixed-wing jet aircraft, alluded to in the introduction, are examples where add-on treatment is generally impractical.

Another example is that of a sewing machine. Sewing machines cannot be covered and retain their appeal to consumers. A study performed by Lyon [19] showed that the noise emission level of a sewing machine could be reduced by about 6 dBA, primarily by replacing certain solid covers with perforated covers and by using a larger lower speed motor and attendant drive system than had been used previously. Interestingly, as illustrated in Table 8, most of the cost impact was in reduced quality control efforts that had previously been expended to test and rework noisy products. Fractional percent increases in production labor and materials, tooling, and engineering combine with the quality control savings to increase manufacturing costs only 0.3% to achieve the 6 dBA of noise reduction.

TABLE 8. COST INCREASES <DECREASE> OF DESIGNING NOISE CONTROL INTO A SEWING MACHINE [17].

	Untreated Products	Treated Products	Incremental Cost
Quality Control	1.5	0.5%	<1.0>%
Other Variable (Production Labor, Materials, with Overhead)	-	-	0.5
Tooling	-	-	0.65
Engineering	-	-	0.15
			0.3%

4. CONCLUSIONS

The primary conclusion reached in this paper is that controlling noise at the source on new equipment, rather than retrofit, is generally the most cost-effective machine design strategy. Examples of cooling fans and electric motors have shown that noise reduction may often be achieved at little or no incremental expense and may even result in substantial operating cost savings. Systems as diverse as sewing machines and heavy diesel trucks may be quieted by about 5 to 10 dBA at an incremental cost of the order of 0.3% to 3.0% of the base price.

A major question that remains is how best to ensure that noise is controlled at the source. When a product user is primarily affected, a manufacturer can often envision sufficient enhancement in product image and future sales growth to justify the necessary R&D. The sewing machine case is a good example. Few would claim that 6 dBA in noise reduction for this type of product is not worth a 0.3% price increase. With such an incentive, manufacturers can embark with a reasonable level of confidence on a noise control R&D and implementation program.

When noise affects the public rather than the manufacturer or user, the situation is quite different. The truck example shows that noise control may not represent a financially attractive venture even when prices can be raised to recover initial investments and when sales volume is not reduced by higher prices. The helicopter example shows that noise treatment may cause considerable product equipment and operational impacts if treatment is introduced through redesign of an existing product line with relatively few units over which to amortize costs. These types of cases have helped establish my conviction that public investment in noise control R&D through government-sponsored programs is the most promising approach to a quieter environment and healthier workplace. Such an investment minimizes financial risk to manufacturers and increases the likelihood that cost-effective technologies will be available for noise control. Through this mechanism I believe it is possible to reduce occupational and environmental noise reduction in a lasting way with minimal adverse economic impact.

ACKNOWLEDGMENTS

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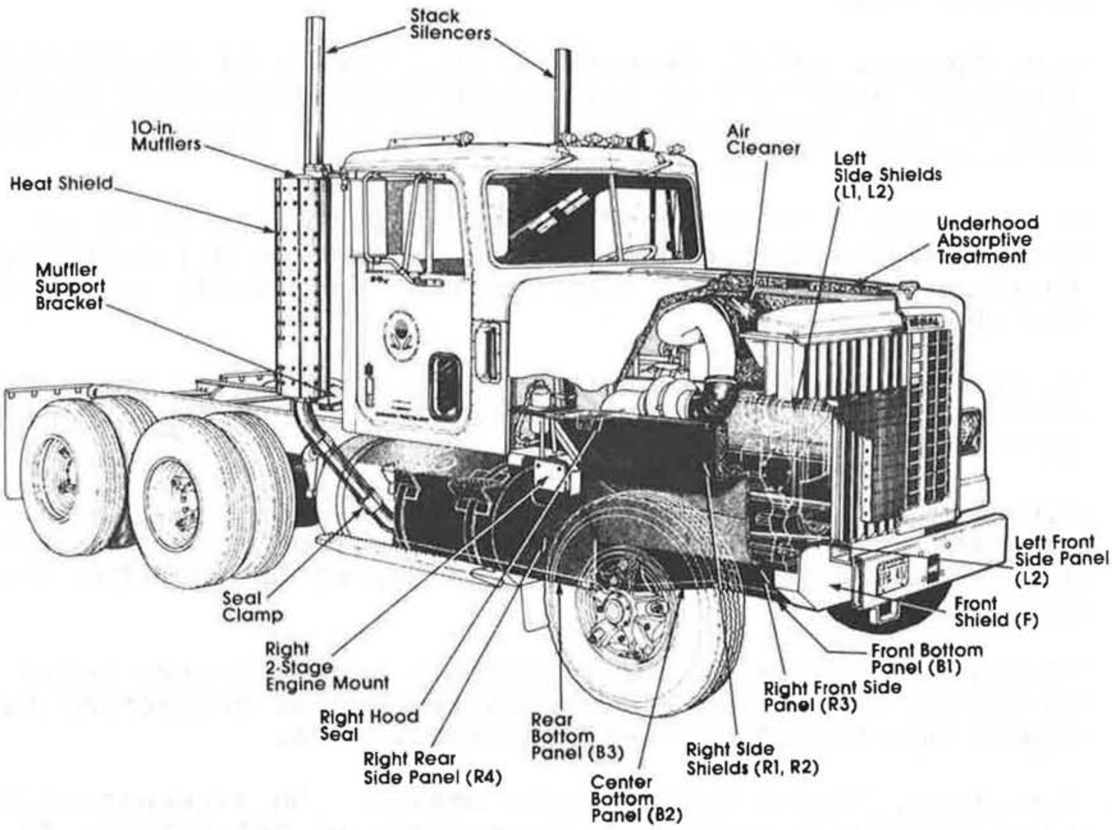

Fig. 1. NOISE TREATMENT FOR HEAVY-DUTY TRUCK.

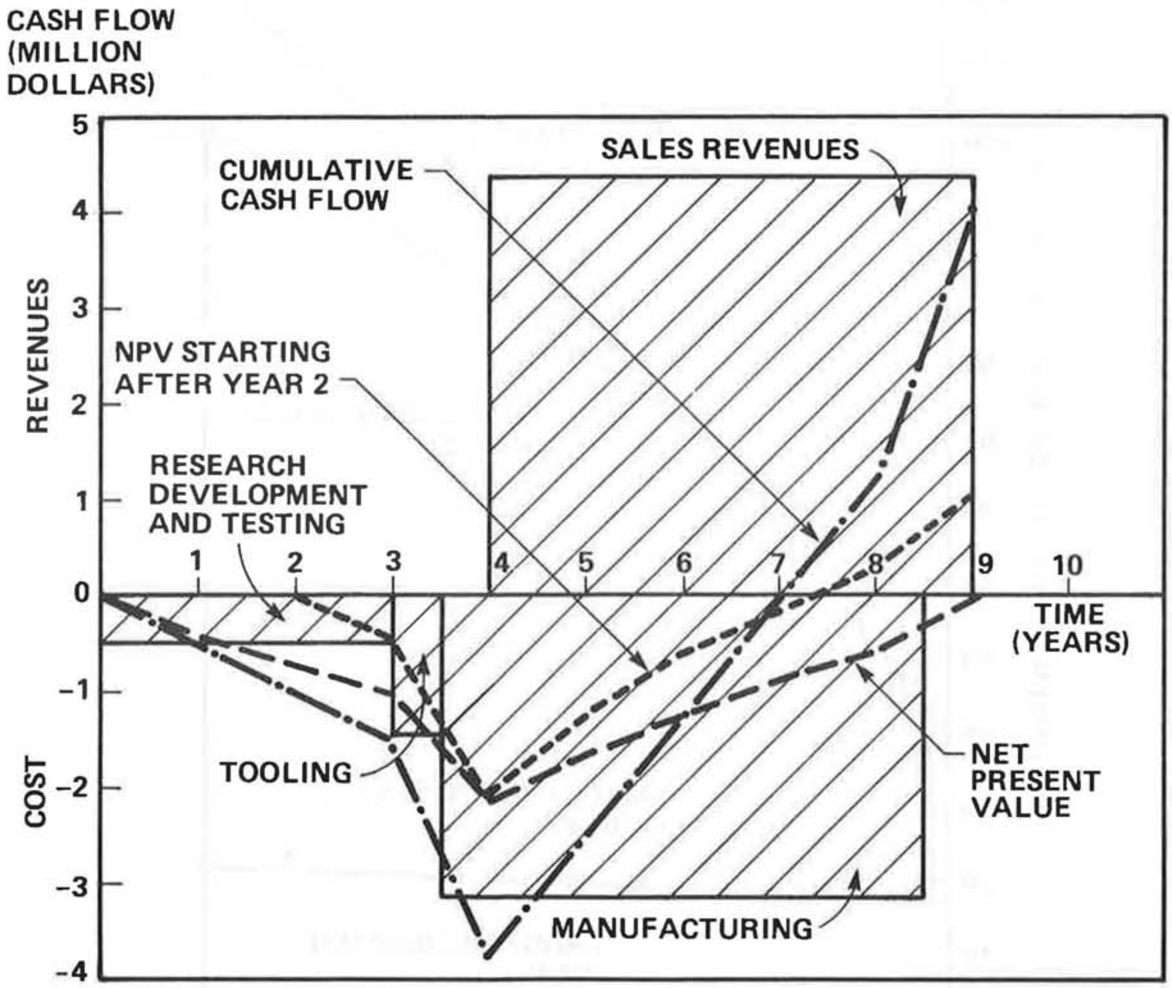

FIG. 2. CASH FLOW AND NPV OVER LIFE CYCLE OF A PRODUCT.

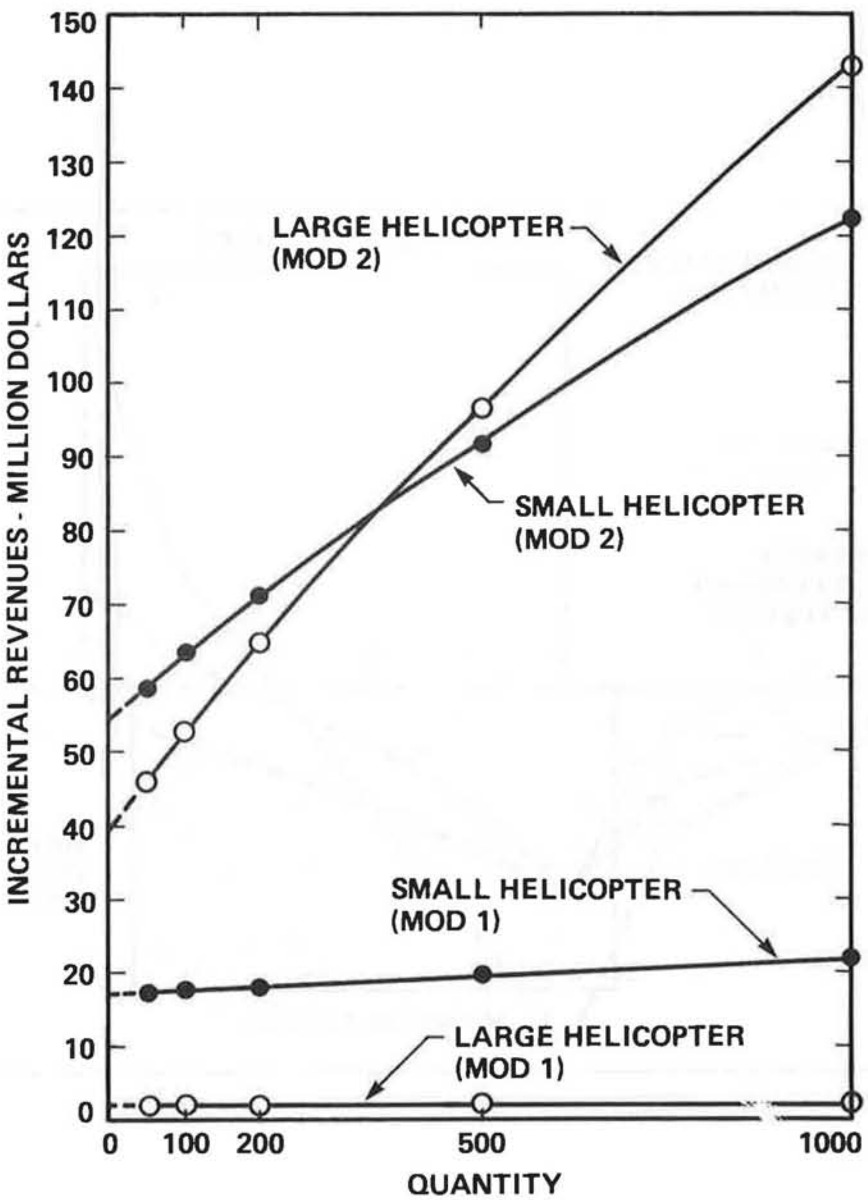

FIG. 3. INCREMENTAL REVENUES NEEDED FOR HELICOPTER NOISE CONTROL.

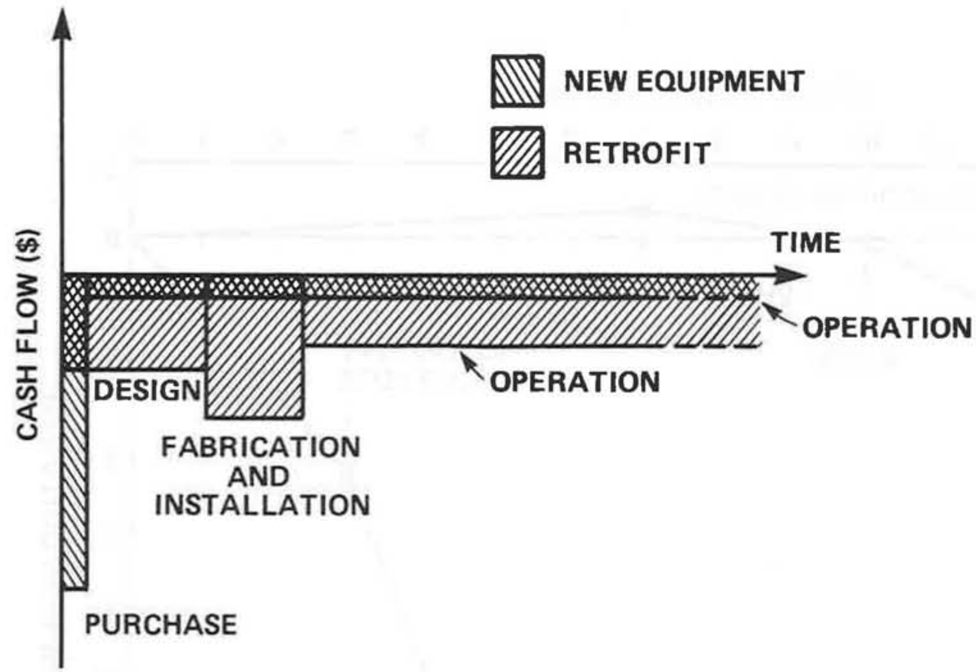

FIG. 4. CASH FLOW FOR RETROFIT PROCESS.

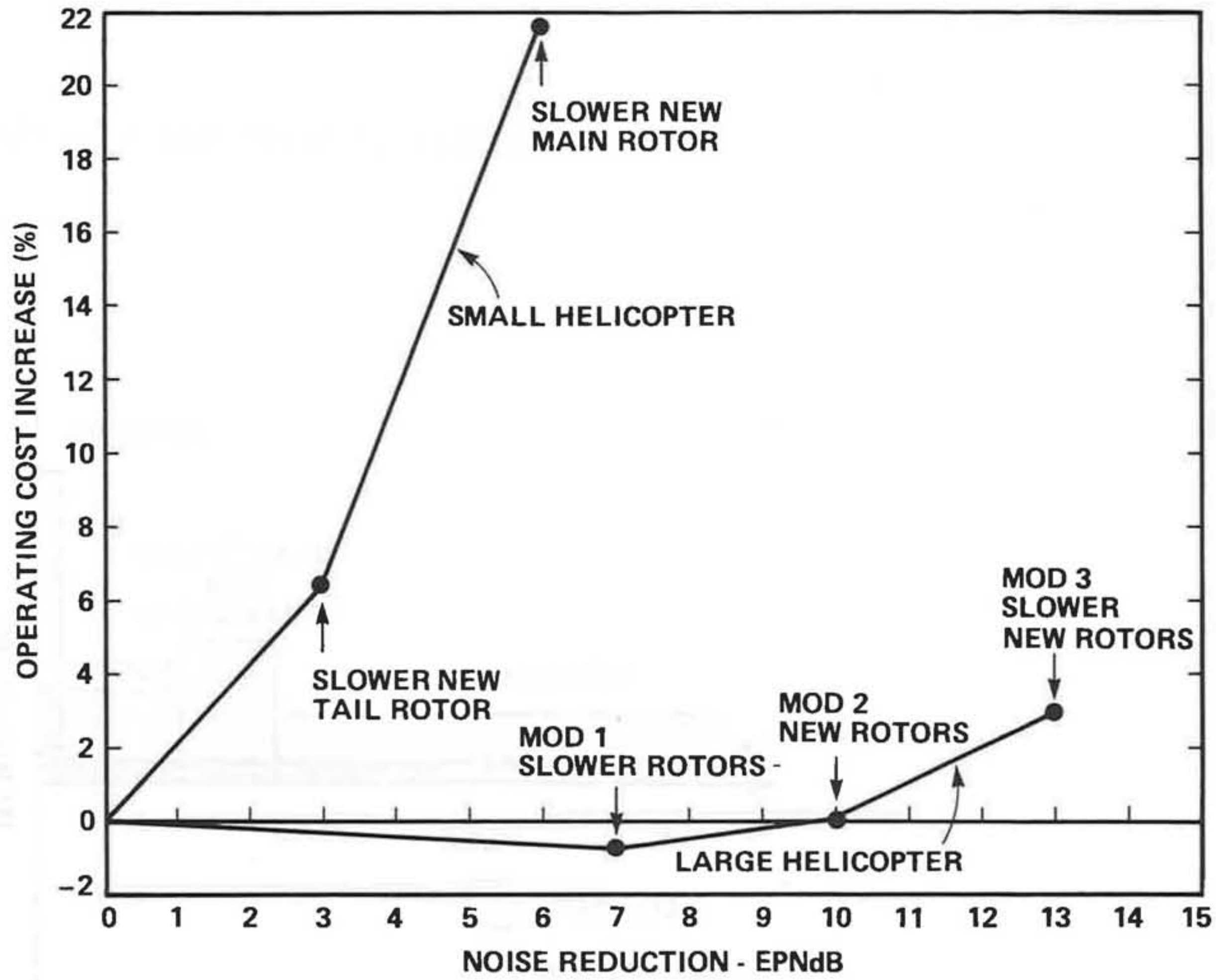

FIG. 5. HELICOPTER OPERATING COST INCREASES.

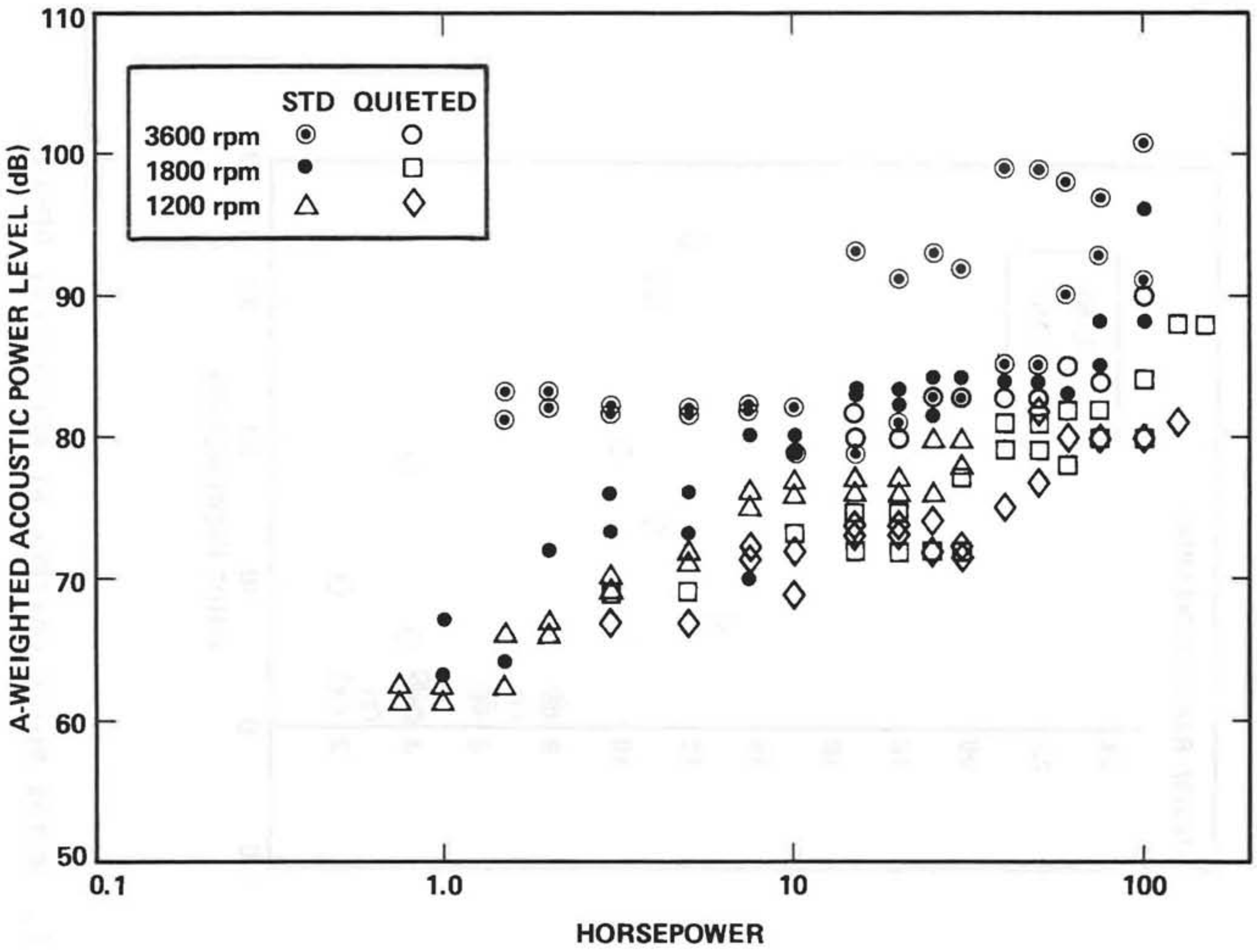

FIG. 6. A-WEIGHTED ACOUSTIC POWER EMISSION LEVELS OF ELECTRIC MOTORS.

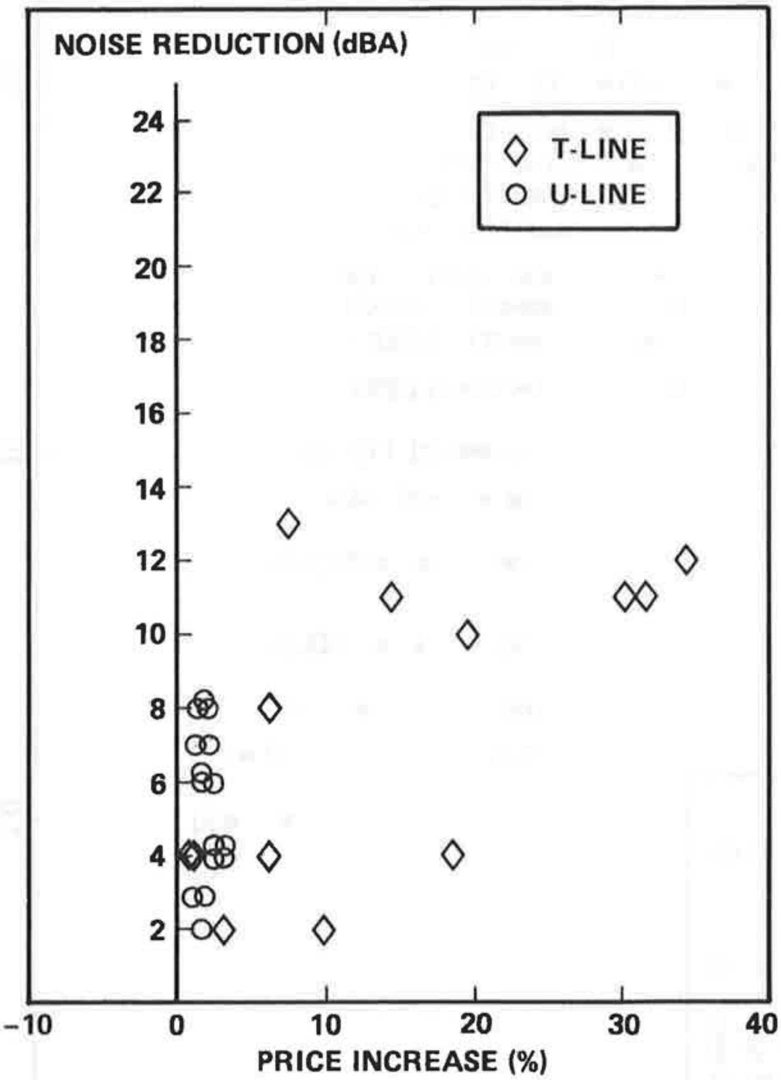

FIG. 7. MOTOR NOISE CONTROL BY MECHANICAL DESIGN.

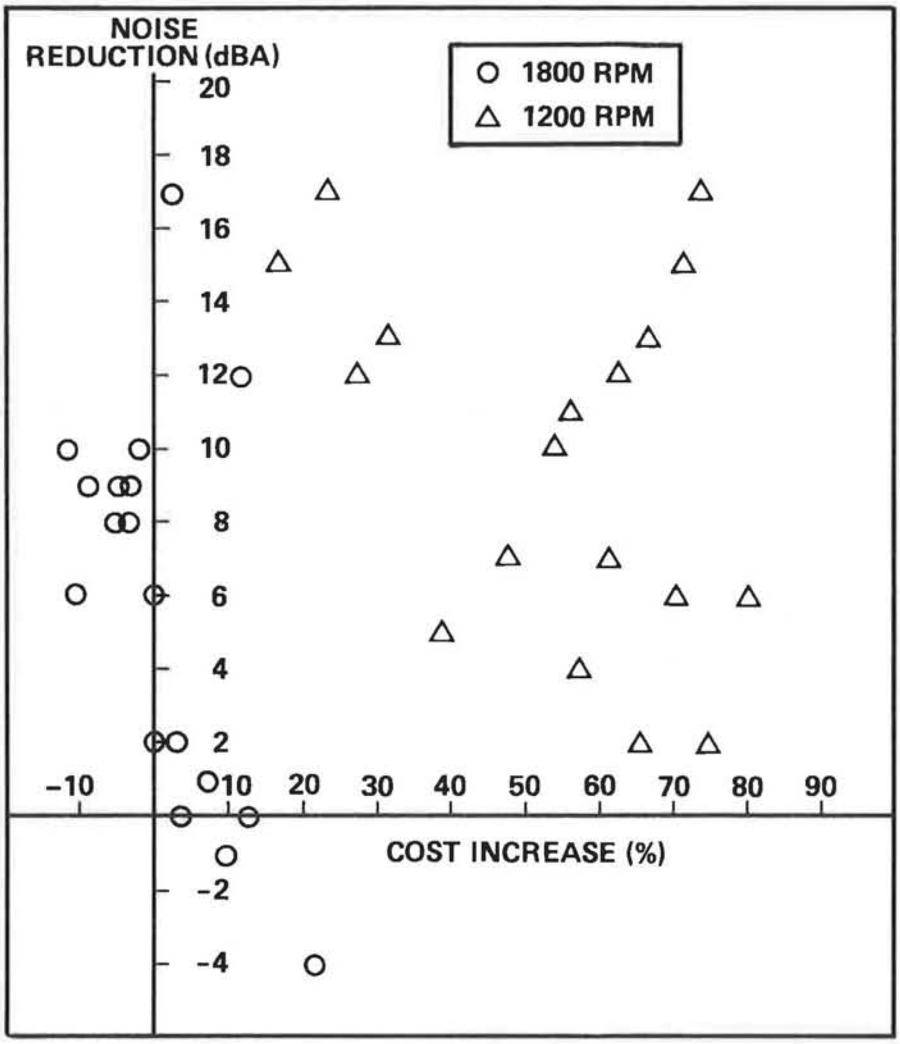

FIG. 8. MOTOR NOISE REDUCTION BY OPERATIONAL CONTROL.

THE PARADOX OF NOISE CONTROL

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INTRODUCTION

The B.H.P. works in South Australia is notable in that all phases of steelmaking can be seen, from the mining and treatment of ore, to ironmaking, then steelmaking and finally the rolling of finished sections.

As well as the production of steel product, our works complex includes facilities to generate power and materials used in the steelmaking process.

- Pelletising Plant.
- 108 Byproduct Coke Ovens in 3 Modules of 36 Each.
- Foundries.
- A Tonnage Oxygen Plant, To Produce High Purity Gaseous Oxygen for the Steelmaking Process.
- Lime Burning Kilns.
- Complete Railways and Transport System and,
- Many Plants for Treatment Of Byproducts and for Services Facilities.

The biggest challenge to noise control is the extremely wide variety of machinery and equipment used by the works.

NOISE CONTROL PROGRAMME

The company first became involved in noise control in 1968. An initial survey of the Whyalla works was completed in early 1971. This survey took account of actual noise levels and employee exposure time.

A second survey was conducted in 1975/76. Since this survey we have devised a priority schedule for all the various plants on the works.

Our present system is to examine a total plant, determine what equipment requires treatment and specify treatment for that equipment We attempt to treat each plant so that no employee is exposed beyond one noise dose per day. Where practical we design our treatment for any source to obtain an Leq of 85 dBA for that source, so that we will not have to follow up with future treatment, if the allowable levels are reduced at some future time.

In conjunction with our treatment programme we drew up a specificatio of maximum permissible noise levels for all new plants and equipment, so as not to add to our existing problems. Portable tools are screened, prior to purchase to obtain the 'quietest' without sacrificing efficiency.

Education programmes are also conducted to make employees aware of noise on the plant and the use of hearing protection.

Audiometric screening of employees is also being carried out by our medical staff. Any cases with high hearing loss are referred back to the Noise Control section who investigate reasons, the cause and provide recommendations. This may involve a specific area being treated to reduce noise or may require the transfer of an employee to a quieter job or location to stop any further deterioration in hearing loss.

I would now like to present a selection of examples of noise treatmen that we carried out on our plant after 1978. The cases listed, are only a "tip of the iceberg", but they provide a broad spectrum of the problems we encounter and the solutions we have devised.

CENTRAL MINERAL DRESSING LABORATORIES

Grinding Machine

This machine is a minature grinding mill. It consists of a steel rotating drum (1m x 0.4mØ) with steel balls moving freely inside to crush the ore. A cover constructed from 12mm plywood and lined with Coustilam 6L25 reduced the noise level from 105 dBA to 84 dBA. Due to the complexity of the required shape at the base of the enclosure, to minimise open area, the unit was built on site by our carpenters, reducing design costs to a minimum. Cost: $1,000.

TONNAGE OXYGEN PLANT

No.'s 1, 2 and 3 Air Turbo Compressors

In this plant oxygen is extracted from the atmosphere and compressed for use in the steelmaking process. The initial stage of air compression is achieved using one or more of these three compressors. The gear box on these units was found to be the main source of noise.

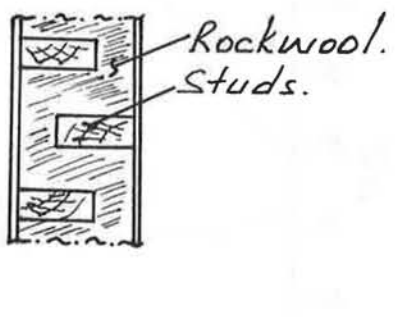
A cover over the gear box only, provided the required reduction from 99 to 88 dBA. The cover was constructed from 3mm mild steel plate with a 50mm internal lining of Bradford Insulation, Rockwool type B, retained with perforated metal. Cost: $7,000/unit.

SLEEPER TIE PLATE PROCESSING PLANT

Press/Shears

This unit punches 6 holes in a sleeper tie plate and simultaneously cut it to the required length. Impulsive noises of 109 dBA were recorded. Due to the cost of modifying the press to reduce noise, a wall was built between the operator and the press.

The wall consisted of 6mm hard board glued to opposite sides of 38 x 75mm staggered wood studs. The space being filled with Rockwool. A maximum level of 93 dBA now exists.
Cost: $8,700.



PUG MILL

Hopper Vibrator

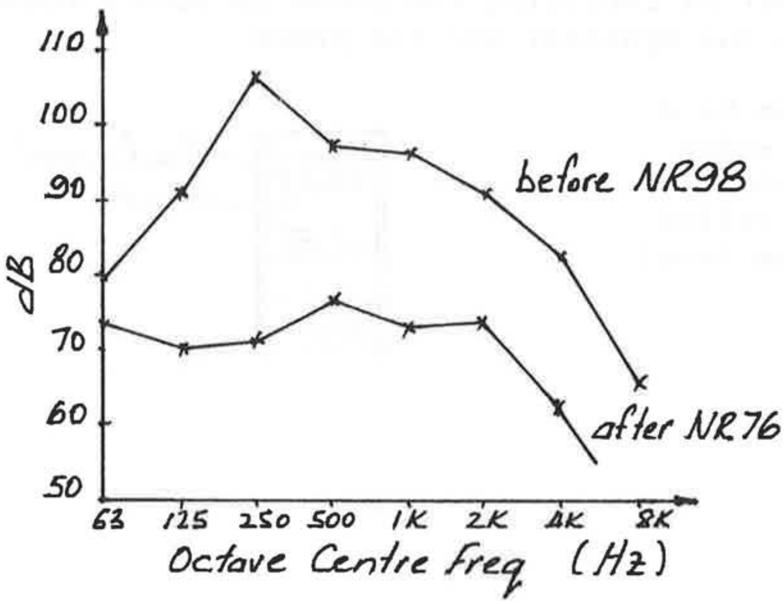
Dust generated during the steelmaking process is collected in two precipitators. From here it is transferred via a sealed conveyor to a large hopper. Periodically the dust in the hopper is emptied into bags for shipment to customer firms for reprocessing as colouring for bricks, paints, etc.

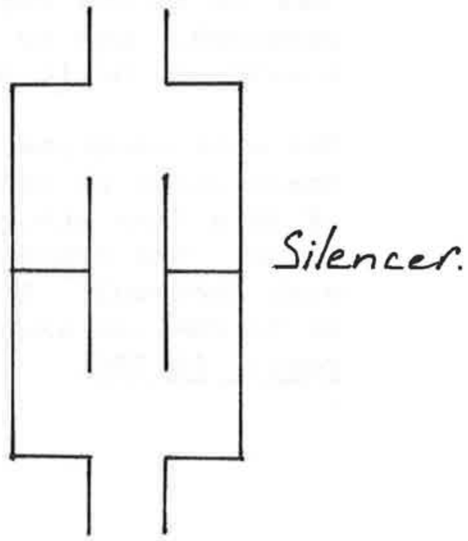
An electro-pneumatic vibrator was provided at the base of the hopper to prevent blockages while the bags are being filled. This vibrator produced a noise level of 116 dBA. Following various unsuccessful attempts at enclosing the vibrator and lagging parts of the bin, two rotary vibrators were purchased for trial. These worked well and reduced the noise level to 83 dBA. Cost: $2,500.

COKE OVENS

Vacuum Cleaner

This unit collects the dust that collects on the tops of the Coke Oven Batteries. When this machine was first installed, it produced a noise level of 102 dBA with a level of 107 dB in the 250 Hz octave. This 'whine' could be heard all around the ovens. The suppliers suggested a sound box to reduce the noise to 85 dBA or use a larger blower at a lower r.p.m. Our investigations however, revealed that the single tone noise was escaping through the exhaust port. Using a 3% narrow band filter, we determined the exact frequency of the noise and designed a silencer to reduce the noise at this frequency. We also built a small cover over the cleaner.
Cost: Silencer $200., Cover $400.





FINISHING END

Transfer Beds

At the finishing End of the Rolling Mills, rolled product bars are taken on roller lines and put over a series of beds for cooling, inspection and packaging. The bars were dragged sideways over the steel bed rails with noise levels on some types of sections of up to 124 dBA. Leq levels were around 104 dBA.

These bed rails are now fitted with polyurethane strips and the noise level during dragging of product bars is below 80 dBA. This treatment is only suitable for beds where cold product is transferred. Cost: $150,000.

CARPENTERS SHOP

Circular Saw Blades

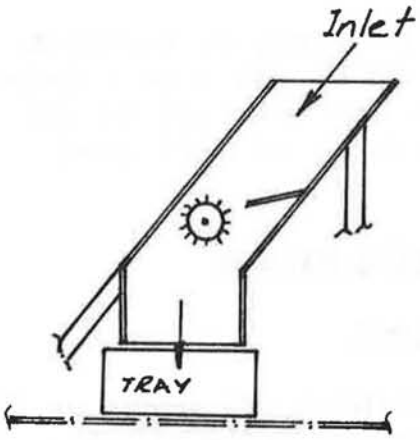
A method of reducing noise emitted from saw blades is to fasten two metal shims about 0.25mm thick on either side of the blade with double sided adhesive tape. This method could not be used on our plant, so we sought an alternative. We have found that metal spraying the blades with a fairly 'solid' material (0.30mm thick) on both sides of the blades, reduces the resonant 'hum' significantly.

	dBA	500Hz	1K	2K	4K
Free Running, Before	100	77	83	94	81
Free Running, After	89	77	75	86	81
Sawing 37mm Mohogany, Before	98		92	93	94
Sawing 37mm Mohogany, After	94		87	84	86

HOSTELS

Ice Crusher

This is a simple machine to crush blocks of ice. However, because it was made from plate steel, the crushing action produced an impulsive noise level of the order of 108 to 110 dBA. Lining the inside of the unit with rubber and placing a cover over the outlet reduced the level to between 90 and 94 dBA. Cost: $220.



HYDROBLAST UNIT

This unit consists of a diesel driven pump and is used to clean various equipment on the plant with a high pressure water jet. It was purchased with a massive acoustic cover and noise levels were satisfactory. Two years later when minor problems developed and the unit needed frequent repair, the cover was found to be very inconvenient, as it took 4 hours to remove and required a crane to do so. Experiments revealed that a simple barrier close to the unit and 1.5m high achieved the same noise reduction from 97 to 90 dBA. The barrier was constructed from the baffles salvaged from inside th old cover and removal now takes 10 minutes. Cost: $350.

HEAVY MACHINE SHOP

Lathe

A noise level of 99 dBA was recorded near the gear box of this lathe investigations revealed that the gears were in a bad state of repair. Replacement of the gear box reduced the noise level to 86 dBA. Cost: $3,600.

BRICK PLANT

Brick Press

This press had two integral cast iron gears which generated a ringin noise of 100 dB at 570 Hz. The ringing occurred once per revolution and lasted 2.5 seconds. Mechanical repair and proper lubrication on the gears reduced the level to 83 dB. Cost: $400.

BRICKLAYERS

Bricksaw

The purchase of sandwich blade has reduced noise levels from 106 to 93 dBA when cutting bricks. The new blades cost $10.00 more than the original blades. An acoustic cover over these units was estimated to cost $600.

WARNING SIRENS

Various

Throughout the plant we discovered that warning sirens produced excessive noise levels. In some cases these levels reached 124 dBA at employee locations.

cont.

By simply 'blocking' the outlets noise levels have been reduced while still being effective as warning devices. Replacing one central siren with two at opposite ends of a building has also allowed for lower levels to be used.

SUMMARY

	Cost $	dB redn.	$/dB
Grinding Mill Cover	1000	21	48 *
Gear Box Cover	7000	11	636 **
Tie Plant Wall	8700	16	544 **
Pug Mill Vibrators	2500	33	76 ++
Vacuum Cleaner Silencer Cover	600	18	33 *
Finishing End Bed Lining	150000	44	3400
Saw Blades	50	7.5	7 ++
Ice Crusher Lining	220	16	14 *
Hydroblast Barrier	350	7	50 *
Lathe - New Gear Box	3600	13	280
Brick Press Overhaul	400	17	24
New Brick Saw	10	13	1 ++
Brick Saw Covers	600	13	46 *

We can conclude that on average it costs about $50.00 per dB reduction for the majority of Noise Control projects. In areas where structural requirements are necessary due to the size of the treatment, cost can increase by 1000% for design, manufacture and construction.

These costs however, do not include the costs of our investigative and experimental work which can again double the cost/dB.

In addition to these, we have spent $130,000 to reduce noise in the Tonnage Oxygen Plant. This work mainly involved acoustic curtains, pipe lagging and silencers.

PROBLEMS ASSOCIATED WITH NOISE CONTROL PROGRAMME

While we have been successful in reducing a large number of noise sources, there are still many which require investigation and treatment.

The present Noise Control Act in South Australia deals mainly with noise levels at employee work stations or on the domestic scene at the neighbour's front door. With both cases the source is almost always equipment purchased from another company. Because the owner of the noisy equipment is operating the unit it becomes his responsibility to comply with the Act, not the manufacturer who produced the unit. With a domestic air conditioner it becomes the owner's responsibility to control the noise when his neighbour complains.

As stated earlier, we have a noise specification that all incoming equipment should comply with. This system reduces the number of noisy equipment items entering the plant but we still have problems with some new equipment which does not comply. We have also encountered manufacturers who state that a unit has a noise level of 85 dBA and after its installation, levels are found to be higher. In one instance we received two 'quiet' compressors which when installed, produced a maximum noise level of the order of 124 dBA. Initially the suppliers argued that the increased noise was due to the compressors location and pipework resonance. However, when they did install a silencer and an acoustic cover, the noise level was reduced to 92 dBA.

With portable tools, we test each type before it is accepted for purchase. In the two years of screening these tools, the free running noise level has been reduced from an average of 105 to 95 dBA. This is due mainly to us sacrificing cost economy for lower noise levels. A smaller company may not have had the same bargaining power.

If however, there was adequate legislation regarding the production and marketing of noisy equipment, the onus would be shifted to the manufacturer and benefits would be reaped throughout industry. Reduction of noise at the design stage is far less costly and thus would reduce the total cost of noise control throughout the country. When providing such legislation, manufacturers should also be encouraged by some sort of incentive scheme and there should be adequate information relating to various aspects of noise control, readily available. These incentive schemes could perhaps involve Government subsidies to manufacturer's for noise control investigation programmes.

To date, there is no feasible method of control for most portable pneumatic tools, hammering etc. In these cases and wherever excessive noise still exists, our company provides hearing protectors. Various types of protectors are available on the plant and educational programmes on their use are conducted regularly. Employees are also made aware of the noise levels in their area of the plant. The final decision on the use of protectors, still however, rests with each respective employee. There are approximately 60-70% of employees who do wear protectors where required. The remainder are apathetic.

We conducted a trial of a method of motivation called "Information Feedback" as used in Israel. This method involves the recording of each employee's audiogram before and after work, with and without the use of hearing protection. The employee can then visually see the effects of hearing protection on temporary threshold shift. Results of this experiment indicate there has been an increase in the wearing of protector to 80% on the section of plant where it was conducted. However, there still is the 20% who in getting N.I.H.L. may later be compensable, through no fault or neglect of the company.

With the new Common Law Act, there is a strong possibility of employee's claiming negligence in terms of hearing loss. It will be extremely difficult for employers to resist these claims. The company is currently negotiating one such claim.

Every burden, it seems, tends to be placed on the shoulders of the employers. Why cannot an employer claim negligence on an employee and so reduce the percentage of hearing loss which is compensable? An employer should not be liable for hearing loss which is caused outside of working hours, i.e. car racing, portable tools use and other hobbies. It should be possible to deduct such loss in determining the extent of compensable N.I.H.L.

In conclusion, I would like to say that:-

1. We need stricter legislation on the manufacture of noise equipment with incentives to ease the cost of control.

2. An awareness campaign throughout Australia on the problem of N.I.H.L.

3. Penalties enforced for the non-use of hearing protectors where required and provided.

4. All aspects of noise; domestic, industrial etc., should be under the control of one body, to allow for a co-ordinated noise control programme nationwide.

THE ECONOMICS OF NOISE CONTROL

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Economics can be described as the science of providing the most efficient use of resources. In the case of noise control it means the cheapest method or the lowest cost in dealing with noise.

Cost of course can be measured in two ways; (a) by money and (b) in human resources which in my terms is workers health. Both the employer who is largely responsible for the creation of noise and the worker who is largely the recipient of the affects of noise are affected in varying degrees by money loss and other less tangible losses.

Understandably not all workers are affected in the same way by varying degrees by noise exposure. For example we have found that on examination, a worker who was almost 65 years of age, and who had worked in a noisy powerhouse for the best part of his working life had almost no hearing loss, but on the other hand much younger men exposed to the same noise in the same environment had quite considerable losses, in the order of 20 and 30% binaurally. Equally we discovered a 21 year old fitter who had only been employed through his 5 years of apprenticeship had a hearing loss of almost 10%, and yet middle age men with some 20 to 25 years of work in the same place had losses equal to that of the young man. As is the severity of the noise exposure often unrelated to the degree of loss incurred, so is the degree of loss incurred often unrelated to the affects upon the injured worker.

Naturally in the main a high degree of noise exposure over a long period of time produces a severe hearing loss and by the same token a severe hearing loss in the main produces the greatest affect upon the injured worker. Many of the workers with hearing loss that seek the assistance of the A.M.W.S.U. talk about embarrassment amongst friends because they do not hear conversations properly. Inconvenience in other situations and loss of enjoyment of life, particularly amongst older people trying to communicate with their grandchildren. Frustration also occurs, as does family disruption by way of squabbles etc. because there is basically a lack of sympathy and understanding for people who are hard of hearing. Finally isolation occurs when people with a hearing handicap are either rejected and ignored or simply do not participate and withdraw from conversation and other communal activities.

Other physical affects to workers have also been noticed. A common one is tinitus which causes a great deal of concern to many workers, and is not compensable. This appears to affect those with the lower losses, more than the more severe losses.

We have dealt with a workers compensation claim for a nervous breakdown directly related to exposure to noise, and this resulted in the worker receiving $18,000 for total partial incapacity. In 1977 we settled a workers compensation claim for a young lady who was working in a press shop. It appeared that every time she worked on a large press her body began to swell, and she was not able to continue working. Two other rather unusual cases originated in the same factory, Mechanical Handling Pty. Ltd. The first was a worker employed on a guillotine, cutting heavy steel plate. He had worked on the guillotine for some 15 or so years but then around 1976 devoped "startle reaction". This meant that every time there was a sudden increase in sound pressure he became unwell, and began to vomit, and showed signs of vertigo. The other worker that came to us about the same time from the same factory was first diagnosed as having Le Noyez variation of Meniere's syndrome, but after a surgical procedure was carried out, it was finally concluded that the noise levels at that place had exacerbated a true Meniere's syndrome.

The other cost of course to the workers is that of a financial one which invariably occurs whenever any of the previously mentioned problems lead to partial or permanent incapacity. No amount of money will ever compensate many of those workers who have suffered from the conditions or symptoms described previously.

The cost to the employer on the other hand occurs in two ways as does the cost to the worker in that there is an unseen cost, and a visual cost. The unseen cost perhaps comes with lower production or loss of production, and the inefficiency of skilled workers, and perhaps even the loss of those skilled workers because of the symptoms of noise exposure. Other costs are direct as in compensation payments for disability, and the costs of noise reduction programmes.

The A.M.W.S.U. has conducted many very important test cases around industrial deafness, and the results have been that claiming compensation for this type of injury is in most cases more simple than for any other injury.

Under the Workers Compensation Act that applied from January 1974 until the end of June 1982, a maximum of $15,000 was payable for total deafness. Accordingly, percentage losses of hearing were awarded compensation as percentages of that $15,000. During 1977 the Amalgamated Metal Workers' & Shipwrights' Union settled a total of 448 claims for the amount of $1,112,838.00 (see table on page 6).

The Workers Compensation Act presumes under Section 74 that all noise induced hearing loss is assessed as if the whole of the loss of function occurred immediately before the notice of injury was given. This has meant that a worker does not have to prove what proportion of loss occurred over a given period, or with a given employer. This has been a very valuable tool for workers claiming compensation for hearing loss. The legislators of the time recognised that there was a practical difficulty with this Section because of the presumption that all of the loss occurred immediately prior to the claim. It was alleged that employers were turning away potential employees because they had a hearing loss, and that they did not wish to be saddled with somebody elses claim.

With this in vew a new Section was added in 1979, Section 74A, that allowed for a prospective employer to have a new employee examined, his or her loss assessed, and then after serving the new employee with a copy of the assessment, and a notice, was free from any claim for that degree of loss. It took sometime before that started to become effective, but even today that has not worked as well as it should have. The problems that we have seen are that some employers are still not aware of that provision. Where workers are examined, often the proper procedure is not observed and employers do not serve either one or both of the notices upon the worker. They have then not absolved their liability. A good number of workers on the other hand accepted the proper notices served upon them, and did not realize what they represented. Many thousands of dollars have simply been put in the bottom of a draw, or discarded by the many workers who have not realized their value.

In 1982 the Government amended the Workers Compensation Act and in doing so increased the maximum available to workers for noise induced hearing loss, from $15,000 to $22,500 from the 1st of July 1982, and from the 1st of July 1983, $30,000. In addition to that they discounted all claims in that the first 10% of hearing loss was no longer claimable. (see page 7) On the calculations of the A.M.W.S.U. it is estimated that over 41% of those people formerly eligible for compensation for industrial deafness no longer have a claim. (see page 8)

We also calculated that of all those who had a claim, over 84% would be worse off under the amending legislation from the 1st of July 1982 until the 1st of July 1983. After that second date over 55% of those eligible would be worse off than those who could claim before the 1st of July 1982, and still over 41% would have no claim at all. The effect of this amendment has been a considerable inhibiting factor in people wishing to pursue workers compensation claims because of the risk of incurring unrecoverable legal costs, and or not being able to recover the high cost of medical reports.

The Labor Party's proposal which is supported by the Trade Union movement in general would mean that all payments under the Workers Compensation Act would be automatically increased annually and would be calculated as a percentage of the average weekly earnings for the March quarter of the year in question. Our estimation is that the approximate amount for total deafness would be around $43,500 which is almost double that presently prescribed.

Unions whose basic interest is the welfare of their members must work towards getting the best possible payouts for disability. There are two reasons to justify the Union's attempt to maintain high payouts for disability under workers compensation, and they are to provide a fair and just compensation for the disability and to make it economically feasible for employers to institute programmes of noise control. After all this is the economics of noise control. The long term objective of the Unions is to reduce the noise, and not have compensation paid because there is no noise induced hearing loss. Unfortunately an apathy has developed in some workers. Initially there was a great deal of concern expressed by workers that they should have suffered hearing loss, and they were very active in encouraging the employer to reduce noise levels in their workplace. This attitude has not perpetuated with some people regarding the claiming of compensation for noise induced hearing loss as simply a benefit that can be obtained from Industry. It must be stressed that this is not the attitude of all workers.

The changes in the Workers Compensation Act have meant that Unions have had to look more closely at how they can increase the benefits to their members, and continue to encourage the employers who are the people best able to control noise in the workplace, to play a positive role. In looking around the Unions have found only one other avenue worth considering, and that is the persuit of Common Law claims for negligence. If it can be shown that the noise levels in the workplace were excessive or more particularly that the employer made no reasonable steps to reduce noise levels in that workplace, then such a claim could be established. Several claims have already been prosecuted in New South Wales with one being quoted as indicating that a worker received $18,000. The same loss under the NSW Act would have attracted about $3,000. In that case the worker received six times the legislated amount.

It is not unforeseen for example in the application of machinery in the factories, that if an employer purchased a machine which had excessive noise emissions, that employer could be held negligent. Carrying that a step further it is not beyond the realms of possiblity that even the machine manufacturer could be held liable.

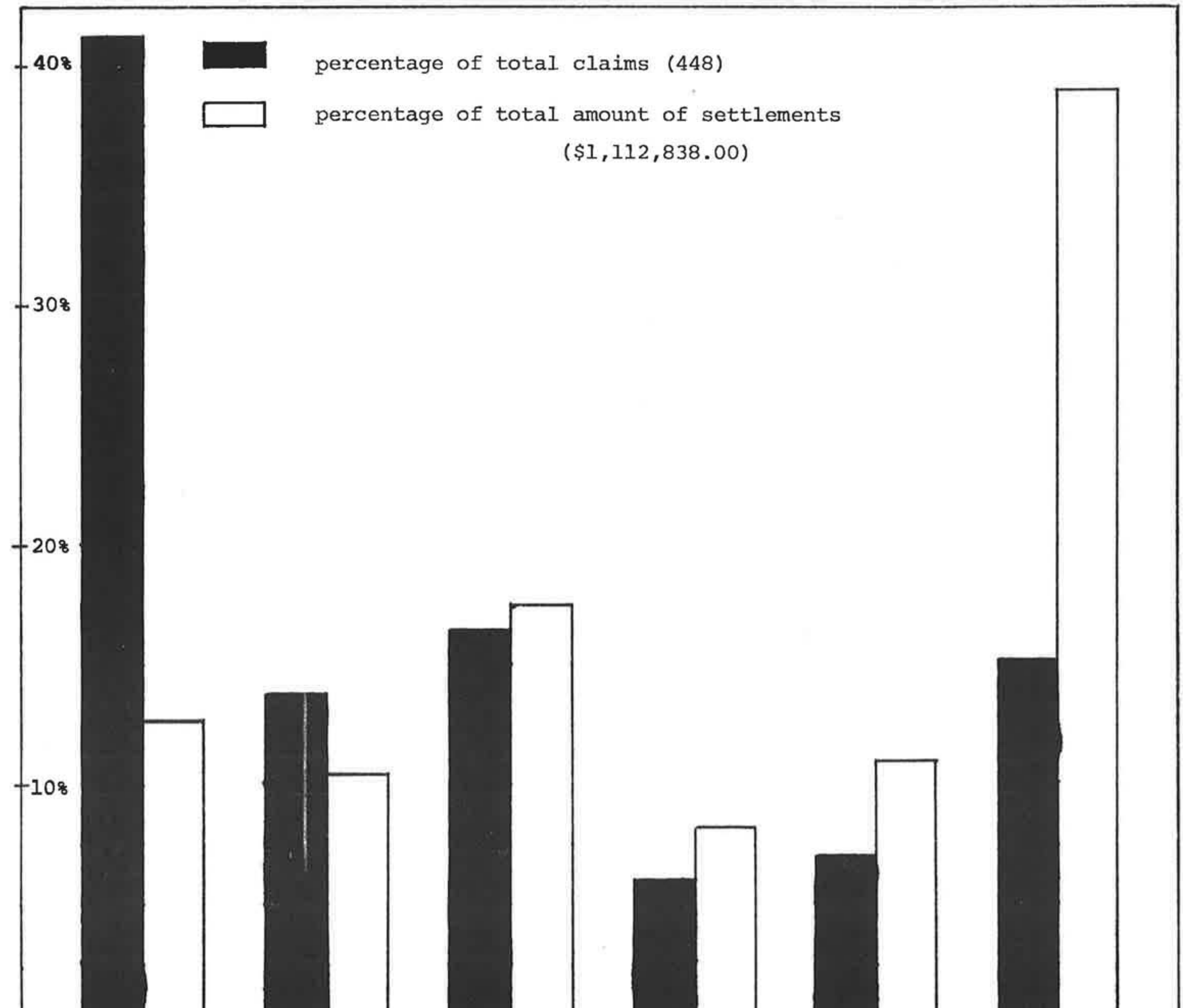
Noise reduction is not necessarily expensive, it simply takes a little thought. Many employers do not seem to want to make any effort and are content to pay compensation in many cases. The most common answer to a noise problem is to slap a pair of ear muffs on a worker and blame him if he goes deaf. Muffs are not the answer to noise control by any stretch of the imagination. They are uncomfortable if required to be worn all the time, particularly in hot conditions.

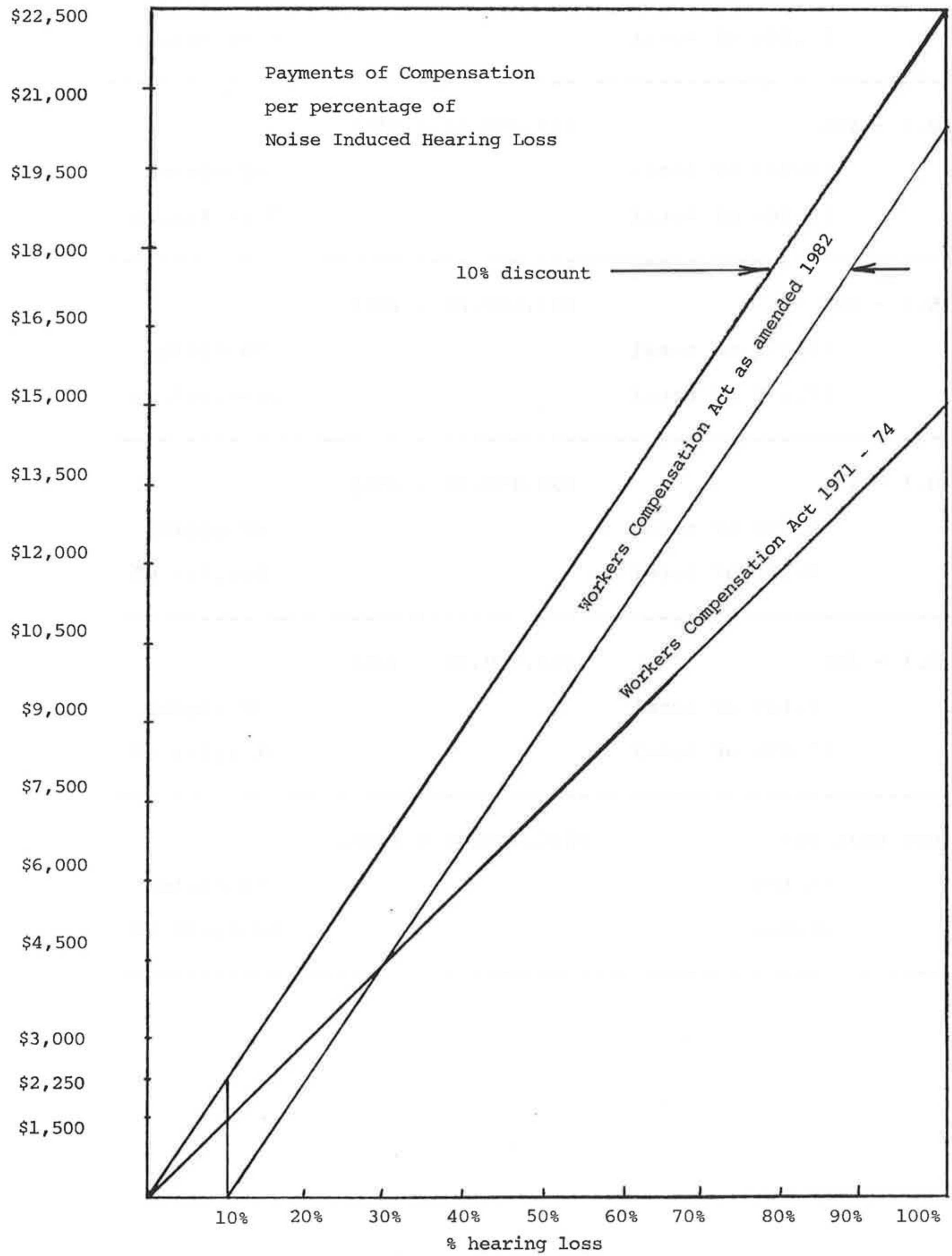
Noise must be controlled at the source wherever possible. If employers simply talked to workers about the problem they may obtain some answers.

GROUPS OF PERCENTAGE LOSSES AGAINST :-

(a) Total Hearing Loss Claims - 448 ;

(b) Total Hearing Loss Lump Sum Settlements - $1,112,838.00 ; based on the A.M.W.S.U. experience in 1977.




Payments of Compensation
per percentage of
Noise Induced Hearing Loss
10% discount
Workers Compensation Act as amended 1982
Workers Compensation Act 1971 - 74
$22,500
$21,000
$19,500
$18,000
$16,500
$15,000
$13,500
$12,000
$10,500
$9,000
$7,500
$6,000
$4,500
$3,000
$2,250
$1,500
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
% hearing loss

1977	Total H/L Claims	448
	Total H/L Settlements	$1,112,838.00
10% or less	($1,500.00 = 10%)	
41.29% of total		185 claims
12.76% of total		$141,982.00
10.1 - 15%	($2,250.00 = 15%)	
13.84% of total		62 claims
10.46% of total		$116.423.00
15.1 - 20%	($3,000.00 = 20%)	
16.52% of total		74 claims
17.59% of total		$195,767.00
20.1 - 25%	($3,750.00 = 25%)	
6.03% of total		27 claims
8.22% of total		$91,515.00
25.1 - 30%	($4,500.00 = 30%)	
7.14% of total		32 claims
11.09% of total		$132,453.00
more than 30%	($15,000.00 = 100%)	
15.18%		68 claims
39.06%		$434,698.00

ECONOMICS OF NOISE CONTROL FOR AN OIL REFINERY

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ABSTRACT

This paper considers a typical oil refinery and the costs associated in meeting environmental and occupational health regulations. Part 1 examines the economics of three options ranging from "Do Nothing" to Engineering Control and Hearing Protection, and Part 2 illustrates the costs and results of noise control on a major item of equipment. The conclusion is that environmental regulation and local community concerns dictate the cost of noise control although the tangible benefits are found in the reduction of employee noise exposure.

INTRODUCTION

Society's awareness of noise and the need to control noise both in the community and industry has increased significantly in the last two decades. This has led to various environmental noise and hearing conservation regulations to which industry has responded with varying degrees of success.

This paper draws on experience from several refineries and discusses both costs and the effect of noise control measures on environmental noise and occupational noise exposure.

Refineries vary in the nature and location of particular noise sources within their plant (with resulting effects on both environmental and occupational noise levels) and legal controls on noise also vary from State to State. Since this paper is presented at a symposium in South Australia, I have decided to use the regulatory controls in South Australia to characterise the legal requirements applying to the refinery but I would emphasise that the data and characteristics of the hypothetical refinery used in this case are not those of the Port Stanvac refinery, which is the only major refinery in South Australia.

All the economics are based on 1982 Australian dollars and the costs of various options for this hypothetical refinery are listed.

PART 1

BACKGROUND

A. NOISE CONTROL LEGISLATION

1. The South Australian Noise Control Act, 1976, was introduced to control the emission of excessive noise . The Act extends to control of noise from and within industrial premises. Protection of employees' hearing is covered by the Hearing Conservation Regulation 1978.

In relation to the industrial plant, Part III of the Act ("Industrial and Other Non-Domestic Noise") applies. The appropriate regulations are the Industrial Noise Control Regulations, 1978.

Controls are based not on a system of licensing but upon conformity to prescribed standards, enforced on complaint.

2. Industrial Noise Control Regulation

(a) Excessive Noise and Notices

Where excessive noise is emitted from industrial premises, an inspector appointed under the Act may issue a notice to the occupier of the premises requiring him to ensure that excessive noise is not emitted from the premises [Section 10(1)]. The maximum penalty for non-compliance with such a notice is $5,000 [Section 10(6)].

Excessive noise is defined by Section 10(2). The regulations are based upon prescribed emission levels for particular times of the day, depending upon the local land use as defined by the Noise Control Branch of S.A.D.E.P. (Industrial Noise Control Regulations, Schedules 2 and 3).

(b) Exemptions

The Minister may exempt from the operation of Section 10 any non-domestic premises, but this may be subject to conditions. In determining whether to exempt non-domestic premises, the Minister must take into account a number of matters (Section 11) including:

* the technical feasibility of reducing the noise;
* the economic cost of such reduction;
* the effect of noise on health and safety;

* the number of persons affected;
* the times at which the noise occurs.

Failure to comply with a condition of exemption attracts a maximum penalty of $5,000.

3. Hearing Conservation Regulation

This regulation provides standards and practices for the protection of the hearing of industrial workers.

Section 12 of the Noise Control Act prescribes a maximum penalty of $5,000 for an employer permitting an employee to be exposed to "excessive noise". In no circumstances (other than there being a reasonable excuse [Section 12(1)]) should noise levels exceed 115 decibels. The Act is also contravened if an equivalent continuous noise level of 90 decibels, calculated in accordance with the regulations, is exceeded (Reg.3).

A review of the Hearing Conservation Regulation reveals that this regulation is similar to other Hearing Conservation Regulations throughout Australia in that the exposure of an employee to noise:

(a) should not exceed an equivalent continuous noise level of 90 decibels for the workday, and
(b) should not exceed 115 decibels for any period of employment during the workday.

However, the S.A. regulation differs in respect to the options open to the employer to reduce noise level. In S.A. the employer shall "where practicable, take action to reduce the equivalent continuous level to the allowable limit by means of either:

(a) engineering noise reduction, or
(b) administrative noise control or a combination of both." (Section 3).

("Administrative noise control" means any procedure that limits the daily exposure of a worker to noise by control of the work schedule).

The unique feature of the S.A. regulation is the absence of the option to use personal hearing protection to control employee noise exposure.

The regulation does provide for an exemption where the employer is unable to comply (Section 7). The application for exemption requires:

(a) The reasons for non-compliance.

(b) The period for which the exemption is sought.

(c) The program proposed by the employer to comply with the regulation including the date for either the introduction of further engineering noise reduction or administrative noise control or both.

(d) The components of a Hearing Conservation Program which will be introduced to protect the employee until the proposed program (c) above has been implemented. (These components are covered in detail in Section 2.1 of the regulation).

B. OPTIONS

In the oil industry in Australia no new major processing installations have been built in the last decade. Consequently the industry has been faced with both an environmental and occupational noise problem as a result of the regulatory requirements which have been introduced in the period.

Possible options for consideration in responding to these requirements include:

1. Do nothing,

2. Introduce a Hearing Protection Program to protect employees,

3. Retrofit Engineering Noise Control and Hearing Protection Program.

All these options have direct cost implications and therefore need to be examined to assess their economic impact.

The costs of the choices would seem to range from zero to several million, however this is not the case as will be shown.

In reality Option 3 is the only viable alternative. Options 1 and 2 are untenable for several reasons, not the least of which is that the oil industry is concerned about its community relationships and image as well as the health of its employees. Community environmental awareness and concern has grown in recent years and is reflected in the principles embodied in environmental regulations and policies. These are typified by socio-economic effects statements in the Victorian Environment Protection Policy which state, inter alia, that noise sufferers should enjoy natural rights to a clean and quiet environment irrespective of cost/benefit analyses.(1)

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(1) Vic. State Environment Protection Policy No. N-1 Feb. 1981 Socio-Economic Effects

C. THE ECONOMICS OF NOISE CONTROL

To illustrate the economics of noise control, consider the following example:

An oil refinery comprising:

* a large processing plant using oil and gas fired heaters, gas compressors, boilers and motors of greater than 450HP.

* built prior to 1970, located in an urban area with one boundary in close proximity to houses.

* 300 employees (mainly plant operators and maintenance workers) exposed to occupational noise.

Because the refinery was built prior to the introduction of the current noise regulations, in-plant noise exceeds the regulations for occupational noise exposure and the refinery is under pressure from environmental authorities and the community to reduce boundary noise levels. For political reasons an exemption due to the cost of noise reduction is considered unlikely.

The refinery is situated in an area designated "urban residential with some manufacturing industry" under the Act. Maximum boundary noise levels at particular times are:

7.00 a.m - 10.00 p.m.	58 dB(A)
10.00 p.m - 7.00 a.m.	50 dB(A)

Noise level at the plant boundary is due to many individual items of equipment and each emit different noise levels and with different characteristics of noise (72 noise sources exceed 90 dBA and of these, 18 exceed 100 dBA).

OPTION 1 - DO NOTHING

In examining the economics of each choice even the first choice "Do Nothing" has substantial costs. These costs are direct and quantifiable and include fines and hearing compensation claims. Others are direct although difficult to quantify, such as legal costs and common law actions, (both personal and class actions). On the latter, Professor Frank Stevens has commented that the "damages awards made by the Supreme Court for hearing loss are about ten times the statutory limit set by workers' compensation legislation".(2)

Indirect and indeterminate costs result from employee dissatisfaction, adverse publicity and customer reaction, local community complaints, poor community and employee relations. This may generate costly responses such as increased advertising and public relations activities, or the costs resulting from consumer rejection of the Company's products.

The cost of "Do Nothing", while difficult to assess, probably has a potential direct cost in excess of $1,000,000 made up as follows:

Fines - Hearing Protection	$5,000
- Industrial Noise	$5,000
Potential Workers' Compensation*	$90,000
Potential Common Law Claims	$900,000
(10 x Workers' Compensation)	
	$1,000,000

e.g. Australian Draft Standard DR 82008, Appendix 4 contains Table D1 Calculated Incidence and Degree of Hearing Loss in Noise-Exposed Otologically Normal Male Population. Based on $15,000 Workers' Compensation Claim for total hearing loss and applying this to the hypothetical Refinery workforce:

200 plant operators' exposure levels, ranging from 75-100 dBA with an average of) Leq_8 90 dBA, with 25 years service

from Table D1

55% of plant operators will have 3% loss of hearing, therefore

200 operators x 55/100 x 3/100 x $15,000 = $49,500

(2) "Occupational Health" Newsletter No.15, October 12, 1981

100 maintenance workers' exposure level Leq_8 90 dBA with 30 years service

67% of maintenance workers will have 4% loss of hearing, therefore

100 workers x 67/100 x 4/100 x \$15,000 = \$40,200

Potential Total Workers' Compensation Claim \$89,700

(rounded to \$90,000)

Actual Common Law claims as yet have not been evident, however the potential claims are estimated at 10 times the Workers' Compensation claims, i.e. \$900,000.

OPTION 2 - PROTECTION OF EMPLOYEES

The next choice is to protect employees' hearing through the use of hearing protection devices.

Although some reduction would occur in hearing compensation claims and presumably common law claims, the fines and legal costs for environmental noise are unchanged.

The indirect costs associated with poor community relations and local community complaints would still occur.

The cost of the Hearing Protection Program option is $36,000 plus $2,300 p.a. for maintenance of the program, (e.g. Annual audiometric testing $1100, maintenance and replacement of ear muffs $1200).

Industrial Noise Fines	$5,000	
Hearing Protection	$9,000	+ $2,300 p.a.
Potential Workers' Compensation*	$2,000	
Potential Common Law Claims (10 x Workers' Compensation)	$20,000	
Total Cost	$36,000	+ $2,300 p.a.

* Option 1 with 20 dBA reduction in exposure levels.

From Table D1:

14 plant operators work in areas where the average Leq_8 = 95 dBA.

Plant Operators (with hearing protection Leq 95-20 = 75)

14 x 21/100 x 2/100 x $15,000 = $882

5 drivers are exposed to Leq_8 85 dBA. Drivers do not wear hearing protection.

5 x 48/100 x 3/100 x $15,000 = $1,080

Total $1,962

(Rounded to $2,000)

Recognising that the refinery operation is a continuous one, the use of administrative control (viz. control of work schedules), would be extremely complex. It is estimated that six additional employees would be required to administer such controls resulting in an ongoing cost of $360,000 p.a. with some uncertainty of success, therefore administrative control has been dismissed as a viable alternative to hearing protection.

OPTION 3 - ENGINEERING NOISE CONTROL

The next choice is to approach both the occupational and environmental noise problems by using a Hearing Protection Program and engineering noise controls.

The implementation of engineering noise control will take 2-6 years from identification of the noise problem through allocation of budget monies, approval of designs, fabrication and finally to installation.

The introduction of a Hearing Protection Program would take in the order of 1 year and could be implemented within 3 months from identification of the noise problem.

Considering the example of the refinery in an urban environment, the objectives of this choice would be defined as follows:

(a) Reduce the noise level at the community boundary to an acceptable level (e.g. 50 dBA). (Reduction of 15 dBA required).

(b) Reduce the noise level in-plant to meet the occupational noise exposure criteria Leq_8 = 90 dBA, however since the model regulation indicates Leq_8 = 85 dBA as preferred, the refinery objective will be Leq_8 = 85 dBA. To achieve this for all equipment greater than or equal to 90 dBA, the target for engineering noise control will be 85 dBA at 1 meter from the equipment except in special cases where the cost is not justified or the effect on equipment is excessive. This means a reduction of 20 dBA would be required on most equipment.

A. Cost of Total Engineering Noise Control Program for Equipment Noise greater than or equal to 90 dBA $2,453,000

Comprising:		Range $/unit	$
Heaters	(15)	16,000 - 160,000	1,530,000
Compressors	(9)	8,000 - 30,000	172,000
Pumps	(36)	1,500 - 15,000	161,000
Fin Fans	(4)	Approx. 40,000	157,000
Boilers	(4)	79,000 - 118,000	424,000
Misc.	(4)	2,000 - 2,500	9,000
			$2,453,000

It should be noted that the engineering noise control only reduces noise from continuous sources. Hearing Protection measures would still be in force to protect employees against intermittent noise sources, e.g. air releases, portable tools, etc.

Cost of Hearing Protection measures	$ 9,000+
Potential Workers' Compensation Claims and Common Law claims	$ 8,000
Total Cost	$2,470,000

B. Cost of Part Engineering Noise Control Program for Equipment Noise greater than or equal to 95 dBA — $1,771,000

Comprising:		Range $/unit	$
Heaters	(15)	16,000 - 160,000	1,530,000
Compressors	(7)	8,000 - 30,000	140,000
Pumps	(3)	6,000	18,000
Fin Fans	(-)	-	-
Boilers	(1)	-	79,000
Misc.	(1)	-	8,000
			$1,771,000

Cost of Hearing Protection measures	$ 9,000+
Potential Workers' Compensation Claims and Common Law claims	$ 8,000
Total Cost	$1,788,000

C. Cost of Part Engineering Noise Control Program for Equipment Noise greater than or equal to 100 dBA $1,595,000

Comprising:		$
Heaters	(14)	1,510,000
Compressors	(4)	85,000
		$1,595,000

Cost of Hearing Protection measures	$ 9,000+
Potential Workers' Compensation Claims and Common Law claims	$ 8,000
Total Cost	$1,612,000

IN SUMMARY, THE ECONOMICS ARE:

1.	Do Nothing	$1,000,000
2.	Hearing Protection Program	$ 36,000
3.	Hearing Protection Program with Engineering Noise Control for:	
	A. greater than or equal to 90 dBA	$2,470,000
	B. greater than or equal to 95 dBA	$1,788,000
	C. greater than or equal to 100 dBA	$1,612,000

PART 2 - NOISE CONTROL COSTS OF A HEATER

The following example illustrates the actual costs of noise suppression on a major item of equipment, viz. Crude Heater 184 Million BTU/hr (or 54 MW) of Fired Capacity which was attenuated at an Australian Refinery during 1982.

Cost		$155,000
Comprising:	Design	$ 21,000
	Prefabrication of ducting	63,500
	Prefabrication of piping to burners	10,000
	Turnaround and Installation	43,000
	Miscellaneous (Cranage, lagging, painting, transportation)	17,500
	Total:	$155,000

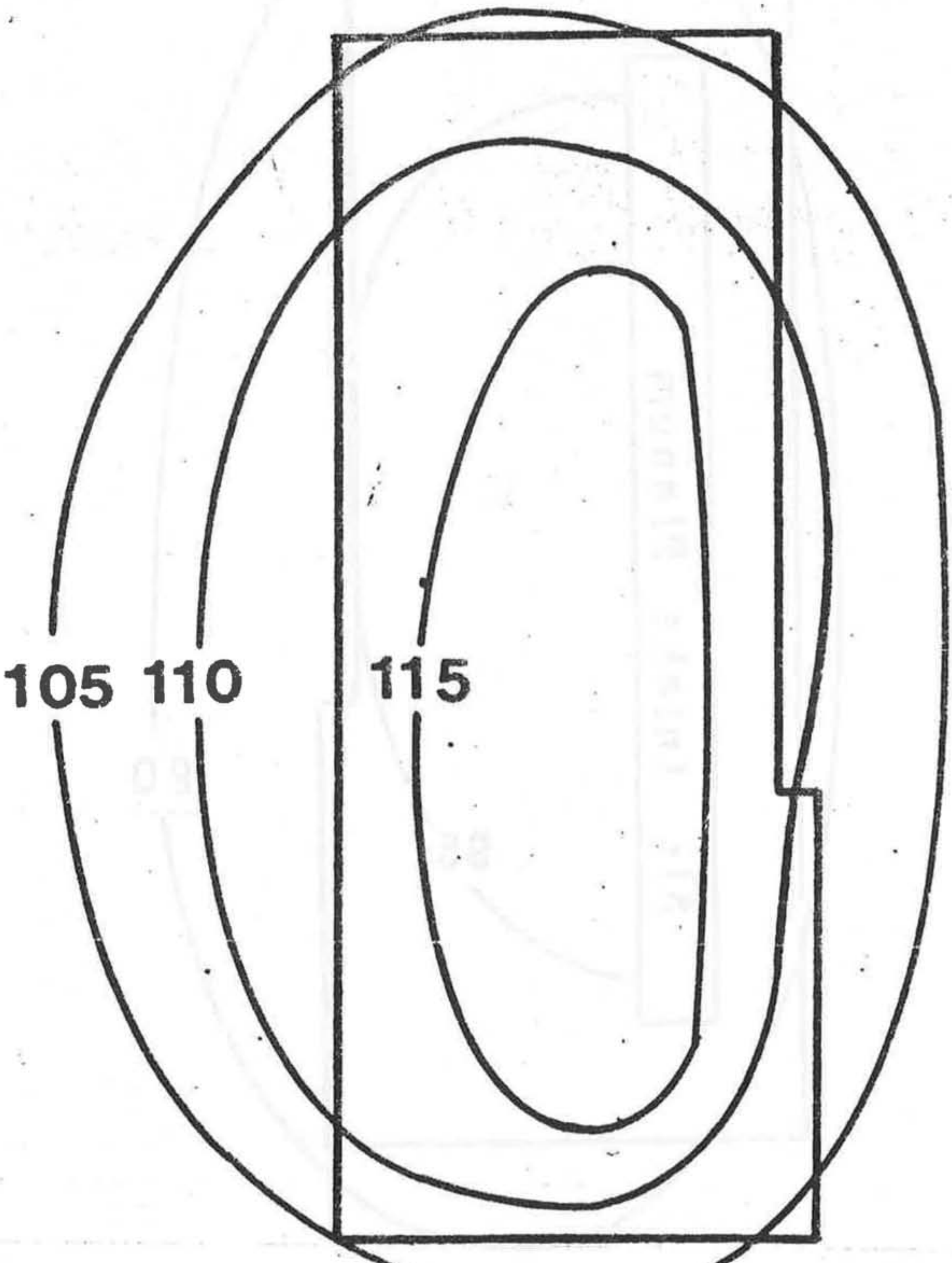
For this cost:

(a) the noise level under the heater was reduced from 119 dBA to 95 dBA (Refer Fig. 1A "Noise Contour prior Noise Control" and Fig. 1B "Noise Contour post Noise Control").

(b) occupational exposure is now Leq_8 81-83 dBA (formerly Leq_8 91-102 dBA). Hearing Protection Program is still in operation. (Refer Table 1).

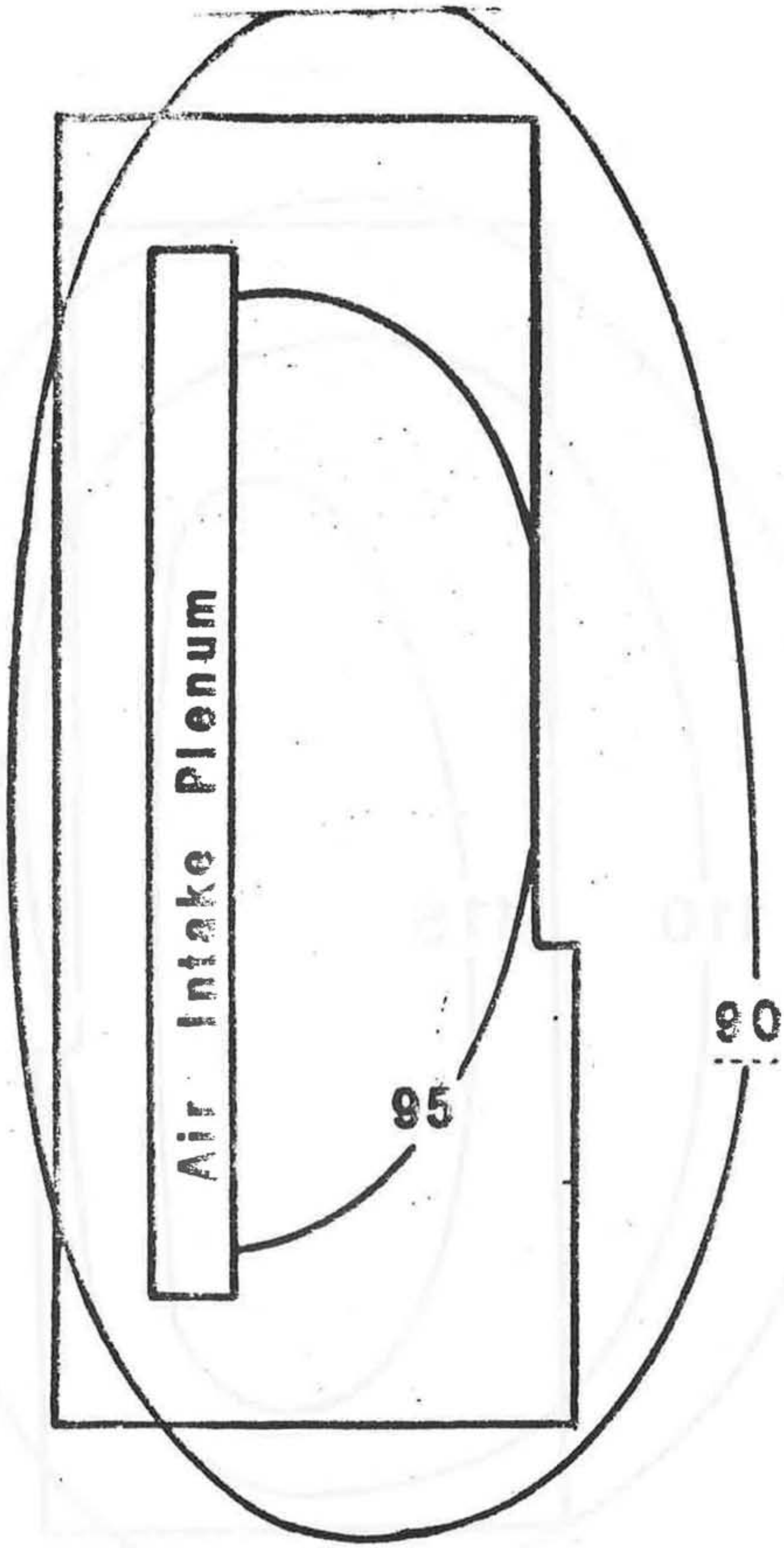
(c) the noise contour of the refinery has marginally altered and is 60 dBA at the community boundary. (Refer Fig. 2A "Prior to Noise Reduction" and Fig. 2B "Post Noise Reduction).

In summary, for $155,000, a marked reduction has been achieved in occupational exposure to noise; however, the environmental noise level has not been significantly altered. This illustrates that although noise control measures have been applied to meet both the environmental and occupational noise regulations, it is the reduction of employee noise exposure where tangible benefits are found.



Crude Heater

FIG. 1A



Noise Reduction of Crude Heater

FIG. 1B

Table No. 1

OCCUPATIONAL NOISE EXPOSURE

Hearing Conservation Regulation	Leq_8 90 dBA max.	Lmax 115 dBA max.
Heater - No Noise Suppression[1]	100	122
	98	118
	91	114
	102	118
	94	114
Heater - Noise Reduction[2]	83	110
	82	109
	81	115

NOTES:

(1) Large variations occur in occupational exposure due to individual work routines and the time spent near the heater. All employees wear hearing protection.

(2) Variations are less noticeable due to lower noise exposures from suppressed heater.

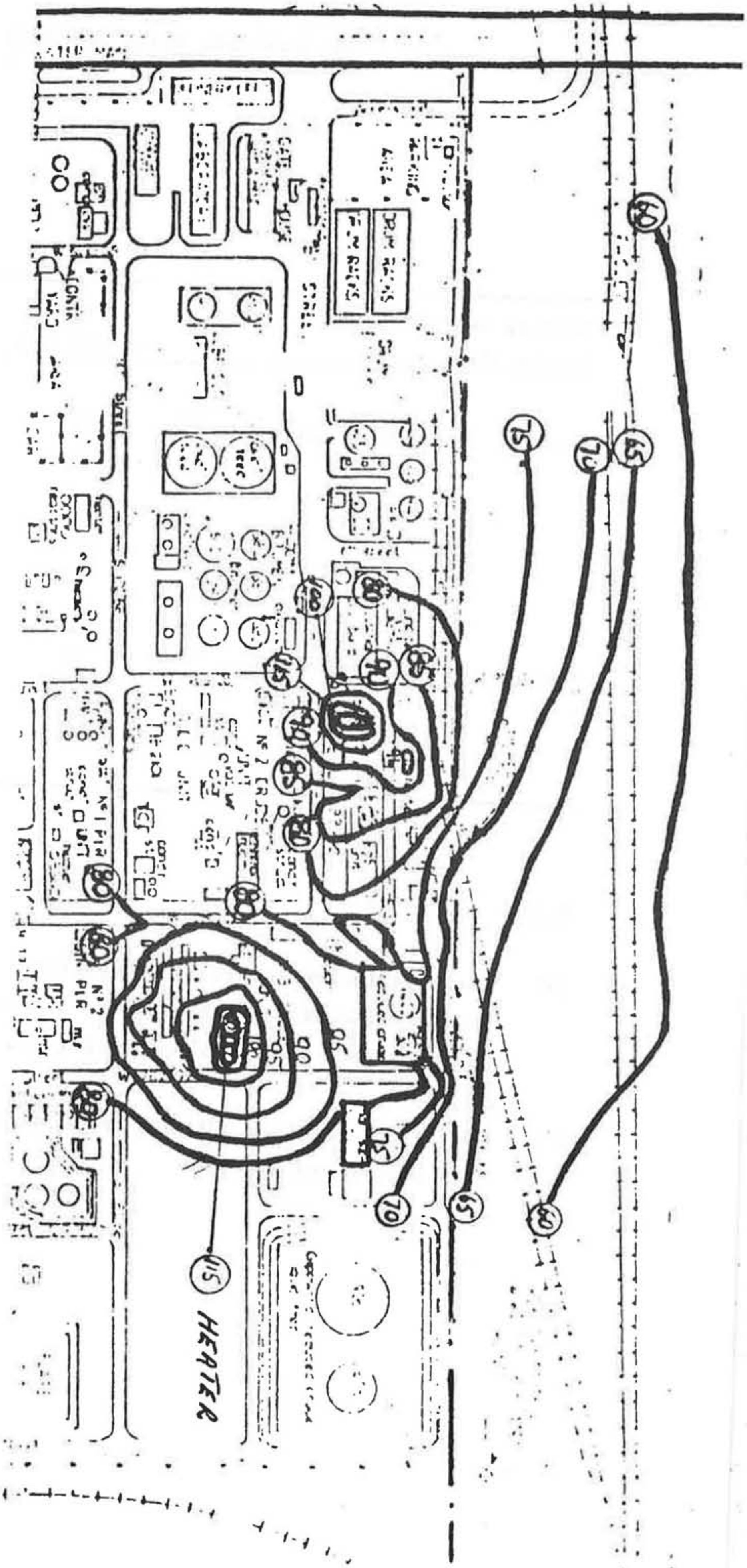


FIG 2A

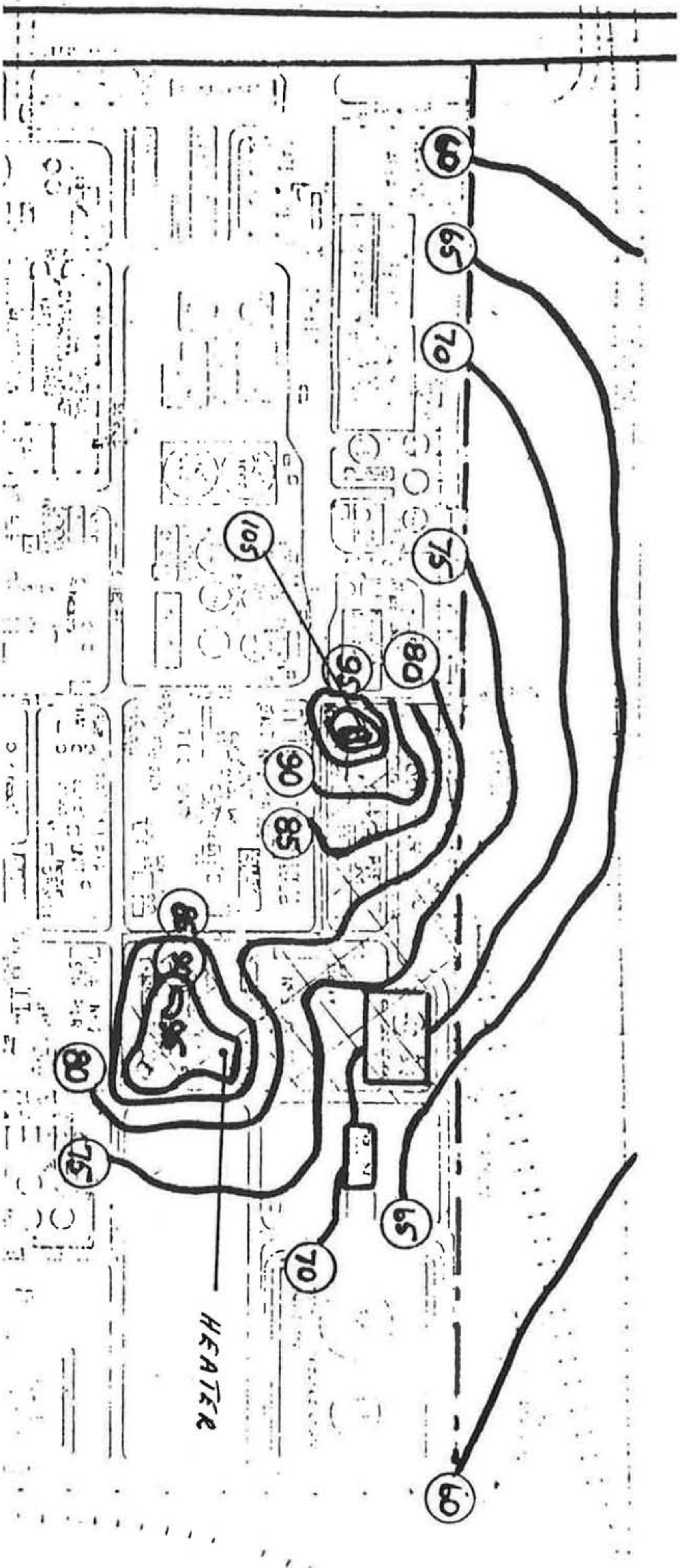


FIG 2B

THE BENEFITS OF NOISE CONTROL

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ABSTRACT

The obvious benefit of noise control is the solution to an acoustic problem. Less obvious benefits also accrue to people in the surrounding community because of the money spent on implementation of the acoustic solution. That money generates work and therefore stimulates the community's economy. If there is an unpleasant aspect to spending money on noise control, it is probable that it involves a redistribution of wealth away from the owners of the noise problem. Unlike expenditures on other things, the benefits of noise control solutions are not exclusively obtained by those paying for it. It is the non-exclusivity of benefits that may give rise to annoyance when people are confronted with the need to pay for the solution to an acoustic problem. If people saw expenditure on noise control in a wider social context, they would tend to be less adverse to spending money on better acoustic environments. Examples are presented to illustrate these points.

THE SOCIAL CONTEXT OF NOISE PROBLEMS

It is because of social pressures that we try to solve acoustic problems. These social pressures include legislation and regulations controlling environmental pollution, noise nuisance and occupational noise exposure. Besides State regulations, there are also Federal (such as car Design Rules) and Local Government regulations (such as building requirements) that often have quite significant impact on what we would like to do. The State, Federal and Local Government regulations are all there because enough people have expressed the wish to see them enacted. They all have some effect because there are enough people either raising complaints or objecting to proposals to ensure that those responsible for carrying out the regulations do their job.

If we don't spend money to solve acoustic problems, we can expect people to get noise induced deafness, headaches, sick, nervous disorders, to suggest a few consequences. Noise may be a nuisance when trying to take sensitive measurements and when listening for machine malfunctions, but it is the effect of noise on people that is the cause of most acoustic problems.

Too often, it is apparent that people complaining about a noise are unusual or at least a little strange. They may say that they are "driven mad" by the noise. The problem we face in trying to decide whether their complaint is justified is; is it really the noise that is making them behave unusually or were they mad before the noise started?

In our society we have many freedoms and some responsibilities. We have the freedom to do nearly anything we like provided we are responsible in ensuring that our actions do not cause a nuisance to other reasonable people. This is where it helps to know the answer to the difficult question above - was the noise complainant mad before or after the noise arrived?

It is easier to see our social responsibilities if we see ourselves as part of a larger group. In one case in which the writer was involved, a neighbour saw himself as having the right to undisturbed quiet while on the other side of the fence, a drummer had previously decided that he had the freedom to play the drums at any time without being dictated to by "crackpots" next door. Had each of the families seen themselves as part of a street with responsibilities to others in their community rather than as small units responsible only to family members (who may have liked either the quiet or the drumming), then the noise problem may not have arisen.

It is by seeing ourselves as part of a larger social context that makes the cost of acoustic solutions more bearable. When neighbours are seen to care about the employment and wealth generating functions of (sometimes noisy) industry, and when industry is seen to worry about its effect on neighbours, complaints and responses will be more reasonable.

ECONOMIC CONTEXT

Just as one's viewpoint or social context influences how one feels about a noise problem, the economic context can have similar distorting effects on how a problem is presented. In large cities, it is easy to feel that money spent on reducing a neighbourhood noise nuisance benefits only the neighbours, and the expense is entirely borne by the owners of the nuisance.

In a smaller community such as a town, the work required to control a noise problem would probably be done locally and the improvements evaluated by all those involved. Because townspeople may identify with most of their community, they may see the work being done by neighbours, so that the results of their actions are more readily identified than in a city.

Taken to an extreme, if we saw ourselves as part of one world community, we would not want to spend money or time on war.

ECONOMIC PARAMETERS OF WELL BEING

Terms such as the "Quality of Life" and "Standard of Living" are often used because of their looseness of meaning as well as their usefullness as phrases to indicate how well off people are. It is useful in this paper to use "standard of living" to mean the objective availability of material goods and "quality of life" to indicate the subjective feelings of a person living in an environment. The distinction is useful when considering whether to allocate resources to produce material goods very cheaply, perhaps with a minimum of labour (i.e. high standard of living) or to concentrate on reducing pollution at the expense of production.

Some people now choose to forego a high standard of living by earning only a subsistance income in a rural enviroment where they perceive a higher quality of life. They may have fewer material goods and hence a lower standard of living than people working in a city.

"Gross National Product" (G.N.P.) measures the value of production in a country. It includes some services such as acoustical consulting and excludes others like unpaid services in the home. It is intended to indicate the sum standard of living of a population and is meant to exclude non-economic parameters such as whether it is possible to sleep at night because of noise pollution. If in a hypothetical example a person is unable to sleep because of the high standard of living of his neighbours driving by in noisy motor cars, and that person has to spend money on thick glazing and air conditioning, the Gross National Product increases. In a similar vein, if an aggrieved party over a noise problem attempts to obtain an injunction restraining a neighbour emitting noise, the G.N.P. increases due to the legal fees paid out by both parties whatever the result. The standard of living goes up with G.N.P. and quality of life is measured by something else.

A contrasting example is how both the standard of living and quality of life improve when noise control is successfully implemented. Consider a concert hall with potentially noisy airconditioning equipment being designed for it. The acoustical consultant advises on the selection of quieter equipment, minimum pressure drop acoustic louvres and silencers etc. in order to achieve the required satisfactory sound level at the nearest residential boundary. In so doing the value of the project has been increased with the result that G.N.P. and standard of living also increase. The neighbours' quality of life is not adversely affected by the new development which could reasonably be expected to increase the facilities available to those neighbours with a nett improvement in their quality of life.

The cost of acoustic treatment generates work and income for consultants, manufacturers and suppliers of raw materials.

If there is a nett benefit for those involved in the production process, they may also benefit with a raised standard of living and a better quality of life if they choose to go to the new concert hall.

ACOUSTIC DESIGN IS GOOD DESIGN

Because design for acoustical objectives results in minimum wastage of acoustic energy, it can often save money, energy and improve comfort as well as noise levels. Where a project warrants consideration of these factors, the involvement of an acoustical consultant often means that the design process becomes more sophisticated, it may be more expensive but much more effective. The following example may illustrate the point.

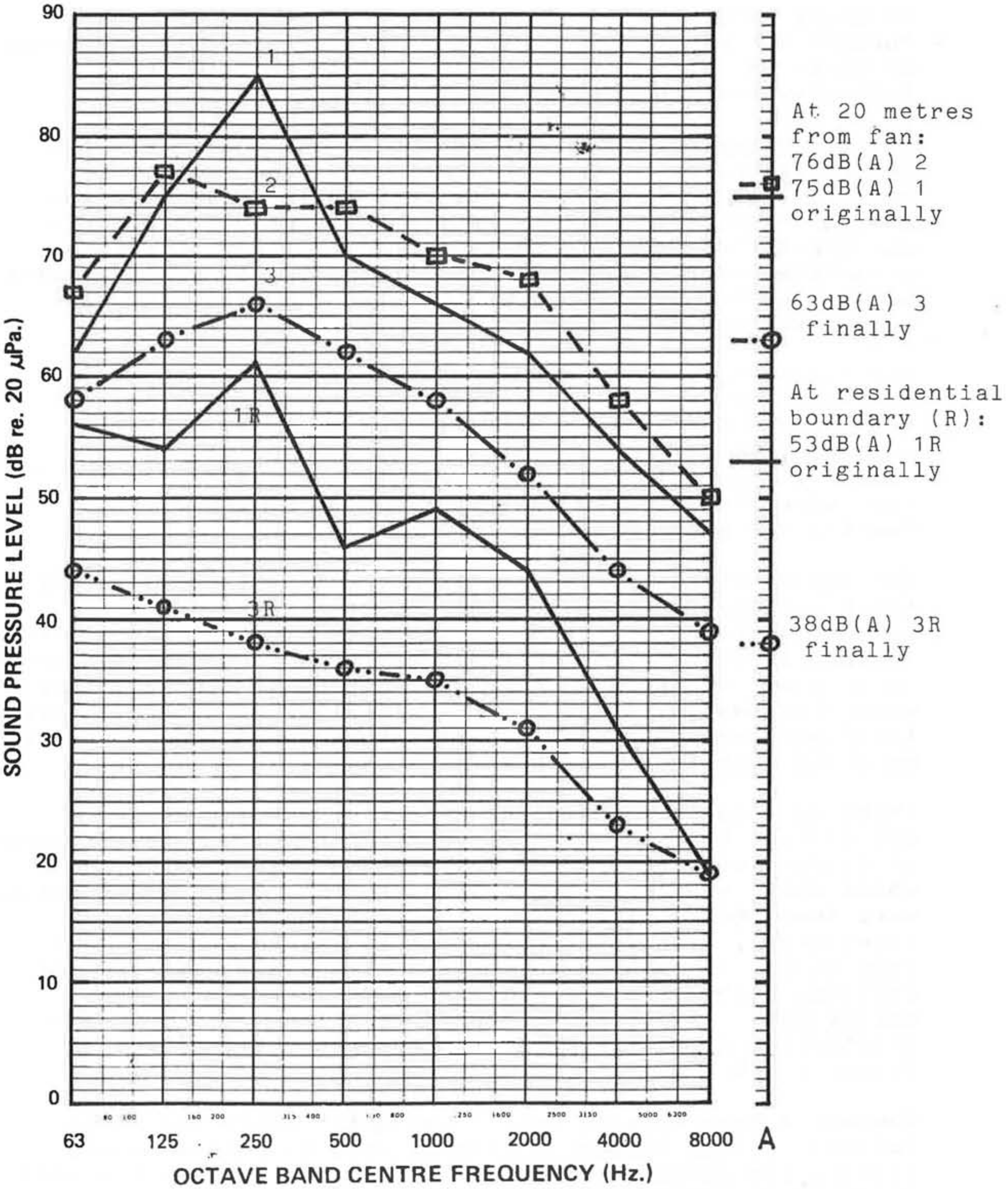
A water cooling tower and its fan had been moved from the back of an industrial site closer to the front property boundary which was separated from a neighbouring residential area by a busy road and a railway line. Whereas the noise from the cooling tower fan had previously been well removed from neighbours, it then became an obvious nuisance. The users of the cooling tower were prepared to spend thousands of dollars on either silencers for the fan, or a new fan, or a screen wall, new fan and silencers. In the figure, graph 1 shows the sound pressure levels measured at 20 metres from the fan. Graph 1R shows sound levels measured at the closest residential boundary 300 metres away.

Inspection of the fan showed that it was of the axial flow type (like a propeller) and that it had 8 blades. Immediately downstream of the fan was a flow straightening device which also had 8 blades. The prominent tonal component at 192 hertz was due to vortex shedding from the fan impeller and the resulting turbulence when the vortices met the downstream flow straightener.

By recommending that the fan and its motor should be turned around, the distance between the impeller and the flow straightener was greatly increased. Graph 2 shows the measured sound levels at 20 metres after the change, which took just one morning to implement. Although the overall sound level increased, the annoying tonal characteristics at the blade passing frequency had been dramatically reduced so that the problem was close to being solved.

Construction of a brick safety screen around the cooling tower and separation of the chain wire inlet guard from the impeller resulted in the sound levels measured on graph 3. That change lowered the overall sound levels. It was no longer necessary (or perhaps possible) to measure the sound level at the nearest residential area, with the results shown in graph 3R.

SOUND PRESSURE LEVEL MEASUREMENTS OF A COOLING TOWER FAN
taken at 20 metres near a factory and at the closest residential boundary, 300 metres away.



Graphs 1 and 1R show the original sound levels.
Graph 2 shows the effect of moving the fan away from its flow straighteners, but closer to its inlet guard.
Graphs 3 and 3R show final results with inlet guard moved upstream and a brick screen wall erected.

The important acoustic point is, of course, that the reduction in annoyance to neighbours was achieved by removal of the blade passing frequency pure tone, despite at one stage increasing the overall sound levels.

It would have been interesting to measure the airflow through the fan at the various stages of acoustic treatment as there may have been improved airflow and cooling following from the better acoustic design.

In this example, the people who spent the money were the industrial users of the cooling tower. The people who received the acoustic benefits were their neighbours who had their previous quality of life restored. The people who benefitted from the expenditure were initially the acoustical consultant, and the fitters who turned the motor around and the bricklayer who erected the safety screen around the cooling tower.

Our G.N.P. increased because of the expenditure, raising the "standard of living" of the acoustical consultant, fitters and bricklayer initially and eventually the community in which they spend their income. As in this case, all those involved belonged to the same community, the industrialists too benefit from the flow on or "multiplier effect" of the expenditure.

The owners of the noise problem may not feel overjoyed by their stimulation of G.N.P. because their expenditure will significantly exceed the benefits flowing back to them in increased sales to their now better off customers. But as a result of spending some money on noise control, they knew they had satisfied their residential neighbours, their local government Council and that they could then concentrate on doing what they know best - making their product.

There is also the multiplier effect of the spread of expenditure throughout a community. The direct beneficiaries of expenditure spend it on goods and services which then cause other people to benefit and so on. It is worth noting here that the multiplier effect can be applied very haphazardly, with the result that it may be applied more than once. It tends also to be applied in a discrimatory fashion, usually when claims are made for stimulating employment. It does not seem to be often applied to the deleterious effects such as the reduced availability of resources etc.

However a less obvious cost of acoustic materials is as follows. Using resources (design skills, materials and labour, for example) for noise control will raise the cost of those resources for competing uses. Fewer of those resources will be available in the market place resulting in the cost of production being forced up by the increased demand (using the currently popular and simple economic model). So although the multiplier effect is justifiably used to indicate gross increases in economic activity following on from a noise control stimulus, its effect on inflation is most often ignored.

CONCLUSION

At this conference, the content of this paper may appear obvious and self evident. But I expect some people faced with a noise problem will continue to say that their expenditure to reduce employees' and especially neighbours' complaints against their noise helps them not at all - "it is a complete waste of money". Although forced by law and social pressures to maintain or improve "quality of life", they should remember that their expenditure on noise control also raises Gross National Product, our "standard of living" and stimulates employment. Because noise control work has a high content of local production, because it generates only a little pollution of its own and because the acoustic improvement harms no one, it should compare favourably to expenditure on armaments, for example.

CONSIDFRATIONS ON ACOUSTIC INSULATION PACKAGE DESIGN IN PASSENGER CARS

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(Paper presented to the 1983 conference of the Australian Acoustical Society).

Abstract

Greater attention is being paid to the interior acoustic environment of passenger cars as rising customer expectations come into greater conflict with the constraints of mass and cost. This paper reviews motor vehicle noise sources and acoustics, and explores the application of noise control materials and how they may be effectively applied to achieve acoustic objectives within cost and mass constraints.

1. Introduction.

Increasing attention is being paid to the interior acoustic environment of passenger cars as the constraints of increasing customer expectations, and low mass and cost, come into greater conflict. These tensions have been accentuated as the market has demanded more compact, lightweight vehicles of unitary construction and powered by four cylinder engines. Noise control on these vehicle types is inherently more difficult than on larger, more massive, vehicles.

The measures required to effectively control interior noise depend on the sources of the noise. There are a variety of options open to the noise control engineer, and they include the design of mechanical and structural components to minimize noise at the source, and to mechanically isolate the sources from the passenger environment. However, these basic design approaches are not always sufficient to ensure an acceptable acoustic environment, and specific noise control materials are employed to further improve noise levels. This paper explores the basic economics of noise control materials, and how they may be effectively applied to achieve acoustic objectives within cost and mass constraints. But firstly, the basic aspects of motor vehicle acoustics will be reviewed to provide a framework for the discussion of acoustic objectives and how they may be achieved.

2. The major sources of motor vehicle noise.

Motor vehicle noise may be classified as originating from one of three major sources (see Figure 1). They are: powerplant and driveline, road and tyre interaction, and wind noise. They cover a wide range of frequencies, typically 20 to 10,000 Hz. Some sources are narrow band, such as the firing frequency noise generated by four cylinder engines, while other sources may be broad band in nature, such as road noise and wind noise. A detailed review of these sources, and appropriate noise control techniques, can be found in references (1) and (2).

The sound pressure level (S.P.L.) at a particular point in the vehicle (a typical measurement point is at the driver's left ear) is generated principally by the radiation of sound from panels surrounding the vehicle cabin. The panels may be acoustically excited by sources such as the engine and exhaust system, or they may be mechanically excited by vibration from the wheels and the engine. Below 200 Hz the various panels composing the structure must be considered as coherent sources, while above 500 Hz they may be treated as incoherent sources, with a mixture of coherent and incoherent sources in between. Noise control materials are most effective in reducing incoherent radiation from panels. Acoustic leaks which allow noise to pass directly into the cabin also contribute to the measured interior sound pressure levels.

3. Review of noise control materials used in motor vehicles.

The three normal basic categories of noise control materials are employed in motor vehicles. They are:

(a) damping materials, comprising heat-fusible deadeners that are fused to the upper side of the floorplan, sprayed materials and self adhesive sheet;

(b) barrier materials (or isolation materials) which are used under the carpet on the floor, and over the firewall area - these materials are usually felt, foam or glass fibre covered with a limp layer with a high surface density;

(c) absorption materials such as open cell foam, fibrous materials and resinated cotton felt which may be used in the headlining, engine hood or upper dash areas.

The combination of these materials used in the vehicle is loosely referred to as the acoustic insulation package. An example of a typical insulation package is shown in Figure 2, and it demonstrates how much of it is concentrated around the firewall area, where direct acoustic radiation from the engine is greatest.

4. The spectrum of interior noise.

It is usual, for the purposes of insulation package development, to measure the spectrum of interior noise in one-third octave bands because narrow band data is too confusing to interpret.

The generalized shape of a typical one-third octave "A" - weighted spectrum is shown in Figure 3. It has a plateau extending from about 125 Hz to 800 Hz, dropping off on either side of the plateau. The height of the plateau is the principal determinant of the total interior sound pressure level. Acoustic insulation materials affect mainly the higher frequencies of the spectrum, and this is indicated in Figure 3. Consequently, insulation materials do not always have a big influence on the overall S.P.L., but they do greatly influence the "quality" of sound. It is well established that two different sounds of equal S.P.L. can sound subjectively different to the listener, and in motor vehicles, it is largely the high frequency content that determines the "quality" (or "pleasibility") of the acoustic environment.

Other factors besides the insulation materials influence the spectrum of interior noise, and they include road surface conditions, vehicle speed tyre construction and wind conditions. The influence of some of these are illustrated in Figure 4. During insulation package development it is important to carefully control these parameters.

Another measure of interior noise is the Articulation Index (A.I.) which is a measure of the ability to comprehend speech in the presence of noise interference and is expressed as a percentage. An A.I. of 100% means that voice communication can be by whisper, and an A.I. of 0% requires

the occupants to shout to be able to communicate. Speech frequencies lay in the range 200 to 6300 Hz, but most information is carried near the centre of this band, so that the masking effect of background noise depends on both its frequency content and its level. The unweighted spectrum of interior noise cuts through the speech band as demonstrated in Figure 5, and the A.I. may be calculated from tables which determine speech interference levels in one-third octave bands. This procedure is usually computerized.

5. Noise control objectives.

Objectives for the control of interior noise are set using criteria discussed above (total S.P.L., and A.I. or frequency spectrum). Whereas objectives relating to exterior noise simply involve compliance with a single number (total S.P.L.) legislated noise limit measured under a single carefully specified condition, objectives relating to interior noise are much more difficult to define. Essentially they are determined by market expectations for that particular class of vehicle. Interior noise levels are substantially lower than any legislated limits for industrial workplaces, so that objectives must be set based on subjective evaluations of what is considered acceptable for the class of vehicle.

Because the interior acoustic environment is evaluated in relatively poorly defined subjective terms, a multiplicity of objectives is required to ensure acceptable standards. The most commonly employed objectives are illustrated in Figure 6. They include, as primary objectives, the specification of maximum S.P.L.'s as a function of vehicle speed, and articulation index as a function of speed. Other objectives relate to the presence of localized peaks in the S.P.L. versus speed trace and in the narrow band frequency spectrum - these localized peaks should not be greater than 3 dB as illustrated in Figures 6c and 6a. These peaks are readily discerned by the ear, and because they usually focus attention on a particular mechanical component, they can be extremely annoying. However, such peaks are usually controlled by careful mechanical design rather than by insulation package application. The specification of articulation index as a function of vehicle speed effectively defines the frequency spectrum, but an alternative and equally feasible approach is to define the frequency spectrum at discrete vehicle speeds.

It is interesting to observe the role of economic considerations in the setting of acoustic objectives. A vehicle with an acoustic environment which is inferior (however that may be determined) to competitor vehicles will suffer a market disadvantage, and to minimize lost sales, it will be economical to provide more acoustic insulation in the vehicle; that is, to upgrade the acoustic objectives. This will be valid only up to a certain point, whereupon it becomes less economic to invest in improved sound insulation because the increased market penetration per dollar invested will start to decline. The maximum benefit probably occurs when there is just a small market advantage. A factor which complicates this simplified analysis is that different customers place different emphasis on the interior acoustic environment, and in fact, probably very few people consider it as a specific reason for buying a particular car. Instead, the acoustic environment contributes to what may be called "vehicle refinement" which includes vehicle ride, handling, comfort and precision of control as well as acoustics. For acoustic refinement to be economic, these other aspects of refinement must also be acceptable.

6. The selection of noise control materials.

Noise control materials are selected to achieve the acoustic objectives within the constraints of mass and cost. These constraints may be set during the planning stages of vehicle development. Material selection is also influenced by the noise control strategy employed. For example, one strategy may emphasize the use of one of the three basic types of materials over the other two, and it may be as equally effective as any other strategy. The strategy must, of course, be suitable to that particular vehicle type and also to vehicle assembly plant capabilities - if a material cannot be handled by the assembly plant, for whatever reasons, such as equipment limitations or health risks, then that material cannot be considered. If the material is especially effective, it may be economic to introduce special equipment or handling techniques specific to that material. Having settled upon the noise control strategy, the materials are then chosen according to the cost and mass constraints.

The actual material selection procedure may take a variety of forms, but some parameters are required which enable the mass and cost effectiveness of various materials to be compared. For this purpose it is convenient to define the following parameters for each material:

$\triangle$ SPL/M - reduction in overall SPL per unit mass;
$\triangle$ SPL/C - reduction in overall SPL per unit cost;
$\triangle$ AI/M - increase in articulation index per unit mass;
$\triangle$ AI/C - increase in articulation index per unit cost.

Figure 7 shows these parameters for a variety of material applications in a vehicle. The data is shown for three vehicle speed and road surface combinations, the measurements being made at the driver's ear position. It is very easy to generate vast quantities of such information for a broad range of materials, different road and speed conditions, and different microphone positions. The sheer quantity of data may serve to confuse rather than assist the selection process, so it is usually desirable to average the results from several microphone positions. Most product development programmes have rigid time constraints as well, providing further incentive to minimize the number of measurements without sacrificing accuracy, and this is where the experience of the noise control engineer is crucial.

The data in Figure 7 demonstrates that the characteristics of mass efficiency and cost effectiveness do not necessarily go together. For example, the heat-fusible deadener application obtains a result which is reasonably cost-effective, but suffers a severe mass penalty. Clearly, the mass and cost of the individual insulation package components must be juggled within the boundary constraints of total mass and total cost to achieve the acoustic objectives. This has to be done manually because, at this point in time, a formal analytical or numerical optimization procedure is too difficult to implement.

It is also apparent from Figure 7 that noise control materials are not very effective on the coarse road surface. This indicates that road noise, which dominates the interior noise levels, is most effectively controlled by careful mechanical and structural design of the vehicle.

It is instructive to examine a typical vehicle insulation package to observe the distribution of mass and cost within the package:

MATERIAL CATEGORY	MASS	COST
ABSORPTION	12%	13%
ISOLATION	48%	73%
DAMPING	40%	14%

It is apparent that, in this particular application, isolation (barrier) materials are extremely effective in achieving the acoustic objectives because they account for about half the mass and three quarters of the cost of the package. Most of the barrier materials are applied to the inner and outer dash and front floorpan areas adjacent to the engine compartment where the ambient noise levels are 30 dB(A) or more higher than in the vehicle cabin. The mass of these materials is a manifestation of the well known mass law of noise control, and their cost is due to the moulding of these parts to suit the cabin contours, the moulding operation being expensive.

7. Conclusions.

The design of a motor vehicle acoustic insulation package is not usually a straightforward task. To achieve the acoustic objectives within the cost and mass constraints an appropriate strategy and material selection technique is required. However, other constraints also influence the development process, and they include time constraints, intrusion of acoustic materials into the passenger space, compatability with trim items, and interference with vehicle control systems.

There is no single strategy that can be used for every vehicle so the noise control engineer must assess all of the relevant characteristics of the vehicle and the nature of the noise sources, and apply his experience along with a reasonable selection process to obtain the final result which meets the acoustic objectives within cost and mass constraints.

References:

1. L.A. Wood, C.A. Joachim, T.J. Gibson and L.J. Sparke. 1979 Noise and Vibration Control in Passenger Cars and Trucks. Journal of the Society of Automotive Engineers - Australasia, 39(3), 96-111.

2. L.A. Wood 1982 Noise and Vibration Control in Modern Lightweight Passenger Vehicles. Journal of the Society of Automotive Engineers - Australiasia, 42(4), 200-214.

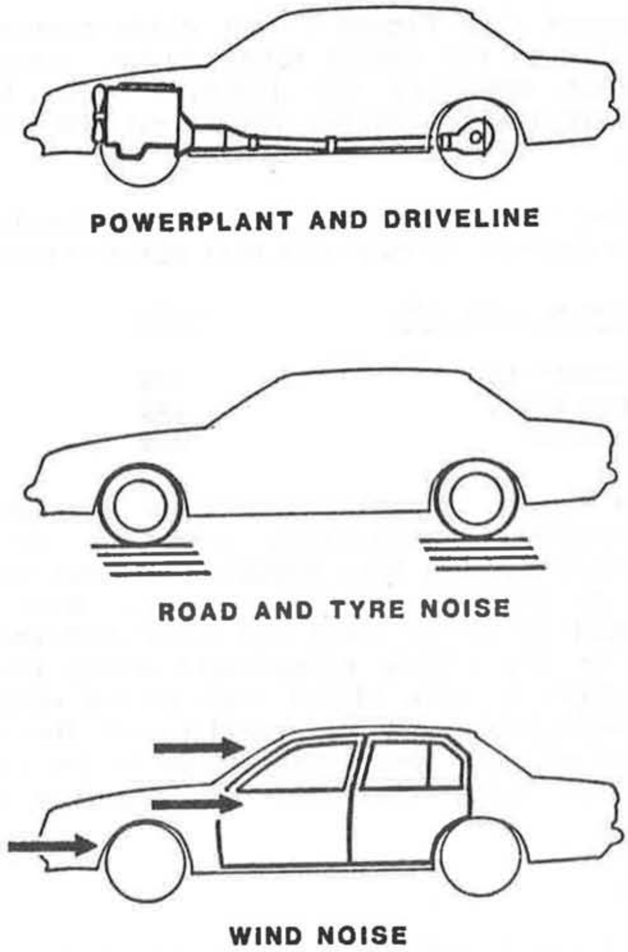

FIGURE 1: SOURCES OF MOTOR VEHICLE NOISE.

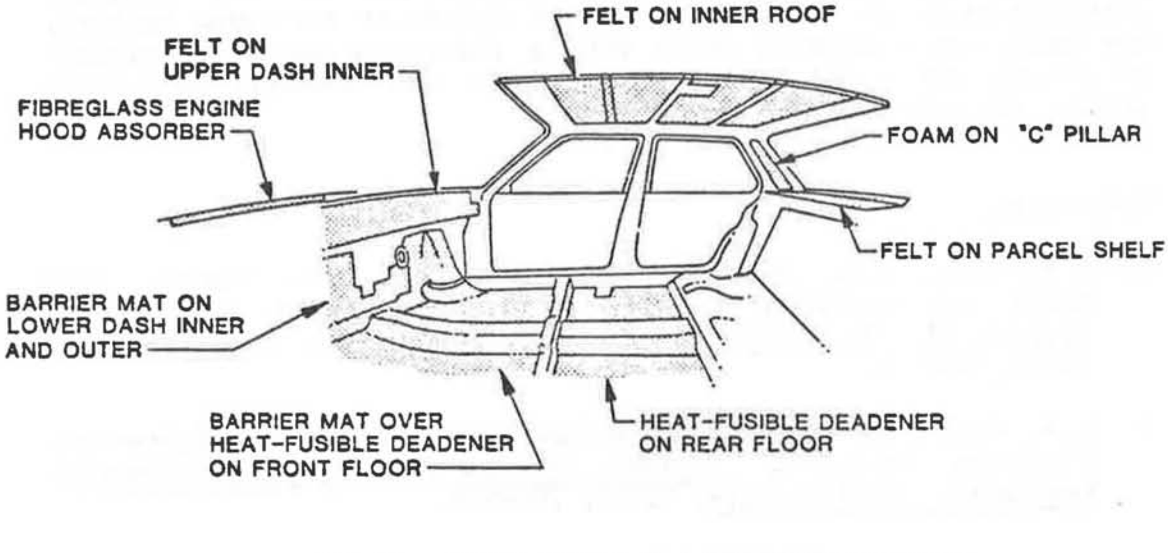

FIGURE 2: TYPICAL PASSENGER CAR ACOUSTIC INSULATION PACKAGE FOR CONTROL OF INTERIOR NOISE LEVELS.

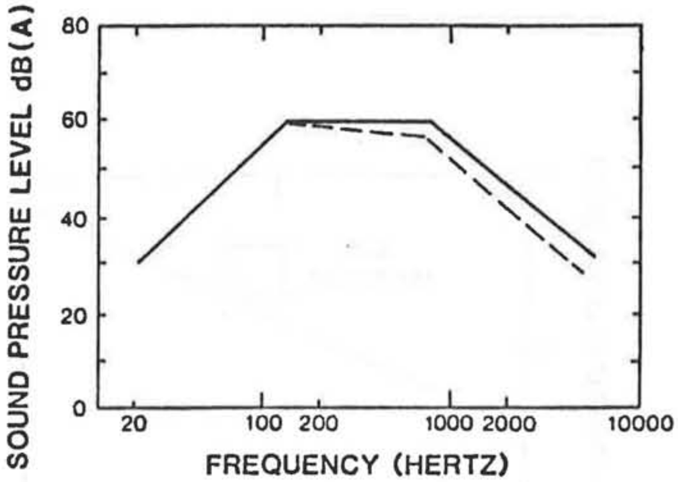

FIGURE 3: THE SPECTRUM OF INTERIOR NOISE. ——, GENERALIZED SHAPE OF A TYPICAL ONE-THIRD OCTAVE "A"-WEIGHTED SPECTRUM. - - -, INTERIOR NOISE SPECTRUM SHOWING THE EFFECT OF IMPROVED ACOUSTIC INSULATION PACKAGE.

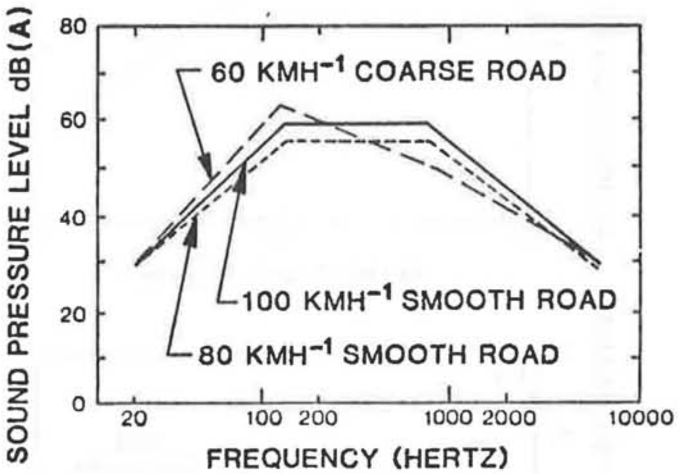

FIGURE 4: THE INFLUENCE OF ROAD AND SPEED CONDITIONS ON THE SPECTRUM OF INTERIOR NOISE.

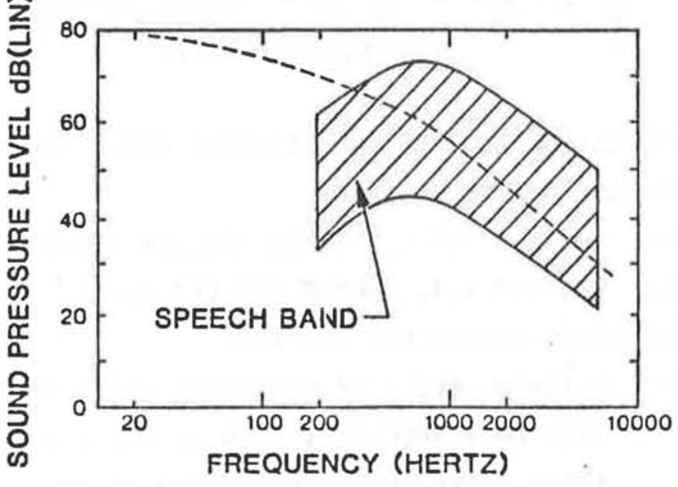

FIGURE 5: THE ARTICULATION INDEX IS CALCULATED FROM THE INTERSECTION OF THE UNWEIGHTED (LIN) SPECTRUM WITH THE SPEECH BAND.

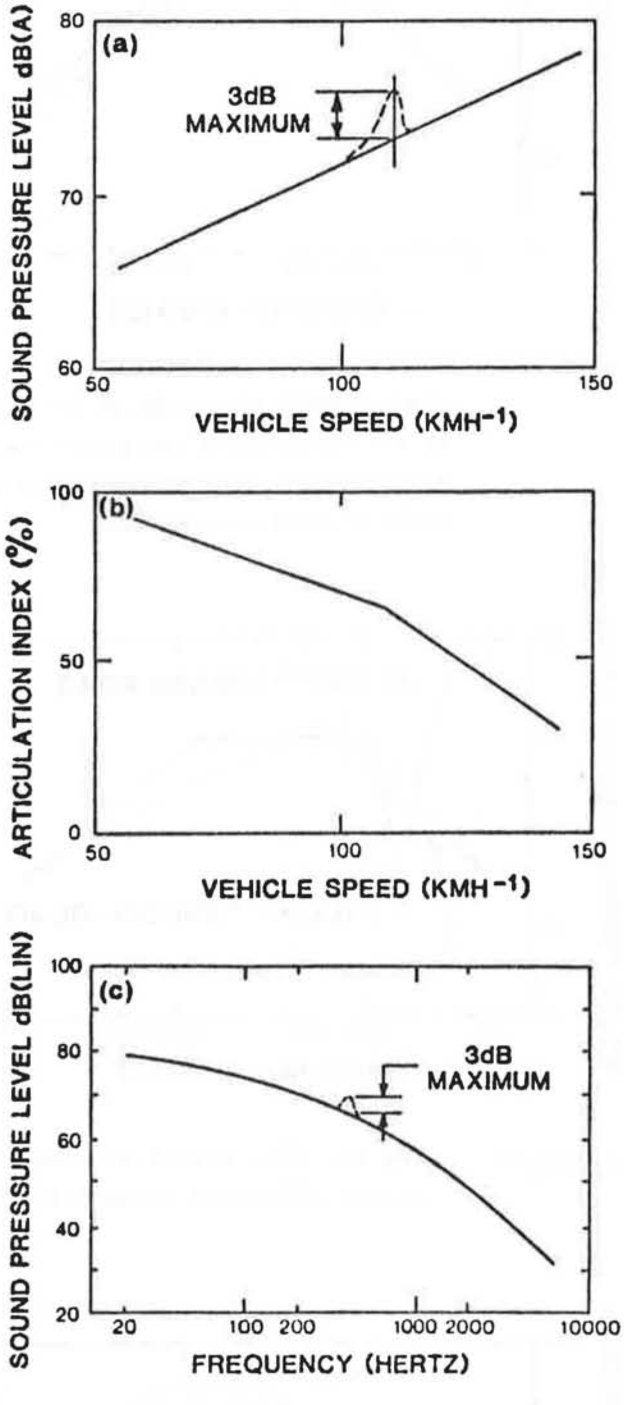

FIGURE 6: TYPICAL OBJECTIVES FOR INTERIOR NOISE CONTROL.
PRIMARY OBJECTIVES ARE:

(a) MAXIMUM S.P.L. VERSUS VEHICLE SPEED;

(b) MINIMUM A.I. VERSUS VEHICLE SPEED.

SECONDARY OBJECTIVES SPECIFY:

(c) MAXIMUM LEVELS OF LOCALIZED PEAKS IN THE FREQUENCY SPECTRUM; AND IN THE S.P.L. VERSUS SPEED CURVE ALSO ILLUSTRATED IN (a).

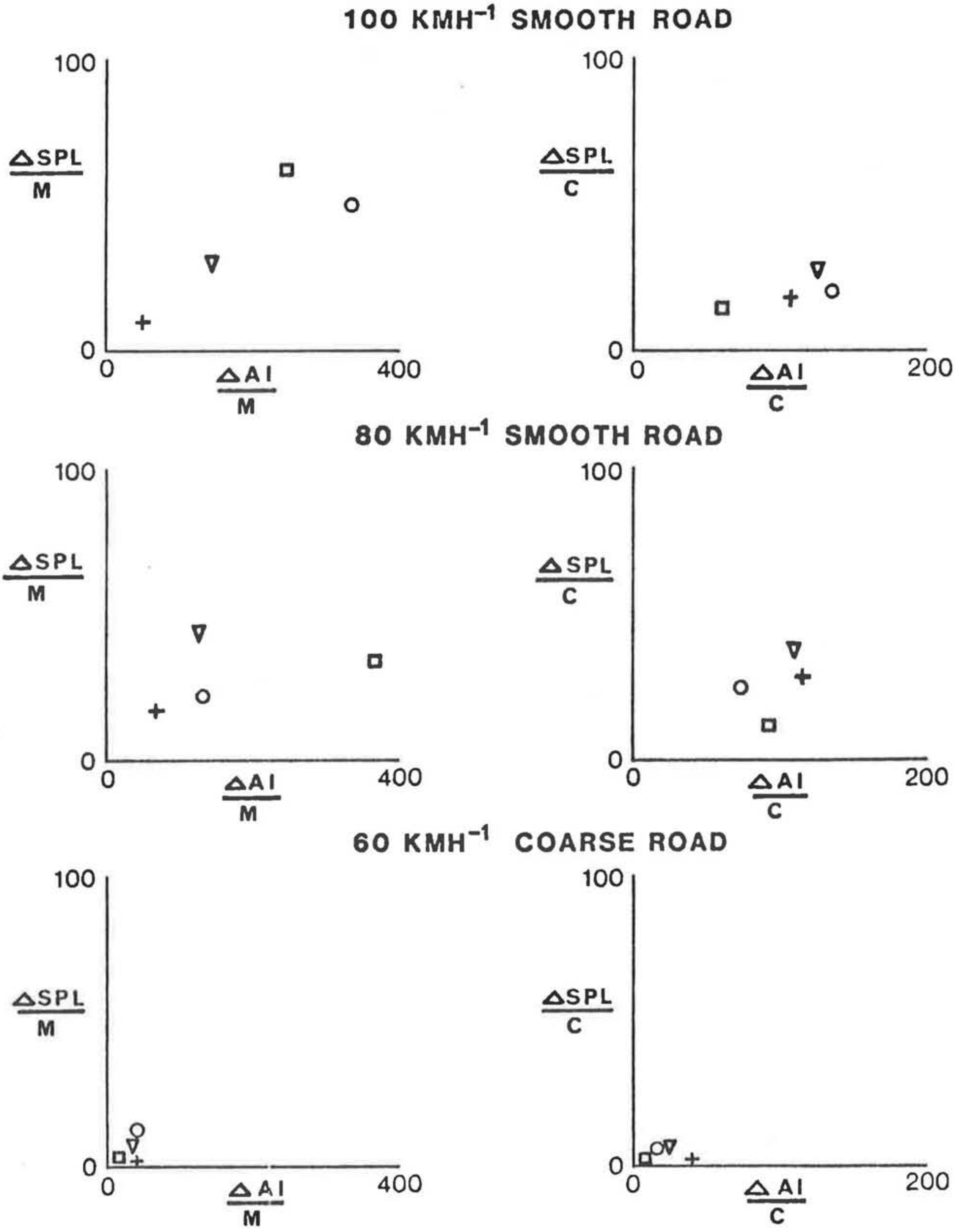

FIGURE 7: MASS AND COST EFFECTIVENESS OF SELECTED NOISE CONTROL MATERIALS. KEY TO MATERIALS:

○ OPEN CELL POLYURETHANE FOAM COVERED WITH SYNTHETIC RUBBER SHEET.
+ 2.3 mm BITUMINOUS HEAT-FUSIBLE DEADENER.
▽ 12 mm RESINATED COTTON FELT HEADLINING.
□ GLASS FIBRE ENGINE HOOD ABSORBER.

PRODUCT DEVELOPMENT - THE WAY TO REDUCE NOISE CONTROL COSTS

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INTRODUCTION

Noise is a design parameter which must be taken into account in new product planning and development.

This is a very simple statement. However, I do not believe that noise has been so considered in the past - or if it has it has featured very low on the list of priorities in that ever growing list of design parameters which now include:

Operational Performance
Ergonomics
Reliability
Maintainability
Producibility
Weight
Energy Efficiency
Cost
etc. etc.

Certainly in my limited experience, which has mainly been concerned with the design of military vehicles and Armoured Fighting Vehicles in particular - noise has been considered as the natural consequence of design that the troops have to learn to live with. Hence we have the noise levels in the M113A1 for example of something in the order of 124 dBA. In other equipment such as ships, e.g. Toobruk - and helicopters, e.g. Chinnook, noise and its partner vibration levels are sufficient to constitute a real problem.

Military equipment does not stand alone in this arena - we have already heard the continuing saga of the Punch Press - no acoustic conference would be complete without it. Other speakers have addressed other equipment. We have all probably experienced the noisy air conditioning systems in multi-storey buildings or our own homes - and many other situations.

The answer, I believe, is contained in the statement that noise is a design parameter. The realistic acceptable noise level must be set as a target for design.

AIM

In this address I intend to clearly identify that not only is product development (or research and development testing) the way to go to reduce noise control costs: but that such testing in new product planning and development leads to a competitive advantage in the market place.

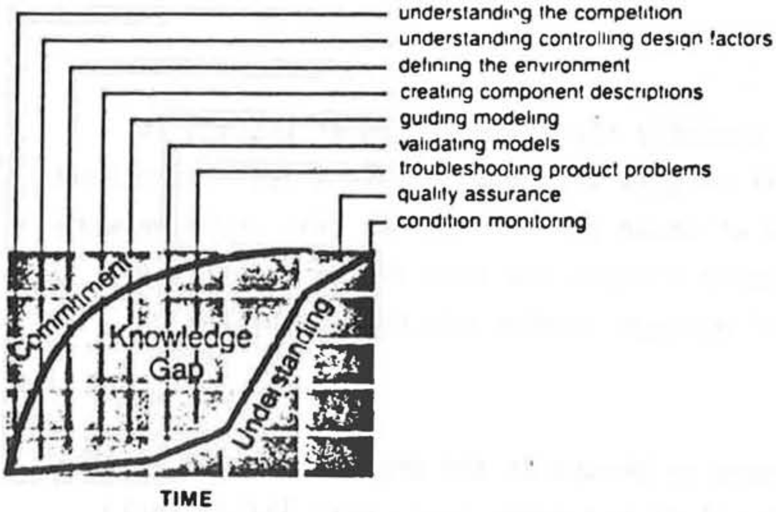
SOURCE OF MATERIAL

I have drawn the material for this address from three sources:

- My own limited knowledge and experience.
- The work being carried out by Vipac Laboratories of which I am privileged to be the General Manager -
- A number of articles from overseas sources such as the Structural Dynamics Research Corporation of U.S.A.

THE GOAL

As I see it, designers have a pretty tough job. Often design commitments must be made before product performance parameters are fully understood. There is a knowledge gap.



Testing can help reduce this knowledge gap. Competitive product analysis is often the first step towards designing new and superior products. Advanced test methods can help in understanding how competing products achieve their market advantage. Test results can help designers set realistic goals, help engineers meet these goals and help quality assurance personnel make sure the manufactured product meets the goal.

The key is understanding. The testing model need not be expensive. The reward is that there are no unpleasant surprises.

The elements are:

- Understanding the competition.
- Understanding controlling design factors.
- Defining the environment.
- Creating component descriptions.
- Model validation.
- Troubleshooting problems.
- Quality assurance.
- Condition monitoring.

There are many examples where this approach has proved to be cost effective - I would like to touch on a few.

Automotive

Field testing while probably the easiest form of testing is limited in the detail of data obtained to gain a full understanding of the mechanism of noise generation. In this study we were concerned with the noise effects and to a lesser extent the braking efficiency of various engine and exhaust brakes on heavy vehicles.

While clear trends were evidenced in the degree of noise emitted from the various exhaust brakes under test, very little could be said as to why one system was better than another.

In order to get down to this detail, one often has to go to the laboratory simulation. In this instance we were concerned with the break-out noise for different material fabrications on a series of dual muffler combinations.

I have to tell you that this is no easy test to conduct - after several weeks of experimentation we concluded that all the results we had achieved were fairly useless - but we learnt a lot in what was required for such testing and persevered Finally after a lot of reading on world experience in muffler testing (and how difficult it is) and a number of very elaborate precautions designed to ensure that we were in fact measuring muffler break-out noise, we were rewarded with some worthwhile results, conclusions and greater understanding of the mechanism of engine exhaust noise generation.

Major conclusions from the testing program can be summarised as follows:

a. The exhaust outlet remained the most powerful source of noise.

b. Significant sources of noise in the exhaust system were identified as:

- Noise radiation from the engine pipe, possibly caused by mechanical excitation from the engine exhaust manifold.
- Noise generation by gas leakage at joins in the exhaust system.
- Noise generation from the front plate of the first muffler.

In this instance laboratory testing allowed the best muffler combination to be identified and gave some insight into the mechanism of noise generation in exhaust systems.

To go that next step further one probably has to resort to more sophisticated modelling and testing techniques.

Dr. David Rennison introduced the work being done to understand and reduce the noise level on the M113 Armoured Personnel carrier. Here the technique of Finite Element Analysis is being employed.

As a result of this study the U.S.A. have moved to the Armoured Infantry Fighting Vehicle (AIFV) which incidently is not only quieter but has better ballistic characteristics from a battlefield survivability point of view.

The Australian Government has sponsored a study into Australian Industry capacity to design, develop and manufacture an Armoured Fighting Vehicle in Australia - Project Waler. It is hoped that some of this high level technology can be brought to bear on this project.

Certainly Australian manufacturers of Heavy Trucks are now paying the penalty of not keeping up to data on product development through research and development. European, Japanese and American truck manufacturers are stealing the market through driver comfort.

However one cannot be too critical of the Australian manufacturers; it does take considerable funds to move into the higher echelons of research and testing. Much of the improvement in the overseas product flowed from their Governments sponsored quietened vehicle programs. The resultant understanding of noise and vibration problems in heavy trucks has given the overseas manufacturers a definite market edge.

Building Industry

There is really no excuse for noisy or inefficient airconditioners in buildings. Testing of individual components to ensure they perform to specified data is the first step.

Full scale mock-up testing of the system to ensure that it performs correctly is the second step. Where these simple steps have been adopted in large multi-storey buildings, considerable cost savings in energy usage and the avoidance of costly corrective action has been achieved - particularly where the testing was conducted early in the design stage.

There are many benefits to be gained from mock-up testing of a typical module. We group these under the total environmental technology concept which embraces:

- Environmental effects statement.
- Wind Studies
- Reflectance and shading coefficient (becoming increasingly important in Glass Facade Buildings).
- Facade leakage tests.
- Interior comfort levels -
  - Temperature gradient
  - Wind velocities
  - Air distribution performance index
  - Noise levels
- Structural Vibration
- Energy Efficiency
- Lighting Levels

Other Examples

There are numerous other examples where product development through research and development testing has shown itself to be cost-effective and the way to go to reduce noise control costs. In most cases the study of the noise aspect has also contributed to overall design improvements. Examples include:

- Dishwashers
- Rangehoods
- Domestic white goods industry.
- Heavy industry and mining applications.
- Off-shore Platforms
- Defence Equipment

INTEGRATED SYSTEMS APPROACH

Like any other design parameter, noise cannot be considered in isolation. It is not much good developing a very quiet punch press if it does not perform its primary mission.

Design parameters are interactive and therefore the design team must be fully integrated and responsive to the systems integration group. Trade offs and compromises are inevitable - however they must be based on the best advise available. Therefore the consideration of noise must be present throughout the design phase from concept right through to production.

Where uncertainties exist, Research and Development testing of an appropriate model must take place to reduce these areas of uncertainty.

COST-EFFECTIVENESS

Well the question has to be asked, "Is the effort of R & D testing in product development cost effective?"

I would like to take as my model the life cycle cost of a very complicated product: namely a Main Battle Tank. The traditional profile is as shown here.

Subsequent research has shown that for an increase of effort (and hence funding) of 1% in the R & D area, a total cost saving of 10% was accrued across the production and particularly the in-service modification and maintenance areas.

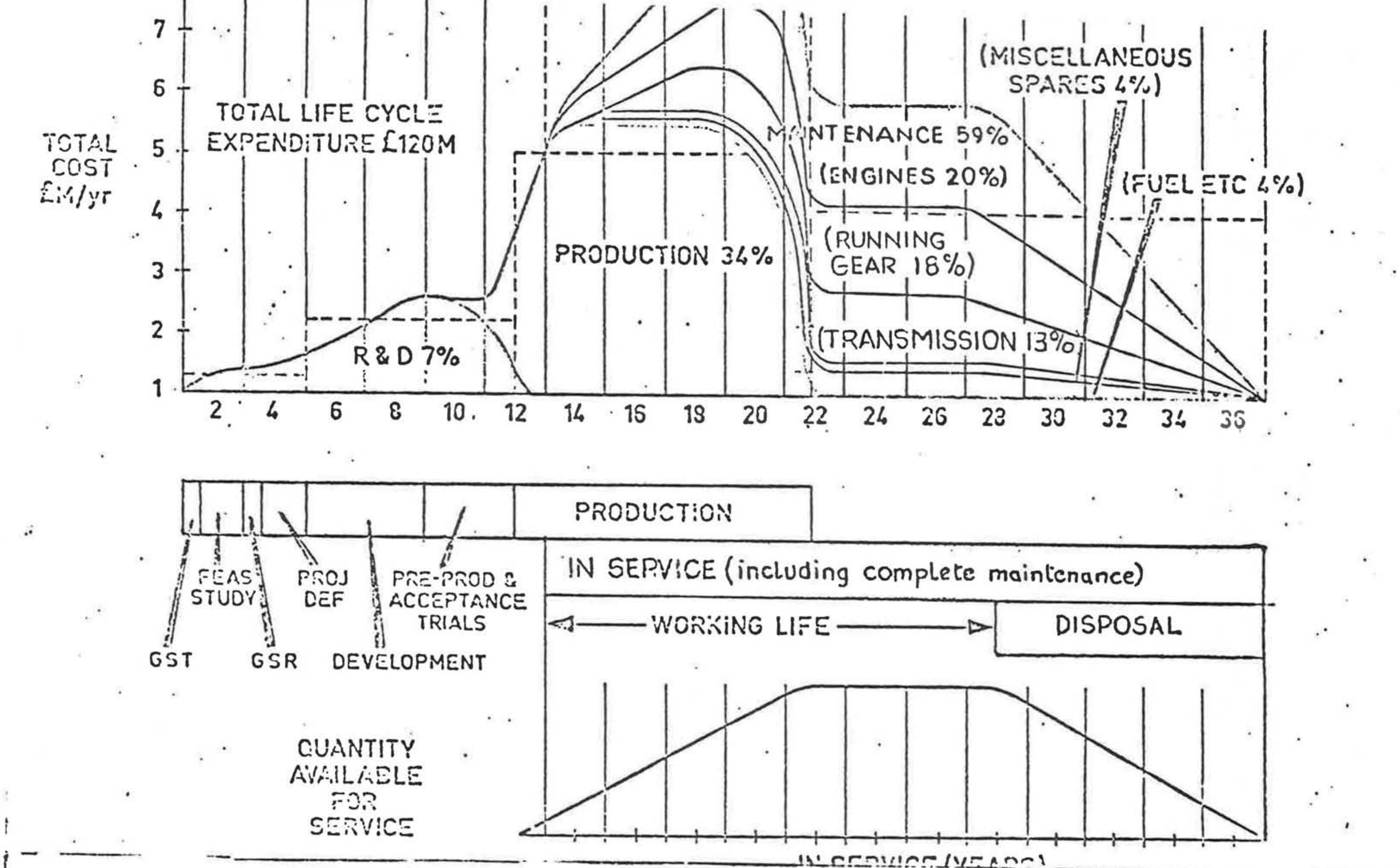
Today there are very powerful computer based techniques available to assist in the R & D product development. These combined with simple model testing should lead to a fuller understanding of the product under development and the achievement of noise level goals.

CONCLUSION

In conclusion I would like to re-iterate that in my opinion the noise expert (acoustician) has an important role to play in the Product Development team. Noise is a design parameter and realistic goals can be set by modelling testing.

To win his spurs and be accepted, the acoustician must be able to make worthwhile contributions from the concept right through to product manufacture. Perhaps it is in the area of how the acoustician can contribute to design that more study is required.

I trust that this address has at least raised the question in your minds.



Contribution

SLIDE 11

SOUND POWER LEVEL MODELLING AS A MEANS OF CONTROLLING NOISE CONTROL COSTS FOR MAJOR PROJECTS

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ABSTRACT

Detailed noise control analyses are required for large plants to meet current noise control criteria. These demand high standards of source identification and of required attenuation to allow cost-effective controls to be implemented. Sound power level modelling is a logical progression from other identification techniques for existing plant. It is also a powerful tool for prediction and control of new plant. One Australian company's experience with such modelling is outlined.

1. COST EFFECTIVENESS

Environmental noise protection follows the law of diminishing returns. At first it is possible to achieve substantial reductions in environmental noise pollution using relatively low cost measures involving simple measures and/or simple control equipment. However, the effects of subsequent increments in noise reduction will rapidly become less significant whereas the measures required become increasingly expensive. In other words, the cost to benefit ratio becomes progressively less favourable [1].

We rely on enlightened political judgements being made to establish the correct balance between the associated costs and benefits. The community relies on the acoustics engineer to ensure the cost-effective application of funds to meet the prescribed criterion.

2. DIMINISHING RETURNS

Increasing complexity for lessening results seemingly also applies to the methods required to correctly interpret the problem and identify the necessary treatment. This seems to be coming about through the combined influence of increasing installed power densities in our industrial facilities, coupled with sharpened awareness of and insistence in achievement of, more stringent environmental quality measures.

Between these often conflicting forces, the environmental engineer has a responsibility to identify and treat existing and potential future noise emissions in a manner using minimum community resources - and minimum industrial cash. This becomes especially important in the light of the incremental costs which could amount to $500,000 per decibel for a large petroleum refinery [2].

An additional complication arises from this need to adequately satisfy (sometimes) conflicting requirements. It concerns uncertainty. Consider, for example, a large and complex noise emission site in an area having a rigidly enforceable noise criterion. The enforcement agency is faced with devising or approving measurement designs that theselves will not introduce bias. Consider an elevated source and the variation of ground effect with receive height. Is a boundary measurement at 1.5 metres a valid predictor for community noise?

The agency must also accept reasonable measurement tolerance (scatter). For example, should a measurement's expected error be normal σ of $\pm$ 2dB then the requirement may be exactly met if 50% of the proving readings are over that requirement. If the designer chooses to keep 2 dB below the limit in an attempt to avoid this problem, we must still expect 26% of the readings to be over the limit. This 2 dB may involve an immense cost penalty [3].

As a result of such variabilities and vagaries, especially in the light of our desire for minimum expenditures, it is most important to use carefully chosen clean and unambiguous assessment and prediction methodologies. We believe that the sound power level techniques described below satisfy this need.

3. IDENTIFICATION

Sound power level modelling for large plant is a logical progression along the acoustic control path - requiring proper noise source identification. Where few sources are involved, basic calculations alone are required to sufficiently understand them. The more difficult problems involve multiple sources or complex noise propagation paths. As instrumentation has evolved, so too the complexity has increased of methods for examination.

With the FFT analyser came copious narrow-band spectral data. They led to co-spectral analysis techniques involving coherent output power measurements. For environmental studies, these breakdown because at typical community distances the signals are wafting sufficiently with time to render the calculation useless.

Following measurements and before positive identification can be approached, individual sources still require supporting calculations of assumed propagation to check relativity between spectral peaks and between different sources.

Identification of sources still falls short of providing sufficient knowledge for cost effectiveness analysis unless a hierarchy of sources is obtained. Dependable modelling algorithms are required.

4. MATHEMATICAL MODELLING

As the initial calculation procedures for noise control involved few variables and few sources, so the literature began to fill with analysis of the miscellaneous descriptions of the various reasons for apparent errors. They were labelled "anomolous" and "excess" attenuation - thoroughly misleading the layment clients. The various component parts of the propagation calculation have now been fairly well examined and described.

Source descriptions are fairly standard. Their spectral nature, directivity, sound power vs process variable (e.g. speed) are being entered into data banks and prediction equations. Path variables involving atmospheric (molecular) attenuation barriers, vegetation and ground surfaces are described. Weather influences seem to be the last frontier. Upwind or downwind? was the initial question. This was tempered by relative velocity differentials causing diffraction. Now atmospheric stability is also incorporated.

It's all very well to bring these into the predictive technique, but most of us can't properly assess the actual conditions prevailing during a simple series of long distance measurements, let alone described them (statistically) over an average year. Here we need assistance from the air pollution engineers and those working in the environmental (wind) boundary layer [4].

5. MODELLING SYNTHESIS

Large scale multi-source, multi-receiver calculations are now practical by computer. Using a PDP-11-23 having random access memory of 1/4 M Byte and using a full 10 M Byte disc, our company's Community Noise Program, COMNOS, has been on-line since 1982. Other teams have had basic models for all-inclusive propagation type calculations since the mid 1970's [5] [6]. No doubt they too have been through evolutionary developments to incorporate the flexibility required for various problem solving situations; optimization, ranking and plotting routines.

The basic algorithims are usually the simple addition of a set of selected attenuation descriptors. [7] [8] [9] [10]. These simulate the propagation from sources of known (directional) sound power by octave bands. The details of the individual descriptors do vary. A model of COMNOS is shown in Figure 1. Various validation measurements are offered in the literature. A typical noise prediction scatter vs distance is shown at Figure 2. The 95% confidence limits for the CONCAWE model, on which COMNOS is substantially based, are given below:

95% Confidence Limits for Final Model								
Meteorological Category	dB(A)	Octave Band Centre Frequency, Hz						
		63	125	250	500	1k	2k	4k
2	6.8	5.4	5.4	9.1	9.4	7.8	9.8	12.4
3	6.9	5.0	6.2	9.4	10.1	8.5	8.5	9.4
4	5.7	4.8	6.5	8.7	9.8	6.6	5.6	6.7
5	4.7	3.9	5.4	8.4	8.1	5.2	5.6	6.7
6	4.5	5.2	6.1	6.7	9.3	4.9	5.5	8.2

Mean differences between the predicted and observed values over all meteorological categories are less than 1 dB for the validation test conducted.

6. INPUT DATA

6.1 Mechanised Data Reduction

This COMNOS model requires Sound Power Level (SWL) by octave bands, directionality and intermittency for each nominated source. Each is located on a three dimensional grid with size and orientation of line and planar sources being used within the program to determine directionality. Sources may be grouped or replicated for multiple unit installations. They may be considered to be contained within enclosures or buildings having defined absorption and transmission characteristics. Building location, size and orientation is considered.

The base SWL data can be input using three methods. Firstly and most obviously, it can be input direct. This allows sources to model specificati or known values and for them to model selected noise reductions from previously defined levels. Secondly, recorded data can be processed througl an FFT analyser and brought direct-on-line into a suitably formatted input file. The processing of site data for this considers acoustic as well as vibration surface measurements over nominated bounding surfaces to the sourc Temporal statistics are computed but Leq is the parameter usually input.

The third method of assembling the source input data is from "potted" data bank information. On-line there are 23 major source types described empirically, using noise vs load/flow/speed characteristics. Additional sources are tabulated off-line in the library data bank.

6.2 Manmade Environment

Enclosing buildings or compartments around sources also act as barriers and reflectors for other sources. All such barriers are specified as planes or cylinders, with or without "porosity" and absorption.

The above data are usually sufficient for the calculations of noise for in-plant or close boundary situations. For these usually the ground is flat and the weather influence small. For distances of more than 500m, further variables are considered.

6.3 Natual Environment

Weather and geographical information complete the input data. Temperatures, humidities, vector wind speeds and the related Pasquil stability index are required for a typical one year period. This enables an overall Leq or a "worst case" scenario to be predicted. The natural ground elevations at nodes of a defined grid are used to allow line-of-sight or (multiple) "rounded hill" barrier calculations. Grazing incidence, ground effect (soft or hard) and vegetation effect are all in-built considerations.

Typical of the large array sizes used to date are for ;

550	(internal or external) sources
75	man made barriers
600	grid points on the receiver array (sources summed)
20	additional nominated receiver locations (sources ranked)

7. OUTPUTS

The COMNOS Program calculates sound level at each receiver location for each source for each octave band for each atmospheric condition. It sums the sound level in dB by octaves and ranks the sources at each nominated location. It provides contours from the grid array.

Determination of high noise level locations is straightforward. So too is the identification of what are the sources contributing to the levels. Examination of the octave band data for those sources, when compared with overall resultant sound spectrum, allows definition of a noise reduction target. This target identifies the source and the required noise reduction by frequency. Without thi data no real feasibility nor cost-effectiveness study can be undertaken.

8. USE

Typical client questions that have been and are being answered include :

- what are the real sources? (how much is me? how much is him?)
- what items do we need to fix to achieve x dBA?
- how much is my noise excess in dB, in $?
- what will be the effect of adding (these) sources?
- how much benefit accrues from (this) treatment to (this) machine?

Typical large calculation runs involve environmental effect statements for power stations, mine sites, waste fill sites, beneficiation and petrochemical plants. Verification runs for existing situations have been carried out in smelters, manufacturing, petrochemical, wood and process plant as well as quarry crushing/ screening plant. Correlation between calculation and observed data for these former examples is most encouraging.

Typical comparison of the predicted and measured data are shown in Figures 3 and 4 below.

9. CONTROL OF CONTROL COSTS

Experience involving eight major project/plant investigations is reported on below It is equally divided between new (proposed) and existing installations and leads us to the following generalisations.

These are based on the hypothetical situation of -
should we have employed simple computational techniques to the extent that would have been possible within the same investigational constraints and budgets - then we believe that :-

a) where there are a few relatively large sources dominating the environment noise, then their identity would have been correctly determined. However, the required changes to the emission spectrum would have been mis-estimated by more than 5 dB in around half the octave bands involved.

b) where there are multiple sources contributing individually 15 to 20 dB or more below the aggregate received sound level, then around one half of the contributing sources would be mis-identified (wrongly included or wrongly excluded) - consider a petrochemical plant with 400 suspected sources, a 10 dB noise excess and 50 sources around 10 dB below the target criterion.

Now while the spectral errors may not have much significance on the ultimate monetary noise control investment, the effect of mis-identification could be significant.

Consider the implications on total control costs. For these examples the estimated incremental capital expenditures attributable to identified noise control treatments varies between 0.2 and 0.6% for proposed plant and between 0.5 and 1.5% of the capital value of relevant plant for existing situations. The result, should all of the 1/3 or 1/2 mis-identification be lost, for say a $100M new plant, is $60,000 to $300,000 or $150,000 to $750,000 for an existing plant.

It is not the intention here to propose that the cautious and experienced noise control engineer could not learn by progressive achievements in a noise control program and hence minimise the errors. It is, however, evident to us that in order to obtain investigation results with high confidence, the model does need to be in itself detailed and definitive. As much as possible of the repetitive analysis and calculation work should be automated. This then allows the engineering time to be maximised for better decision making and better examination of the feasible alternatives.

Because of the diminishing returns available from progressive noise control treatments, we have an obligation to be repeatible, consistent and accurate in our analysis of existing and synthesis of proposed environmental noise controls. It is believed that sound power level modelling is a powerful means of controlling noise control costs in major projects. Comprehensive computer procedures are available for this modelling. They improve the cost-effectiveness both of the modelling and of the control expenditure.

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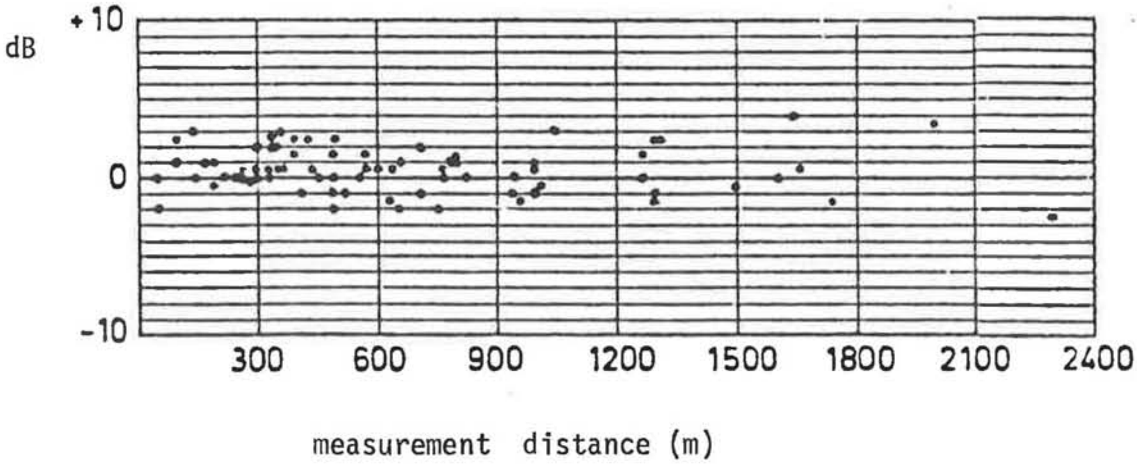

Figure 2: Difference between predicted and measured sound level with distance

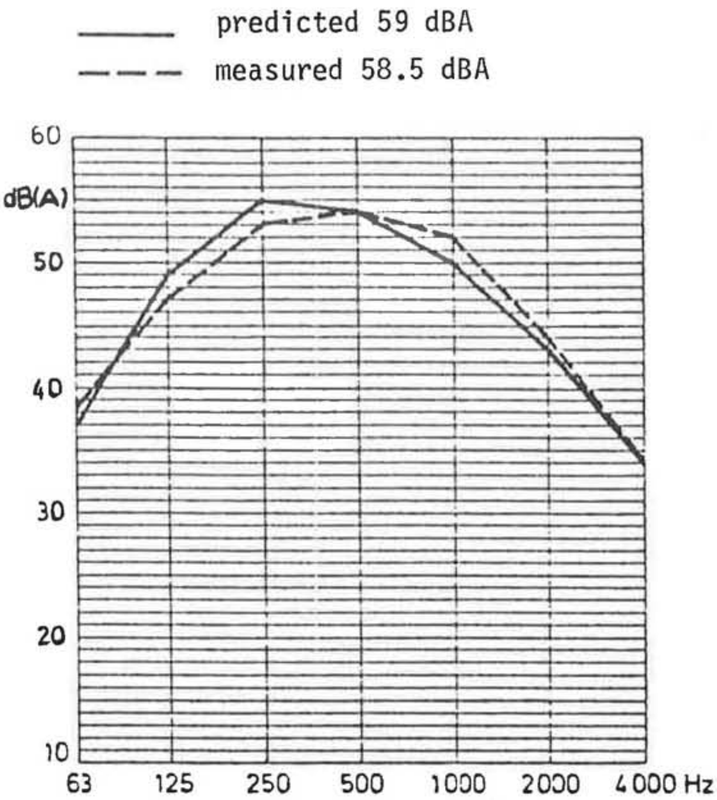

Figure 3 Distance 300m

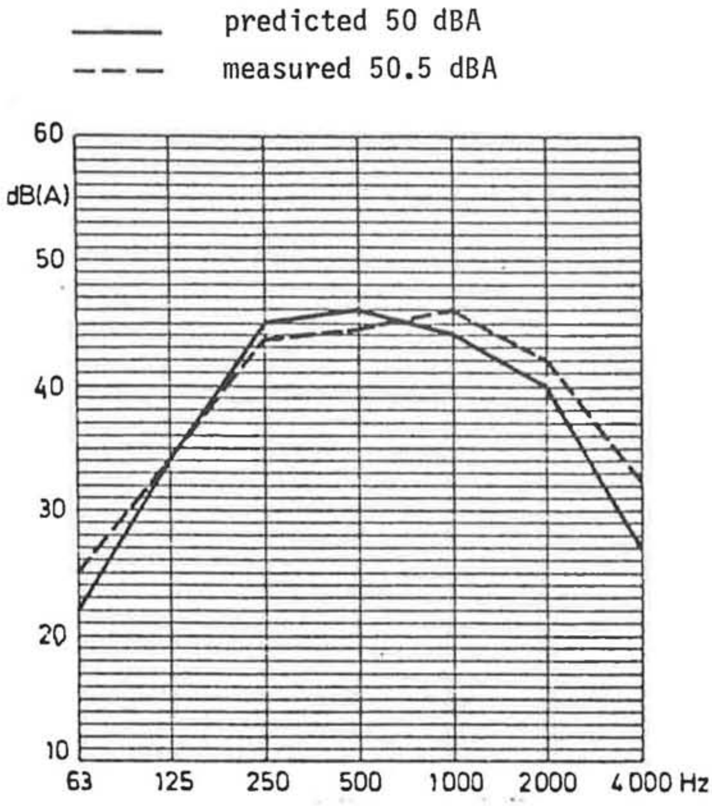

Figure 4 Distance 1010m.

Comparison of measured and predicted community noise levels spectra resulting from petrochemical refinery emission.

VEGETATION - ATTENUATION FOR THE BIRDS?

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University of Sydney

SUMMARY

Many measurements of sound attenuation rates in forests have been made but there is little in common in the measuring procedures used or the results obtained. Consequently there is a considerable divergence of opinion on the effectiveness of vegetation as a noise control measure. The present paper looks at the factors controlling the transmission of sound through vegetation, the attenuation rates achieved in pine plantations, and the reasons for the important perceived reduction in noise that hedges and plantations give.

1. INTRODUCTION

It appears that there is a generally held belief amongst people that vegetation is an effective controller of noise [1]. Since Eyring [2] made his objective measurements of sound attenuation in Panamanian jungles there have been several revivals of interest in vegetation as a noise barrier. Some of these studies [3] & [4] have indicated that trees are an important attenuator of sound, some have shown they aren't [5] & [6] and others have sat on the hedge [7] & [8].

Because the experimental design and the way in which most of the results are presented in the preferences cited it is impossible to make any useful comparisons. Theoretical and model work [9] suggest that the direct effect of vegetation will only be significant at high frequencies. Thus it is unlikely that results indicating the importance of trees for attenuating traffic noise are correct.

Trees are however associated with ground and although trees may not attenuate sound a forest or plantation may because at low frequencies the impedance of the ground is such as to cause a rapid attenuation of the ground wave. In a way it is being pedantic distinguishing the effects of trees from the effects of forests, especially as the ground and trees interact; certain types of vegetation will only grow in certain types of soil and the vegetation will in turn alter the condition of the soil. However, if trees are not necessary, or bushes or grass will do instead, it may be important to distinguish between the effect of the trees and the forest.

The other aspect of the effect of vegetation on sound concerns the perception of sound. In the past Psychologists have gone to great lengths to ensure that extraneous factors, such as thermal and visual conditions do not effect subjects undertaking aural tests. At the same time it has been blindly assumed that there is a cause and effect relationship in any environmental noise problem i.e., that for a given environmental stimulus a given reaction will be produced. This is clearly not the case as the correlations of any measure of noise and subjective response are very low. One of the reasons for the low correlation appears to be that other environmental factors, such as the visual field are important in determining subjective reactions to noise [10], [11] & [12].

This paper presents information on the factors effecting sound propagation through vegetation, the attenuation rates that can be achieved and the importance of the visual field on the perceived noise level.

2. PHENOMENA EFFECTING SOUND TRANSMISSION THROUGH VEGETATION

There appear to be three main phenomena involved in the attenuation of sound in plantations or forests:

(i) Interference,

(ii) Scattering, and

(iii) Absorption.

The impedance of the ground over which the sound propagates effects the attenuation rate mainly in the 250 to 500 Hz frequency range. The effect of the ground can be visualized as in Figure 1. The direct and reflected sound components reaching R interfere. The extent of the interference and whether it is constructive or destructive interference is determined by the path length difference between the direct and reflected sound, the impedance of the ground and the coherence of the direct and reflected signals.

Scattering by the boles and branches and absorption by bark and foliage are higher frequency phenomena. The effect of scattering and absorption by vegetation can be seen in Figure 2 where the attenuation rates through a forest and over open ground are compared. The size and density of trees will be important in determining the attenuation rate. The plantations used to obtain the 'forest' results in Figure 2 had approximately 1500 trees per hectare and the breast height diameter of the trees was about 160mm.

It appears that scattering, rather than absorption, is the more important phenomena at the mid-frequencies. At high frequencies absorption takes over as the dominant phenomenon. This can be surmised from the relationship between the time rate of decay of sound in a forest and the attenuation with distance. If the attenuation was due to absorption then a high attenuation per doubling of distance would be expected to correspond to a high decay rate. If scattering is the cause of attenuation through vegetation then more energy is back-scattered and so the decay with time becomes less as the decay with distance increases. Figures 3 and 4 show the relationship between the attenuation with time and distance. Figures 2 and 3 suggest that scattering by the ground is probably more important than scattering by the vegetation because, at the mid-frequencies where scattering is important, the attenuation in the forest is not significantly different to the attenuation over the open ground.

3. PARASITIC VARIABLES

As indicated in the introduction the attenuation properties of vegetation is questionable. One of the reasons for the variability of the results obtained is the number of variables involved. It may well be that certain types of vegetation are better at attenuating sound than others but unless factors such as the source height, microphone height, placement of source (when inside the forest or outside and if outside, how far outside) the spectrum if the source (if dB(A) attenuation rates are quoted), whether the signal is steady or transient, the size and density of the trees and the atmospheric conditions are the same, then a valid comparison cannot be made.

Chessell's [13] theoretical model gives reasonable agreement with the experimental results obtained by Parkin and Scholes [14] but the effect of the various parameters is perhaps better illustrated in Figure 5. In Figure 5 results are presented of the attenuation rate at different heights above the ground for different surfaces. The important point here is that it is not possible to quote a single figure for the attenuation rate of grass or a forest. The attenuation rate will be highly dependent on the frequency of the sound, the height of the source and the receiver and the impedance of the ground. Over longer distances atmospheric conditions will have an important influence on the attenuation rates achieved.

3.1 Relative Humidity

The effect of wind and temperature gradients have been documented elsewhere (e.g. [15]) and the relative humidity has been assumed to be important at high frequencies only. From some measurements made in a pine plantation over a period of two months (during which time no rain was recorded) it appears that the relative humidity of the atmosphere had a very important effect on the measured attenuation rates. Changes in relative humidity may well account for the previous conclusion [16] that there was no significant difference in the attenuation rates in woodland, sclerophyll and rainforests in N.S.W.

Figure 6 shows the relationship between attenuation rates and R.H. for a pine plantation. The relative humidity appears to effect the attenuation rate at all frequencies and the maximum attenuation rates occur at about 75% relative humidity. It is obvious therefore that the relative humidity of the air is not the important factor as this would not effect the lower frequencies and the maximum effect would occur at around 20% relative humidity.

Rather it seems that the relative humidity effects the impedance of the ground. In some follow-up experiments in a reverberant room it was found that the maximum absorption coefficient of a sample of fibreglass was obtained when the room's relative humidity was about 75%. Ando and Kosaka [17], using an impedance tube, also found that relative humidity influenced the absorption coefficients of porous materials and that the absorption coefficient occurred for a relative humidity of approximately 75%.

3.2 Sound Level Meter Response

In order that sound attenuation measurements can be made over large distances a high intensity noise source must be used. In the present work a gas scare gun was used. The gas scare gun is a device in which a metered amount of gas is exploded at regular intervals giving a short duration sound pulse of high intensity.

It was found that the attenuation rates using this source were the same as that obtained using bands of white noise if the 'fast' response setting was used on the sound level meter. For other meter responses ('impulse' and 'peak') the attenuation rates were different.

It appears likely that scattering by the ground and vegetation reduces the peakness of the impulse whilst the energy content remains the same. This results in higher attenuation rates for shorter meter response times (see Figure 7).

Thus it appears that vegetation can have an important role in attenuating impulse sounds and that attenuation rates should be quoted for different meter responses if transient sounds are used to determine attenuation rates.

4. ATTENUATION OF SOUND IN FORESTS

Having eliminated differences due to the relative humidity, the response of the sound level meter and the height of the source and microphone and ground conditions it can be shown that there are differences in attenuation rates in forests of different tree densities and maturities.

Three pine plantations were used to observe these differences. Two of the plantations were of the same age, one having a tree density of 1500 trees/ha and the other a density of 400 trees/ha. The breast height diameters of trees in both these plantations was about 160mm and the height, 13.5m. The third plantation was of younger trees. The density of the plantation was 1350 trees/ha and the b.h.d. was 110 mm and height, 8m.

At high frequencies the highest attenuation rate was obtained in the older, high density, plantation though there was no significant difference between plantations with the similar density of trees.

At mid-frequencies there was no significant difference between plantations of different densities but the same sized trees. There was a significant difference in the attenuation rates obtained in plantations of different densities and b.h.d.'s. At the 90% level there was also a difference between the attenuation rates in plantations of different b.h.d.'s but the same density: the smaller trees giving the higher attenuation rates.

At low frequencies there was a significant difference between the attenuation rates in all three plantations. The younger plantation had the highest attenuation rate and the older higher density plantation had the lowest attenuation rate.

The high frequency results can be explained in terms of scattering and absorption of the trees but the low frequency result appears to be a result of the ground. Although the ground was nominally the same in each plantation presumably the trees interact with the ground to produce different conditions e.g. moisture content. Thus it can be said that, both directly and indirectly, vegetation effects attenuation rates.

5. METHOD OF PRESENTING ATTENUATION RATES

So far in this paper attenuation rates have been quoted in dB/dd. Often workers have presented results in other ways e.g. excess attenuation (attenuation over and above the attenuation expected by hemispherical spreading of the acoustic energy) and in terms of dB/m.

At the frequencies which the ground effect is the dominant attenuation mechanism it would seem sensible to quote attenuations per doubling of distance as the expected maximum attenuation rate due to this mechanism is 12dB/dd. Where air absorption dominates the attenuation rates are better presented in terms of dB/m. Thus another indication of the mechanisms controlling attenuation rates is the rate at which the sound is attenuated.

At low frequences (31.5 & 63Hz) the highest correlation coefficients were obtained using a dB/dd fit. In the mid-frequencies the attenuation rates were no better correlated using dB/dd or dB/m whilst at the high frequencies dB/m gave better correlations (see Tables 1 & 2). At higher distances of the source and receiver above the ground the excess attenuation tends to be better presented in terms of dB/m.

6. DISCUSSION & CONCLUSIONS

Vegetation has both a direct and an indirect effect on the sound attenuation rates. Vegetation also has important psychological effects [11] [12] in that the visual field appears to significantly effect aural responses. In these respects it appears that vegetation provides an important method of reducing noise annoyance. The quantification of this statement and the determination of the economics of this type of noise control however becomes extremely difficult.

The visual/aural interaction effect appears to be worth up to the equivalent of a 10dB reduction in noise level. The direct attenuation of sound by trees is important only at high frequencies. The excess attenuation rate, which can best be expressed in dB/m (at these high frequencies) is dependent on the size and spacing of the trees. The attenuation rate may also be dependent on the type of vegetation (this has not been determined) though the effect is likely to be small [16]. Even in dense pine plantations the excess attenuation at the higher frequencies is only of the order of 0.1dB/m. A conservative estimate of the attenuation rate would be 0.05dB/m. (See Figure 6.) The attenuation at these high frequencies is primarily due to absorption.

In the mid-frequency range the attenuation is due to scattering of the sound; the scattering of the sound by the ground apparently being more important than that by the trees. The excess attenuation rate data can equally well be presented as dB/m or dB/dd.

At low frequencies the attenuation is due to the ground. The vegetation covering the ground has an indirect effect on the ground condition and hence the attenuation rates at low frequencies. Excess attenuation rates of up to 6dB/dd can be caused by the ground.

The attenuation rates in forests are dependent on climatic conditions. Wind and temperature effects have not been assessed but relative humidity has an important influence on attenuation rates. The attenuation rates also depend on source and receiver heights, though at high frequencies these factors are unlikely to be important in practice. Transient sounds are attenuated faster than steady sounds, the attenuation depending on the meter response. In the present work a 35ms meter response time was used with an impulse source. The attenuation rates achieved are slightly higher than those obtained with a steady source.

Thus in the widest sense trees do control noise. They maintain ground conditions, create a micro climate give a psychophysical benefit and contribute to high frequency attenuation rates. The attenuation of sound by trees is therefore not just for the birds. By attracting birds trees have the added advantage of creating an acceptable masking sound to reduce annoyance.

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TABLE 1

Log/Lin fit to excess attenuation as a function of frequency

	Number of occurrences where fit had higher correlation coefficient								
Octave Band Centre Frequency Hz	31.5	63	125	250	500	1k	2k	4k	8k
Type of curve fit									
LOG	11	9	7	5	9	6	4	4	5
LIN	0	1	6	8	4	6	8	9	8
Significance at 5% Level using Binomial test.	YES	YES	NO	NO	NO	NO	NO	NO	NO

TABLE 2

Log/Lin fit to excess attenuation as a function of frequency range

	Number of occurrences where fit had higher correlation coefficient		
Frequency Range	Low (31.4-125Hz)	Medium (250-1kHz)	High (2k-8kHz)
Type of Curve fit			
LOG	27	20	11
LIN	7	18	25
Significance at 5% Level using Binomial test.	YES	NO	YES

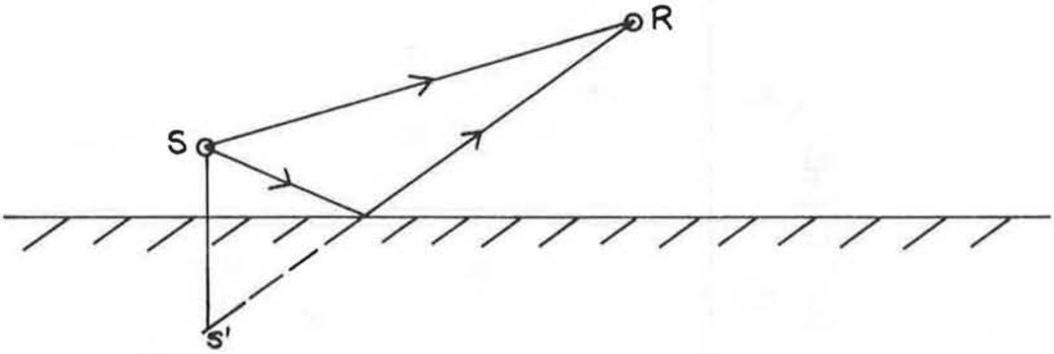

FIG.1 Diagramatic representation of sound propagation over ground

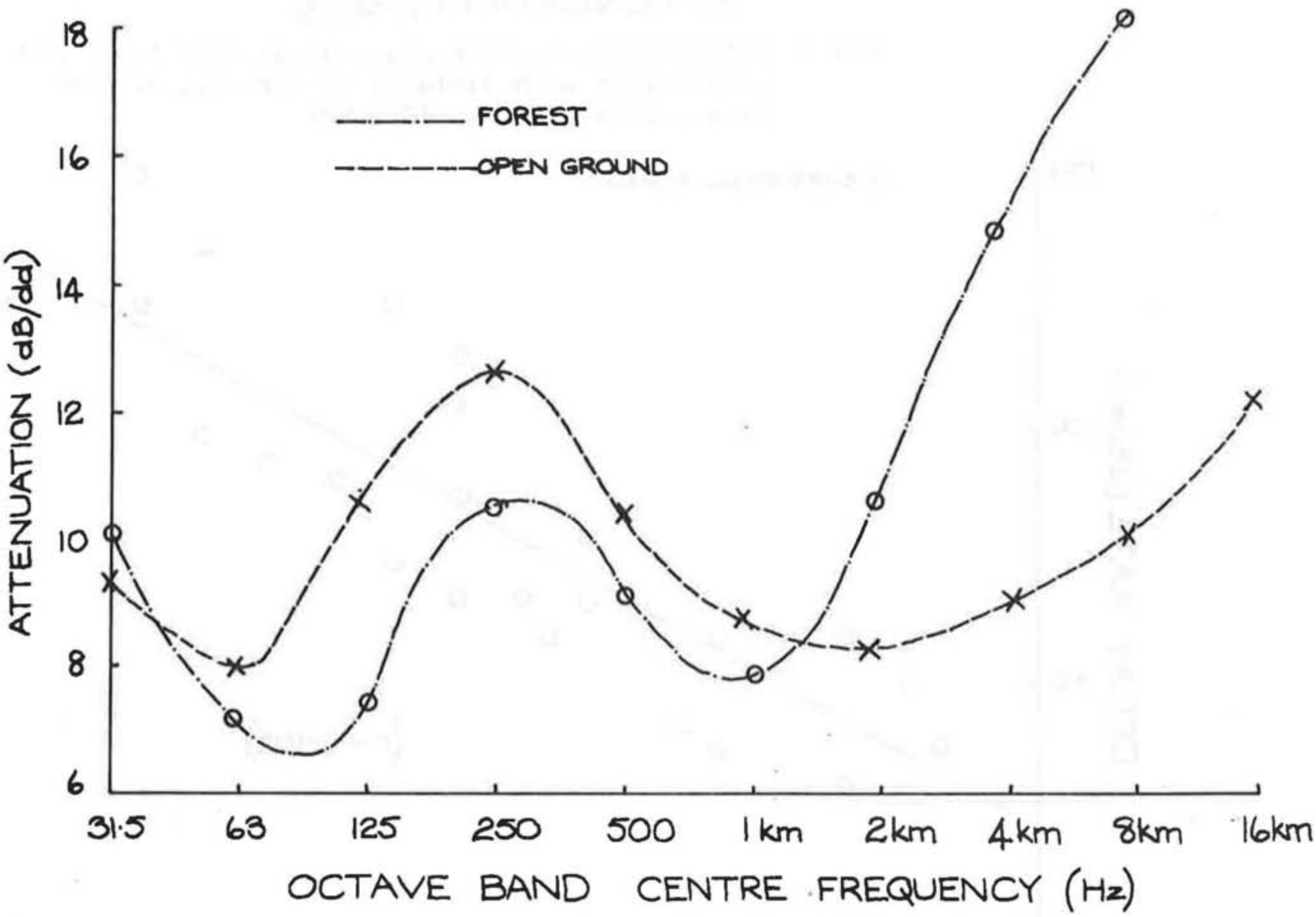

FIG.2 Comparison of attenuation rates in a forest and over open ground

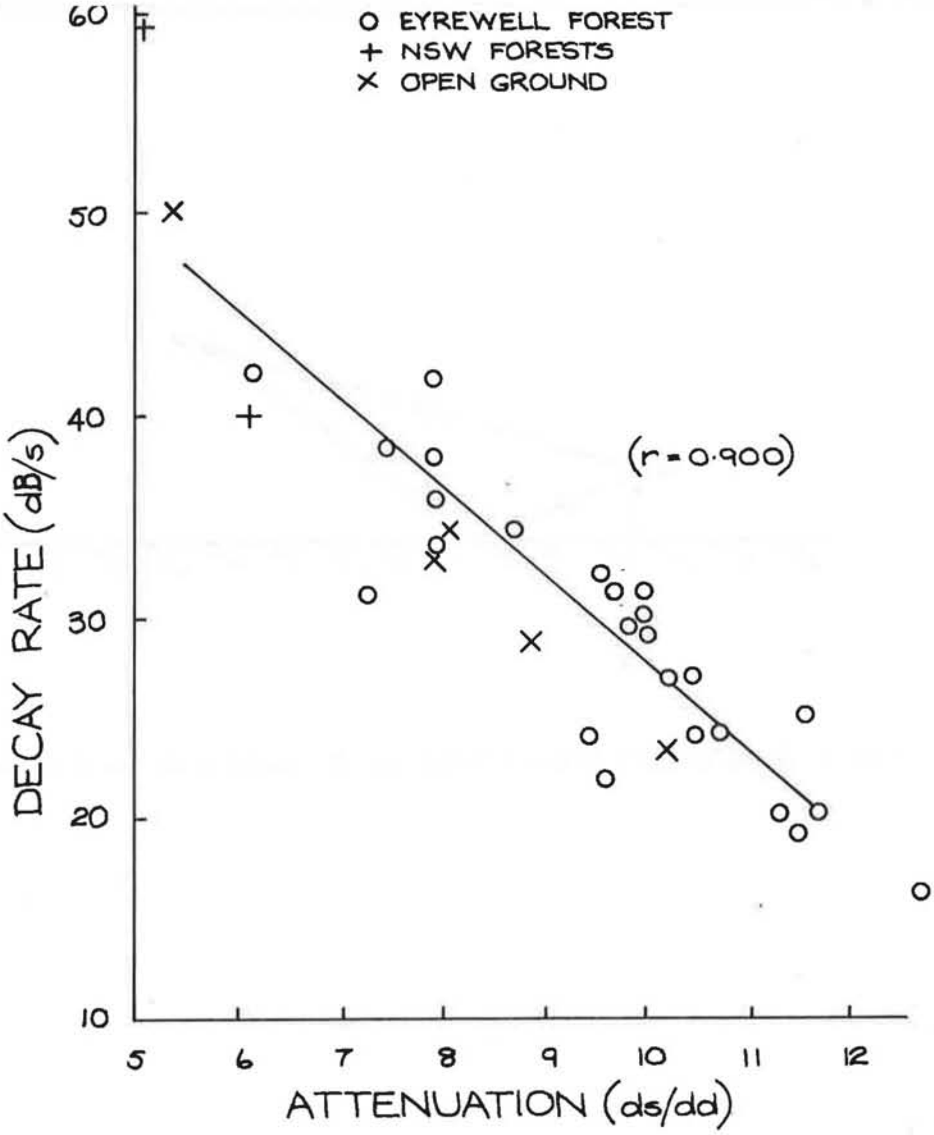

FIG.3 Relationship between sound decay with time and attenuation with distance in forests, at mid-frequencies (250 to 1000 Hz)

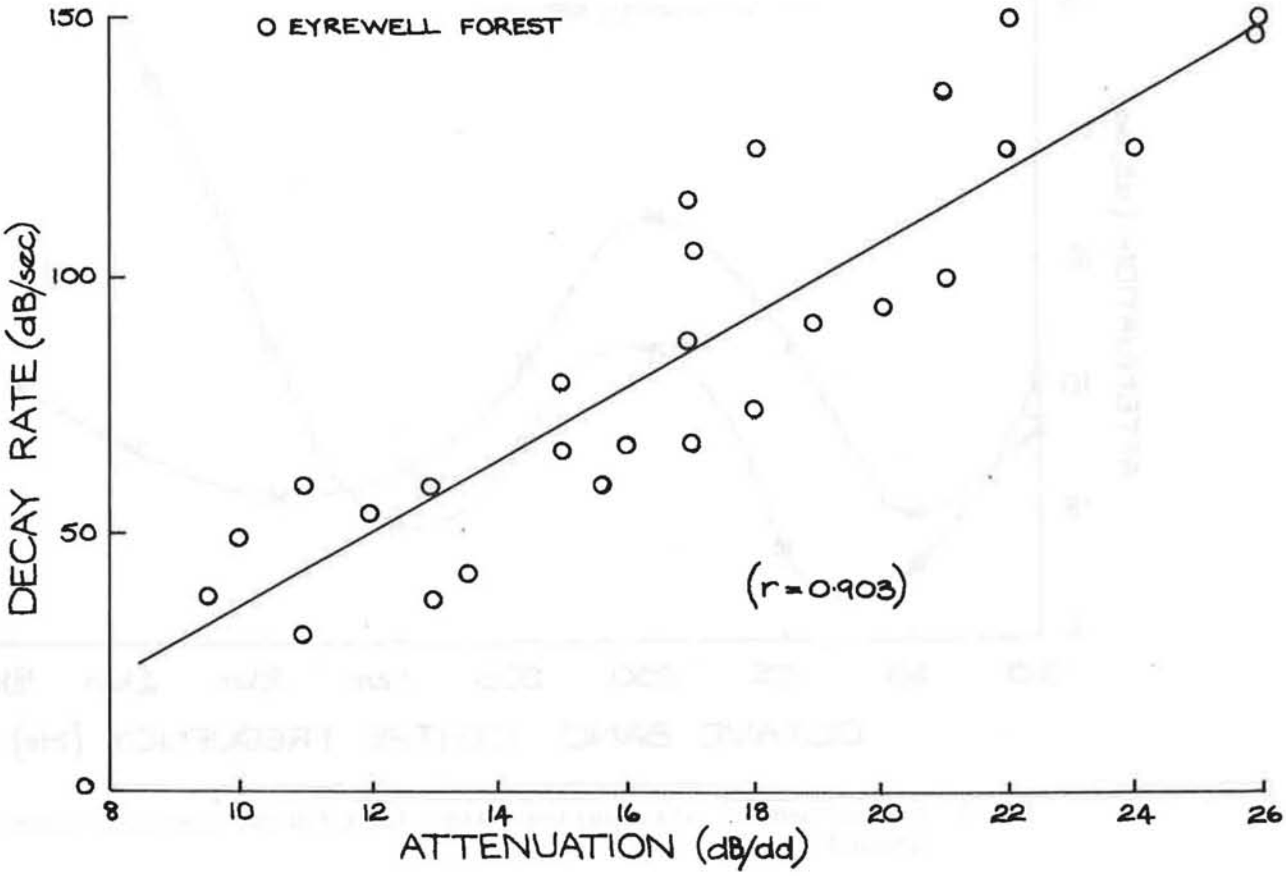

FIG.4 Attenuation in forests, at high frequencies (2kHz - 8kHz)

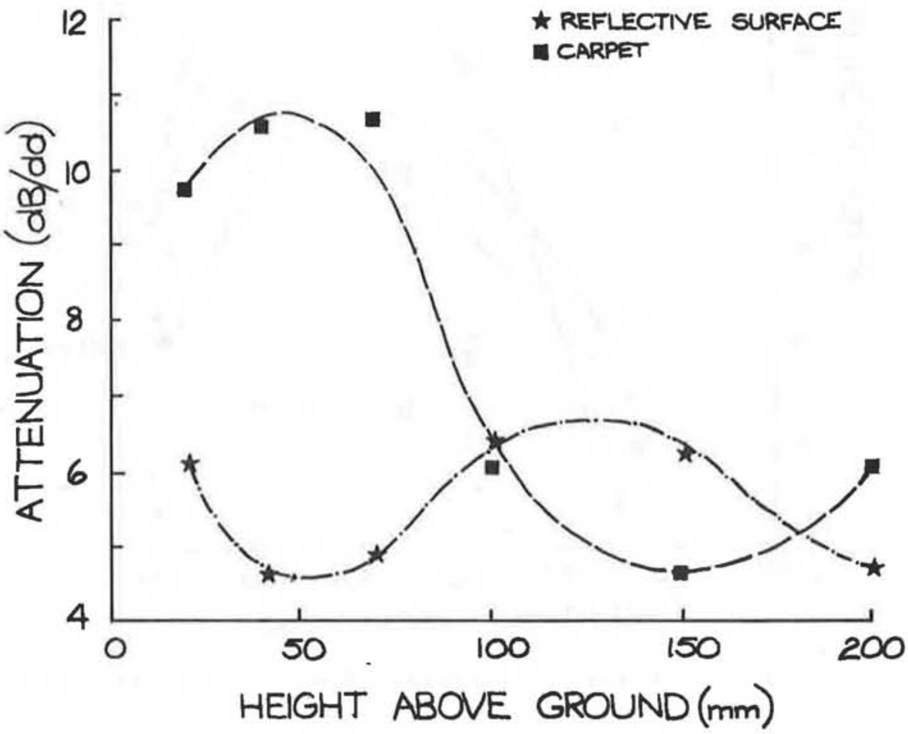

FIG.5 Model attenuation rates at different heights above the ground (4kHz, $\frac{1}{3}$ octave band white noise signal)

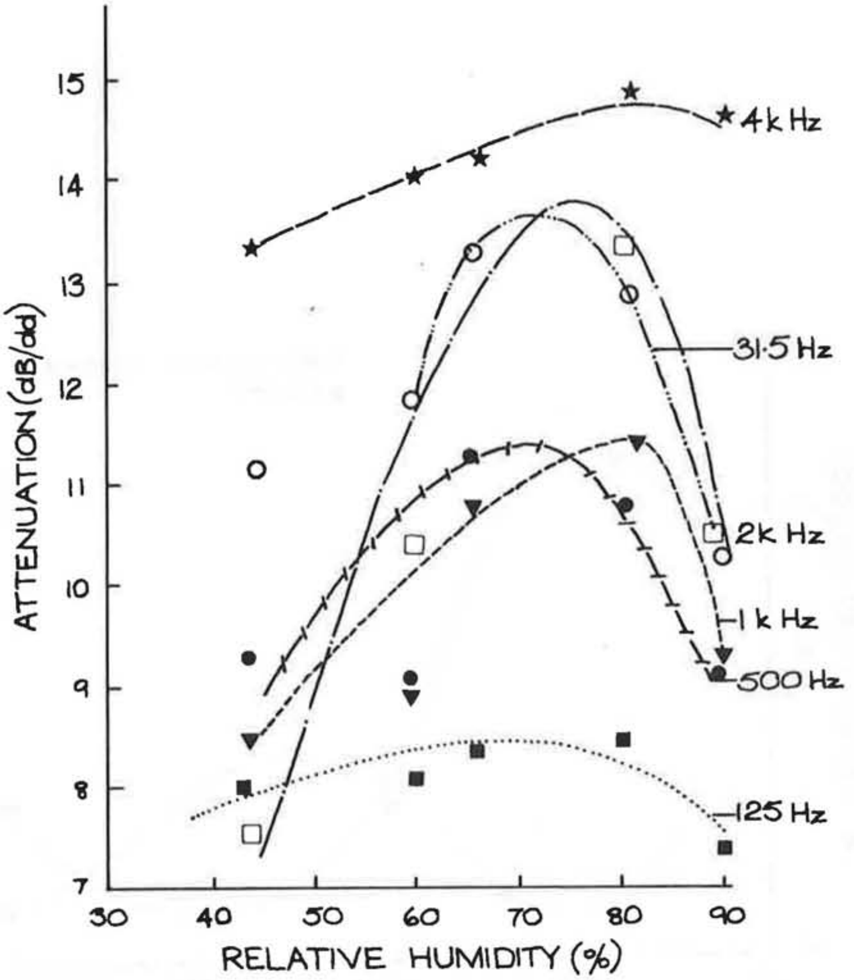

FIG.6 Effect of Relative Humidity on attenuation rates through a forest

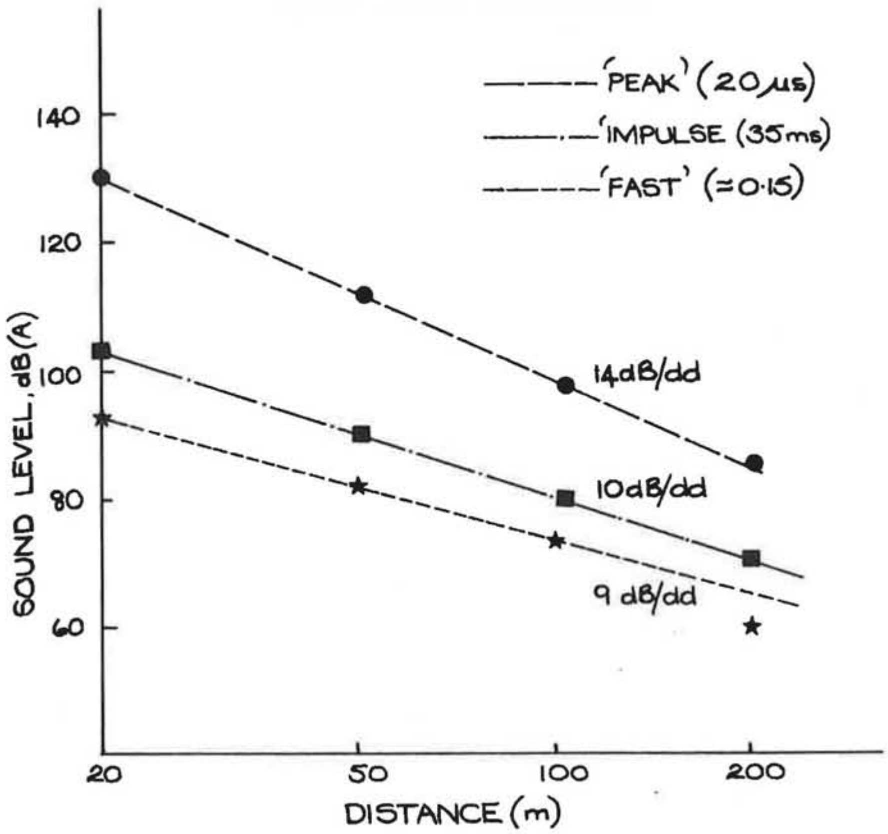

FIG.7 Attenuation rates in a forest using three different meter responses and an impulse source

THE COST OF NOISE IN RESIDENTIAL AREAS

Barry J Murray
Wilkinson-Murray Consulting Pty Ltd

INTRODUCTION

In making decisions regarding the control of noise within the residential community, it is desirable to know the cost or disbenefit of the noise to the community. It is not just a matter of knowing the cheapest method of noise control, but also of knowing if the control costs are justified. For similar reasons, it is also desirable to know the disbenefits of noise that may result from a major development.

Noise is normally regarded by the economist as an external effect; that is a factor not normally taken into account during commercial decision making. Throughout Australia, noise is normally controlled by Government legislation rather than by commercial decision making.

If the cost or disbenefit of noise to the community could be expressed in dollars, then decisions regarding major development with serious community noise implications or decisions regarding control of community noise would be easier to make. However, there is a broadly held view that environmental quality, including noise, cannot, in principle, be expressed in dollars and furthermore, assuming it can, the practical difficulties of obtaining the costs normally result in an inaccurate value.

The principals of estimating noise costs are here discussed along with the practical difficulty of obtaining the required information for costing purposes.

NOISE ANNOYANCE COST

There is a cost, or disbenefit, to an individual associated with being disturbed by noise on a continuing basis. The noise may wake the individual at night, may interrupt television viewing or may generally cause annoyance at a time of relaxation.

If the individual spends a lifetime living in a location seriously affected by noise, the overall cost of noise to him may be expressed as one number called the Noise Annoyance Cost, N. Since there is a large range of reaction to noise within the community, N will be different for different individuals and throughout the community it may be considered as a distribution.

However, most people do not spend all of their lives at one location, affected by one noise level. For practical costing purposes, therefore, it may be necessary to know the cost to an individual over a limited period of time. To do this, it is best to express the Noise Annoyance Cost in terms of an annual cost, n, which is N expressed as an annuity.

Whilst it may appear on the surface that knowledge of N or n per year may be sufficient to estimate the cost of a particular noise to the community, there are a number of other factors which affect the overall cost. Introduction of a noise to an area may reduce house prices in that area and therefore result in further costs to the community. In addition to this, the introduction of a noise may make some residents move out of the area or, at least may be the catalyst in such a move, thereby incurring further costs to the community.

COST OF MOVING HOUSE

Movement Costs

Many of the costs associated with moving house are well known; for example, Solicitors' fees, Estate Agents' fees, removal costs and the welfare cost of time spent in searching for a replacement house. These costs may be called Movement Costs, M.

Home Price Depreciation

If, when the house is sold, it is sold at a price which has been depreciated by environmental noise, the amount of depreciation, D, also adds to the cost of moving.

Householder's Surplus

It is commonly regarded that the market price of a house is based on the value of that house to a large proportion of the community. The householder, in general, does not sell the house for the market price because the house is worth more than market price to him. This situation arises because of such things as the children belonging to the householder may be familiar with the local school, the garden has been, over a period of years, modified to suit the family's particular tastes and the decor of the house has also been so modified. When the householder chooses to sell, it is because the value of that particular house to him falls below market price.

For the majority of people, the value of their house to them exceeds the market price and this excess is often referred to as Householder's Surplus, S. This Surplus is different for different householders and throughout the community may be considered as a distribution. When forced to move because of an inflicted environmental noise, a householder can only sell at the market price and is forced to lose his Householder's Surplus.

COSTS OF NOISE TO EACH COMMUNITY GROUP

If noise is introduced to an area, the community will react to it in normal commercial ways. The cost to each householder depends upon whether the householder stays, moves out because of the noise or moves out for other reasons. In total, the following groups within the community may be identified for costing purposes:

- Natural out-movers - Those householders who would have moved irrespective of the introduction of noise.
- Forced out-movers - Those householders who decide to move because of the noise.
- Stayers - Those householders who decide to stay and bear the noise.
- Informed in-movers - Those people who buy into the area after the noise has commenced with full knowledge of the noise.
- Uninformed in-movers - Those people who move into the area without being fully aware of the effect of the noise.

Natural Out-Movers

These householders experience a disbenefit during the time they remain in the area to the value of n per year. Upon moving they lose the depreciation of their house due to noise, but the actual movement costs would otherwise have been incurred anyway and their Householder's Surplus is considered to be zero (otherwise they would not move). In summary, their cost is:

- n/year until move
- D during move

Forced Out-Movers

These householders incur the cost of n/year until they move and then the full cost of moving house upon moving. In summary, their costs are:

- n/year until move
- D + M + S during move

Stayers

These householders incur the full Noise Annoyance cost, N.

Informed In-Movers

Because of the reduced price of houses in the noise affected area, there is an opportunity for people not sensitive to noise to make a benefit by moving into the area. The benefit would be:

. D - N

Uninformed In-Movers

It is quite common for people to move into an area, for example adjacent to a busy road, without being fully aware of the degree of noise or of the impact upon them. These people may well incur a cost as from the time of moving in, as follows:

. N - D

Identifying Community Groups

It is possible to determine which of those householders will decide to move out of the area as a result of the noise and which will stay. To decide to move would mean that the total noise annoyance costs, N, is greater than the total cost of moving. To stay, the total Noise Annoyance Cost would be less than the total cost of the move; that is,

. For forced out-movers - $N > D + M + S$
. For stayers - $N < D + M + S$

The number of householders moving into the area will equal the number moving out. However, the percentage of informed in-movers versus uninformed in-movers would have to be determined by study of an actual situation involving a similar type of noise.

OBTAINING MODEL INPUTS

In practice, a lot of difficulty may be experienced in obtaining values for inputs to the model.

Noise Annoyance Cost (N)

N could be determined through a social survey in areas where high noise levels currently exist. Respondents could be asked how much money they would need to be paid to compensate them for the loss of amenity caused by the noise.

My experience is that respondents find this question difficult to answer and that the results obtained may not accurately represent N.

House Price Depreciation

Whilst Real Estate Agents will almost always suggest that noise does depreciate house prices, figures of 5% and 10% being commonly mentioned, most investigations into house price depreciations have not identified depreciation with any degree of confidence. Nevertheless, a study of house prices appears to be the most appropriate way to establish such depreciation.

Movement Costs

These costs are readily obtainable for particular or average house prices.

Householder's Surplus

Information regarding Householder's Surplus may be obtained by investigating prices paid by development companies in situations where they are forced for development purposes to take over houses not on the market.

LOCAL GOVERNMENT NOISE CONTROL SCHEME: A COST-EFFECTIVE APPROACH TO NOISE CONTROL

(Stuart McLachlan - New South Wales State Pollution Control Commission)

1. INTRODUCTION

In New South Wales, local government plays an important role in the control of neighbourhood noise sources either by using noise control powers in legislation or through conditions applied in development consent applications. Added to their longstanding responsibilities to control neighbourhood noise, councils also look after noise issues concerning smaller commercial and industrial premises.

The growing number and complexity of noise problems and control issues that councils are called upon to resolve has produced a need for a new and more substantial approach to reducing community noise at the local level.

The approach outlined here integrates a number of noise control philosophies and strategies into a package of regulations, guidelines and policies to suit the resources and needs of different councils. Although the scheme contains some regulations with penalties, it aims at reinforcing an awareness of the responsibilities of the individual living with others in a modern, noise producing society by providing a framework of information for local government and the community.

Each part of the scheme has been designed to ensure that costs of implementation are kept to a minimum.

2. OBJECTIVES OF THE SCHEME

The purpose of the package of noise control regulations, guidelines and support for local government is to provide powers and guidance in the resolution of noise problems in a consistent, predictable and effective manner. Of equal importance is the need to encourage awareness that proper planning can be the most cost-effective approach in controlling noise annoyance for many types of sources.

Already some councils in New South Wales are developing or have developed regulations or guidelines for locally specific noise problems. Two undesirable consequences can arise from unco-ordinated effort: it leads to non-standardised approaches and there are additional development costs to the taxpayer. The early introduction of this co-ordinating scheme should minimise or eliminate those problems.

3. CONTENT OF SCHEME AND PROPOSED STRATEGIES

The local government noise control scheme comprises a package of mutually reinforcing regulations, guidelines and other support arrangements. It is designed to satisfy the widely varying needs of councils and shires in New South Wales. There is considerable contrast in the pattern of noise control needs throughout the State but in general terms these needs are related to the prevalence of residential land-uses and also socio-economic factors.

Councils will have some flexibility in selecting those regulations and policies that are best suited to their own resources and needs. Time spent by council officers in determining noise abatement policy, receiving noise complaints and evaluating the noise impact of development proposals should be reduced and the problem of catering to different needs should be resolved. Every type of noise problem handled by councils would be covered by at least one of the regulation or policy strategies.

3.1 Regulations

The scheme utilises two forms of regulatory control: time-place controls which could be applied universally and which do not require instrumentation or training, and product controls which can be applied in a selective manner.

3.1.1 Time-place regulations

Time-place regulations are direct and simple to administer. By identifying the conditions or circumstances under which noise-generating activities are allowed, they provide a standard for community self-regulation. From our experience, people acquire an awareness of the time limitations and most conform to the requirements, thus avoiding the need for council intervention.

A regulation to limit the time of operation of various items is already in force. This new proposal will incorporate the old list and include some new items. The following table indicates the means for control of noise by restricting the time of operation within residential or commercial premises of devices that cause offensive noise:

- Use of motor vehicle or motor cycle (except when entering or leaving premises)
- Power tools, including saw, grinder, sander, drill, router
- Lawnmower, edgecutter, mulcher, having either an internal combustion engine or an electric motor
- Chain saws
- Any tools, or stationary or mobile equipment used in drilling, construction or demolition work

- Loading, unloading, delivering, packing, unpacking, or otherwise handling any container, product, material or refuse other than household refuse

- Repairing, rebuilding, modifying or testing of the body or engine of any motor vehicle, motor cycle, or motor boat

- Truck mounted refrigeration plant for a period longer than 30 minutes in one location

- Tennis Courts

- Swimming or spa pool equipment
Domestic air conditioner or exhaust fan

- Electrically amplified sound equipment, bell, chime, whistle, horn, siren, musical instrument, in a fixed location. Includes radio, television, tape recorder, record player, tape player, public address system, loud-hailer.

3.1.2 Product regulations

Product regulations require manufacturers, importers or distributors of intrinsically noisy equipment to fix noise labels. The noise level information on the labels will assist owners, users and council officers select the quietest equipment for any application.

Use of product noise regulations can be illustrated with reference to regulations currently under development for construction equipment and air conditioners.

Although there are many different types of noise-generating construction equipment, jackhammers and compressors are in widespread use and are identifiable sources of noise annoyance and complaint. Other construction equipment items could be incorporated into the regulation at later stages as the need arises or as test data is assembled and analysed.

Labelling with noise output encourages the design of quiet products and the use of the quietest available equipment in noise sensitive areas, while at the same time ensures that the costs of noise control are carried by those that most likely will cause annoyance and disturbance. For example, users of construction equipment in urban areas could be required to use items of equipment with low noise ratings whereas users in remote mining areas could use equipment with a higher label rating. To require all equipment to be silenced to a residential standard of noise control would impose unnecessary costs on owners and ultimately the community.

Labelling of construction equipment would facilitate the categorisation of plant into four groups of noise levels that would correspond to noise sensitivity of different land uses. For example councils could insist that only construction equipment that complied with the quietest category "A" could be used in Quiet Zones near hospitals or schools. Category "B" equipment would be required for residential areas; Category "C" for commercial areas and Category "D" for industrial or rural areas. Council officers could assess the suitability of equipment by simply reading the label attached to the plant or otherwise by carrying out a test in accordance with a test procedure.

The labelling of domestic air conditioners with a sound power rating has been endorsed by many State government environmental authorities. A separate regulation is proposed for New South Wales that would limit levels from new air conditioners when installed (including heat-pumps) to specific levels at the receiver. An assessment method has been formulated to determine the noise level from an air conditioner, based on the sound power level of the machine and the nature of the surroundings of the installation. Installers then can plan to locate units in positions that will not affect neighbours.

Provision would be made to ensure that noise certified equipment remained effective when in use, that noise control features were properly maintained and not removed.

3.2 Planning Strategies for Noise Control

Local government has at its disposal through the planning and development processes, the most cost-effective means of ensuring the long-term protection of residential areas from industrial and transportation noise sources. In new developing regions, there is an urgent need to provide strategies and guidelines which would assist local government and developers in the planning and design of new developments that isolate noise generating activities from noise-sensitive land-uses.

Noise zoning aims at the setting of maximum levels for particular types of land-use categories. Planning schemes or local environmental plans defined in the Environmental Planning and Assessment Act 1979 could provide a basis for the definition of noise zones. Noise limitations would be specified in terms of the receiving land-use as designated on the local environmental plan either as residential, commercial or industrial zones. In areas that require special attention to noise control such as locations around hospitals or schools, councils could designate "quiet zones" and ultimately the categorisation may be incorporated into the local plan.

Levels selected for each land-use category may be either the levels derived and suggested by the Commission or levels selected by councils. In either approach, measurement procedures would follow the Australian Standard AS 1055.

Zoning is a cost-effective strategy which can be a successful means of locating noisy industry in areas away from residential zones. In doing so, industry can be saved the high costs of reducing noise to meet residential ambient levels.

3.3 Noise Guidelines and Technical Support

Both the technical and administrative aspects of implementing noise control regulations and planning strategies can be developed in guidelines. These guidelines will provide assistance to councils, particularly in reducing the need for independent development in each council and problems of non-standard approaches.

Guidelines incorporating level criteria are envisaged for the following:

(i) Assessment of noise and vibration from unscheduled commercial/industrial premises. This approach would be used in association with councils responsibilities for reviewing development applications.

(ii) Noise insulation standard for noise generated and received within the same structure.

(iii) Noise insulation standard for noise received from outside such as traffic noise.

(iv) Guidelines for noise control in land-use planning.

(v) Guidelines for noise control in rural areas.

(vi) Blasting.

(vii) Road traffic noise assessment, criteria for residential areas, measurement and prediction for planning purposes.

Publications defining policies and procedures will provide guidance on assessment, enforcement, technical support and the education of noise control officers. Regulation documents only provide a minimum of information and more comprehensive and informal details are needed to confidently use the regulations.

Two other forms of supplementary administrative support will be developed further:

- Authorisation for enforcement and implementation of strategies. Council officers will continue to be authorised to take action against offences specified in the regulations. Two grades of authorisation are possible. The first to give authority to officers to use those regulations which require only a minimum of knowledge about noise and can be administered without the use of any instrumentation. The second grade authorisation would allow better qualified officers, powers under more complex and technical guidelines and regulations.

- Direct technical support. Apart from the publication of guidelines, publications would be produced to specify the type of equipment needed to use regulations and guidelines. These would also aid councils in the purchase of equipment. Additional assistance would involve direct discussions with individual councils on the use and care of equipment and where necessary calibration checks could be carried out by the Commission.

3.4 Training of Authorised Officers

It is proposed to upgrade the existing arrangements for education of authorised officers to a level that would better complement the new regulations and guidelines.

Three levels of training in noise control are proposed, each level relating to the types of noise problems faced by different councils.

A certificate in Environmental Noise Control would be issued to a person who satisfactorily completes any stage in the course.

Subjects covered in each strand could be as follows:

Noise Control I

Introduction to acoustic theory; law; handling of complaints; use of general purpose sound level meter; octave/one third octave band analyser and calibration techniques; measurement of noise from domestic, commercial, industrial premises.

Noise Control II

Theory; law; complaint investigations; tape recorder; precision sound level meter; introduction to assessment criteria; AS 1055; field work; prosecutions.

Noise Control III

Review of Noise Control I and II; theory; law; prosecutions; graphic analyser; statistical analysis; vibration analysis; laboratory practice.

Noise Control IV

Review of Noise Control III; theory; law; signal analysis; digital instrumentation; traffic noise measurements; field investigations; report writing; advanced prosecutions; selection of instrumentation.

Planning for Noise Control

A special short course is planned for local government planners to provide instruction in the use of a publication on guidelines for planning and the use of noise zoning as a means of avoiding noise problems.

Further developments

4. The ultimate success of the scheme will depend on local government and its views on the usefulness of individual guidelines and regulations. Consequently a discussion and review procedure has been established to take account of their opinions and to establish a foundation for later technical, educational and enforcement support. Already authorities have shown enthusiasm for the concept and have indicated a willingness to become involved in the various stages of review.

Discussions with some councils have taken place to assess individual needs and to evaluate the most effective methods of enforcement. As the regulations and guidelines are assembled, councils will again be approached to provide their comments on the specific proposals.

THE COSTS OF TRAFFIC NOISE ABATEMENT

JOHN MODRA : PRINCIPAL NOISE CONTROL OFFICER

COLIN McINTOSH: NOISE CONTROL OFFICER

VICTORIAN ENVIRONMENT PROTECTION AUTHORITY

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1. INTRODUCTION

The Victorian Environment Protection Authority is currently preparing a draft State Environment Protection Policy for road traffic noise which will formalize, and possibly extend, an informal policy (or guideline) which has existed in Victoria since 1976. Under the informal policy the State's road building organization (the Country Roads Board) investigates the need for traffic noise ameliorative measures when the predicted traffic noise level at 1 metre from the facade of residential buildings adjacent to new freeways and expressways exceeds 68dB(A) L 10 (18 hour). The earth mounds and timber barriers constructed by the CRB since 1976 are tangible evidence of this policy.

The United Kingdom, some countries in Europe, Japan and the USA have policies (or other legislation) regarding traffic noise, and some of these are more comprehensive than the Victorian Policy mentioned above. This paper presents cost data associated with these programmes. Unless otherwise indicated costs are in US dollars. The term "billion" means one thousand million. Considerable use is made of cost data presented at the OECD Conference on Noise Abatement Policies held in Paris from 7th - 9th May, 1980.

2. AUSTRALIA (VICTORIA)

2.1 Barriers

Details of the barriers erected in Victoria by the Country Roads Board are given in two papers; Saunders (1981) and Stone and Saunders (1982). The information in these papers can be summarized as follows:

Barrier Type	Length Constructed metres	Cost, $A/metre (year for cost data)
earth mounds	6000	$11 to $70 if retaining wall not required. Over $200 if retaining wall required. (1980).Heights not stated.
timber, with horizontal planks.	1000	$115 (1981), 1.8 metres high.
timber with vertical palings.	1500	$92 (1981). Palings on both sides, 2.1 metres high.$70 (1981)palings on one side only, 2.1 metres high.
"super six" 9mm asbestos cement corrugated sheet with capping, as free-standing fence.	-	$26, materials only.(1982, evidently), 2 metres high.
"Armco" steel noise barrier.	-	$34, materials only.(1982), 2 metres high.

3. DENMARK

3.1 Comprehensive Abatement Strategy

In a submission to the 1980 OECD Conference on Noise Abatement Policies, the Denmark National Agency of Environmental Protection (1980) estimated that about 20% of the population of approximately 5 million are exposed to unacceptable levels of traffic noise (i.e. 65dB(A) L eq 24 hour and above). A medium-term traffic noise abatement strategy (details of which are not provided by the National Agency) is estimated to cost 3.5 thousand million D kr (i.e. $A 427 million). When these measures have been taken, about 600,000 residents will still be exposed to more than 55dB(A) L eq 24 hour at the facade. To achieve an indoor level of 30dB(A) L eq 24 hour for these residents through improved window insulation will involve a further 3.5 thousand million D. kr (i.e. $A 427 million).

4. FRANCE

4.1 Barriers

French data (OECD, 1980) indicates that concrete barriers 3.5 to 6 metres in height cost from $400 to $700 per metre, the exact figure depending on the amount of absorbing material used. In cases where high rise buildings border a road, barriers are not sufficient and an "acoustic shelter" (virtually a tunnel) is used. Shelters 30 metres wide cost from $14,800 (1978) to $33,192 (1978) per metre depending on the type of construction. These costs include lighting and ventilation.

4.2 Facade Insulation

French data (OECD, 1980) for insulating windows indicates costs of $200 (1978) per square metre for single glazing using thick glass to $600 per square metre for a double window, including ventilation.

A French study reported (OECD, 1980) that the average cost of insulating the exposed facades of 600 dwellings in the Department of the Rhone was 20,000 francs per dwelling ($4228,US 1978). This figure relates to dwellings having at least four rooms and includes the cost of ventilation.

The OECD report also indicates that the insulation of a three-room flat costs about 2,700 1978 dollars; for a five-room flat the cost was $3,300. A programme for insulating 2,300 flats in the Lyon suburbs will cost Frs. 40 million ($8.5 million), that is, an average cost of $3,700 per flat.

Some French costs relating to new dwellings (OECD, 1980) show that to achieve a noise reduction 10dB(A) superior to the protection provided by a standard building adds 1% to building costs; a reduction of 15dB(A)adds 3% and a reduction of 22dB(A) adds 7%.

4.3 Comprehensive Abatement Strategy

Insulating all 4.6 million dwellings exposed to a noise level of 65dB(A) L eq or more will cost Frs. 40 billion ($8.5 billion); if spread over a 10 year period this will be 3 per cent of the construction sector output. The average cost per dwelling is $1850. Protection measures along urban motorways such as barriers, earth mounds etc. are estimated to cost Frs. billion($1.1 billion) which is 0.4 per cent of the construction sector output (OECD, 1980)

5. JAPAN

5.1 Barriers

Koyasu (1978) reports that about 300 kilometres of barriers have been constructed in Japan. (Cohn (1982) reports a figure of 1200 kilometres). Prefabricated steel segments are used, having 50mm of glass fibre or mineral wool behind the perforated front panel. The cost for a 2 metre high wall is approximately $100 per metre. Koyasu has also given details (to Victorian EPA) of an 11 metre high barrier which extends for just under one kilometre and cost over $5 million (i.e. approximately $5000 per metre).

5.2 Comprehensive Abatement Strategy

In Japan (OECD 1980) 3 per cent of the five year programme for road construction (1978 - 1982) is allocated to environmental improvement, 40 per cent of which is directly related to noise abatement (i.e. barriers and building insulation).

6. NETHERLANDS

6.1 Barriers

Dutch costs (OECD, 1980) for aluminium and wooden screens 2 metres high range from $200 (1978) per metre for the wooden screens to $300 per metre for the aluminium screens.

6.2 Facade Insulation

Dutch data (OECD, 1980) for insulated windows not including the cost of ventilation indicates costs ranging from $24 to $261 (1978) per square metre depending on the amount of work involved. The higher figure is for removing the old windows and supplying and fitting "compound sound insulating windows". Supplying and fitting a ventilation unit costs $71 - 95.

The following tabulation (OECD, 1980) is based on actual costs incurred for insulating dwellings against traffic noise.

Noise Reduction		Cost per dwelling ($1978)
20 - 25 dB(A)	Flat	1900
	House	1900
25 - 30 dB(A)	Flat	2850
	House	3325
30 - 35 dB(A)	Flat	4275
	House	5700

6.3 Comprehensive Abatement Strategy

Implementation of the 1979 Dutch Noise Abatement Act (which includes but is not restricted to traffic noise abatement) was estimated to cost 30 million Florins ($10.6 million, Australian) in 1980, increasing to 120 million Florins by 1982 (i.e. $42 million, Australian).(Ministry of Health and Environmental Protection, the Netherlands, 1979). Under the Dutch Act, a basic noise reception limit of 50dB(A) applies to all buildings.

For the Netherlands it is estimated that 326,000 dwellings are exposed to traffic noise levels of 65dB(A) L eq or more at the facade (OECD, 1980). Insulating these dwellings in order to provide an indoor level of 45dB(A) L eq will cost between Fl.1.25 and 1.6 billion (i.e. $0.68 to 0.87 billion 1978 dollars). This cost would be incurred if no other source abatement measures were taken.

7. NORWAY

7.1 Comprehensive Abatement Strategy

Norway, a country of 4 million inhabitants, has developed a comprehensive National Traffic Noise Abatement Programme (Grandquist, 1981). The proposed noise abatement measures are basically constructional (e.g. improved window insulation and barriers of timber or earth) and do not include "active" measures such as traffic management.

The urban population in Norway totals 2.1 million people and a comprehensive survey has shown that 400,000 urban residents are exposed to (exterior) facade levels exceeding 60dB(A) L eq 12 hour (NB: the 12 hour period extends from 6am to 6pm). Investing 800 million N. Kr. (145 million US dollars) will reduce this number to 72,000 people. This corresponds to 68 dollars US per urban resident.

A further survey of both urban and non-urban areas has shown that 550,000 people live alongside major highways (i.e. state, county and local authority roads) where the outdoor noise level exceeds60dB(A) L eq (12 hour). Applying the previously mentioned abatement measures will cost an estimated 1,900 million N. Kr. (345 million US dollars). The analysis also showed that it would cost 150 million N. Kr. (27 million US dollars) to apply the proposed abatement measures to the most adversely exposed dwellings (i.e. where the noise level exceeds 70dB(A)). The government has allocated 105 million N. Kr. (19 million US dollars) for noise abatement measures in the four year period 1978 - 1981.

7.2 Facade Insulation

Experience from the first two years of a programme of facade insulation is summarized in a paper by Solberg (1981) of the Oslo City Health Department. This programme was allocated 5 million N. Kr. of the 105 million N. Kr. noise abatement programme funds mentioned previously. Total insulation costs range from 800 to 1700 N. Kr. per square metre (i.e.$144 to $306) for designs giving an attenuation in the range 32 to 37 dB(A), and 2,200 to 3,200 N.Kr. per square metre (i.e. $396 to $576) for windows having an attenuation up to 42dB(A).

7.3 Traffic Management

The Norwegian Institute of Transport Economics has investigated traffic management as a tool for reducing traffic noise (Grandquist, 1980). This is considered to be an "active" tool and a supplement to the "passive" measures previously mentioned.

The tabulation below shows the costs for satisfying various indoor levels (evidently L eq, but time period not stated). This applies to a suburb in Oslo containing 4168 dwellings housing approximately 7000 residents.

Type of Strategy	Necessary costs in Mill N Kr for satisfying different indoor levels		
	35 dB(A)	40 dB(A)	45 dB(A)
Strategy a) Only conventional structural measures	21,1	14,3	5,3
Strategy b) Combination of conventional structural and traffic management measures	17,3	10,1	4,8
Savings for the combination strategy	3,8	4,2	0,5

8. SWEDEN

8.1 Barriers

Swedish data (OECD, 1980) on steel and plastic screens 3.5 metres high or other metals with plastic covering suggests $300 to $500 per metre. The more expensive screens include absorption.

8.2 Comprehensive Abatement Strategy

Sweden is a country of some 8 million inhabitants. In 1974 a Parliamentary Traffic Noise Committee developed immission standards for both new and existing situations. The desirable facade level for new dwellings is 55dB(A), L eq (24 hour). Kihlman (1975) reports the following estimate of capital costs to achieve these levels over a 10 year period; two billion US dollars if the measures include quieter vehicles, and four billion US dollars if lower noise limits for vehicles are not introduced.

Further information is provided in a document summarizing the Committee's proposals (Swedish State Committee on Traffic Noise, 1974).

9. SWITZERLAND

9.1 Facade Insulation

Swiss data for the insulation of buildings (OECD, 1980) indicates that a 35 to 40 dB(A) window treatment costs about $250 per square metre (1978 dollars).

10. UNITED KINGDOM

10.1 The U.K. Noise Insulation Regulations

In the United Kingdom, the Noise Insulation Regulations made under the Land Compensation Act 1973 provide that, where dwellings are or will within 15 years be subjected to an increase in traffic noise from a new or altered highway of at least 1dB(A) resulting in a noise level of 68dB(A) or above on the L 10 (18 hour) index the highway authority has a duty or a power to provide insulation at its own expense. Where possible, road construction Authorities use barriers etc. to prevent facade levels exceeding 68dB(A). It is estimated (OECD, 1980) that some 30,000 dwellings along new or altered major roads are eligible for insulation at an average cost of £ 600 - 700 (i.e. \$1200 - \$1400) per dwelling; a similar number of dwellings are affected along secondary roads. The total cost for all of these dwellings is estimated to be £ 36 - 42 million (\$65 - 76 million).

Alexandre and Barde (1976) report that the cost of sound insulating all residential properties affected by noise of 68dB(A) or above from existing roads has been estimated to be about £ 1,000 million. This can be compared with an estimate of £3,300 million made by Allen et al (1976).

Davies and Dawson (1980) report the costs of attenuation measures in the UK. These are summarized below:

	£
- insulate one facade of a two storey house	1000
- insulate single storey dwelling	720
- fence (i.e. barrier), 3 metres high	80 per metre
- earth mound, 3 metre high using soil found on site	40 per metre
- earth mound, 2 metre high using soil found on site	27 per metre
- earth mound, 3 metres high using imported soil.	95 per metre

Their study indicates that there is no great difference in costs between a solution using double glazing only, and one that used a combination of double glazing and a barrier, the latter combination being slightly cheaper. If the standard was changed from 68 to 64dB(A), this would increase costs by 50%.

The OECD report (1980) gives costs in 1978 dollars for barriers ranging in height from 1.4 metres to 3 metres and constructed of a variety of materials. These range from \$80 per metre to \$260 per metre.

British data (OECD 1980) for window insulation indicates costs of between \$56 (1978) and \$99 per square metre depending on construction.

11. U.S.A.

11.1 Barriers

Cohn (1981) provides data showing that 295 kilometres of barriers have been constructed in 9 States in the U.S.A. The break up is shown below, the total cost being $103,616,600.

Barrier Type	Length, metres	Cost 1980 dollars ($/metre)	
Concrete	133, 120	45, 418, 600	(341)
Combination	69, 449	33, 252, 800	(479)
Wood	48, 081	16, 575, 600	(345)
Earth Berm	39, 668	5, 877, 500	(148)
Metal	4, 445	2, 025,500	(456)?
Other	754	466, 600	(618)?

US estimates given in the OECD report (1980) range from $276 per metre for a 4 metre high timber barrier to $82 for a 2 metre high concrete barrier.

Manhart (1974) reports that, for earthen mounds, landscaping costs range upwards from $10,000 per acre and annual maintenance costs are in the vicinity of $1000 per acre.

12. WEST GERMANY

12.1 Facade Insulation

The Bavarian Government is considering a vast soundproofing programme for housing in towns with a population of over 45,000 (OECD, 1980). The average cost of soundproofing is DM 4,200 ($1,830 Australian), and about DM 61 per capita ($ 27 Australian) for the 2,770,000 people living in the towns considered. Hence the total cost of the programme is approximately DM 169,000,000 ($73 million Australian).

From 1974 to 1979 the City of Munich spent DM 20 million ($9 million) for soundproofing buildings affected by traffic noise, this amount covering 50 per cent of the insulation costs (OECD 1980). The other 50 percent of the cost was borne by the owners.

German data (OECD, 1980) for insulated windows (with the cost of ventilation included) indicates costs ranging from $449 (1978) per square metre to $1005 per square metre. The higher figure is for a "sound insulating box type window with separate frame" having an attenuation of 50dB(A).

12.2 Comprehensive Abatement Strategy

The following cost data for West Germany has been taken from a world survey of traffic noise laws and regulations prepared by the Main Roads Department of Western Australia (1976). The data was originally prepared by the Federal Ministry of Transport and is for"noise barrier construction and sound insulation along new proposed Federally aided highways (Autobahn and Federal Trunk Roads.)"

EXTERNAL L eq			Estimated Costs (1975)
Day	Evening	Night	
70	65	60 dB(A)	3 Billion DM (1.2 Billion US dollars)
65	60	55 dB(A)	8 Billion DM (3.4 Billion US dollars)
65	55	50 dB(A)	18 Billion DM (7.6 Billion US dollars)

13. SUMMARY OF COSTS

Barriers (up to 3.5 metres high) - $A70 - $700 per metre.

Shelter - $14,800 to $33,192 per metre.

Earth Mounds - $A11 to $A200 per metre.

Window insulation - $24 to $1005 per square metre.

Facade insulation - $1200 to $5700 per dwelling.

Abatement Scheme (various population sizes)

- $8.5 billion total (France)
- $A 42 million annually (Netherlands)

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THE ECONOMICAL CONTROL OF MOTOR VEHICLE NOISE VIA TYRE AND ROAD DESIGN

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ABSTRACT

In recent years the author has conducted considerable research on the generation of tyre/road interaction noise. This source of noise is generally thought to be of considerable importance in the treatment of vehicle and traffic noise since, for most vehicles (motorcycles excepted) in a state of reasonable maintenance, it represents the major source of constant speed roadside noise for all speeds exceeding around 30 km/h. Consequently, once the behaviour of this particular source is understood, it may provide a practical avenue towards the economical control of vehicle, and therefore, traffic noise. The present paper commences with a brief outline of some of the more recent data collected by the author. Roadside noise data, monitored under typical Australian conditions, are presented for a range of common road surface macrotextures and tyre tread configurations. From there the trends in these data are quantified via regression analyses which are based on the air pumping noise generation mechanism. This has allowed application of the results to a consideration of vehicle noise control. A useful range of low noise design options is investigated. In particular, it is demonstrated that, due to the interactions between tyre and road, there would seem to be specific lower limits to the noise reduction that may be achieved by the control of road surface macrotexture alone. The economic consequences of these findings are also considered.

1. INTRODUCTION

The generation and control of traffic noise are subjects of considerable world wide interest. Traffic noise may be regarded as the summation of the noise produced by each individual vehicle in a given traffic situation. As such, the noise control options tend to be limited and it generally recognised that the best long-term solution lies in what is known as 'control at source'. This involves firstly understanding how the various sources of traffic noise behave and secondly determining their relative importance. From there, suitable noise control strategies, such as engineering redesign, may be developed and evaluated.

There are three basic sources of individual vehicle noise: the engine and its accessories, aerodynamic effects and the interaction of the tyres with the road. Tyre/road noise has been recognised as an important source of vehicle noise for several years (Corcoran 1972; Harland 1970; Hayden 1971). More recent research (Sandberg 1979) has indicated that this importance may well be greater than was previously recognised. It has been known for some time that for most modern vehicles in a state of reasonable maintenance (motorcycles excepted), tyre/road interaction represents the major source of vehicle noise, observed at the roadside, when the vehicle is operating at constant speed. However, Sandberg (1979) demonstrated that this observation holds true for a range of typical, modern, European passenger vehicles (operating in top gear) for all constant speeds in excess of a low 30 km/h.

It is the intent of this paper to explain and expand upon some of the results of an Australian Road Research Board (ARRB) research program which has concentrated on the tyre/road noise source and the mechanisms by which it is generated. Briefly, this ARRB research was aimed at determining, under Australian conditions, the effects of road surface macrotexture on tyre/road noise. It has achieved this objective from both an empirical and a theoretical viewpoint, which has enabled the present paper to consider several applications of the research findings and their economic consequences.

2. THE DATA

2.1 DATA COLLECTION

Road side noise data were collected for one vehicle in a controlled test situation by what is known as the 'passby' technique (DoTA 1977). A suitable range of road surface macrotextures and (passenger car) radial ply tyres were selected to typify those currently in service throughout Australia and to provide adequate coverage of the relevant road and tyre parameters. Photographs of the tyres and road surfaces used are given in Figs 1 and 2. As shown, Site 1 represented a smooth asphaltic concrete while Sites 2 and 3 typified the range of commonly used chip seal surfaces. Tyres 2 to 5 and Tyre 7 exemplified the range of passenger car radial ply tyres readily available in Australia. Tyres 1 and 6 were prepared especially for the experiments and Tyre 1 was a patternless or 'slick' tread type while Tyre 6 was designed as a simple, not too unrealistic, sample to assist in the understanding of the tyre/road noise generation process.

One vehicle was used throughout all experiments. It was a 1977 Ford Falcon XC Wagon, equipped with a 4.9 l V8 engine and a four speed manual gearbox. This vehicle was originally selected as a typical example of the Australian passenger car population (Samuels and Jarvis 1978) and was equipped to facilitate a wide range of both vehicle and engine speeds during the experiments. Data were collected for all combinations of tyre and road surface at a vehicle trajectory-microphone distance of 15 m. Vehicle conditions of 'coastby' (coasting by in neutral with engine off) and 'driveby' (driving by in fourth gear) were used at each tyre/road combination. A method known as the 'sandpatch technique' (Mitrey et al. 1975) was employed to obtain measures of the road surface macrotexture mean depths and the volumes contained within the tyre tread cavities situated within the tyre/road contact zone. These data are given in Table I.

2.2 TYPICAL EXAMPLES

The interactive effects of tyre tread and road surface are illustrated by the coastby data of Fig 3. Similar effects were observed in the driveby data, and these are discussed in Samuels (1982). As shown in Fig 3, the roadside noise levels increase with increasing speed, but the effects of tyre and road are somewhat more complex. To investigate these effects narrow band (10 Hz) spectral analyses were conducted on the data and again Samuels (1982) provides further details of these. In summary, these analyses revealed that the observed roadside noise spectra could be regarded as comprising spectral components due to the engine (and associated noise sources), the tyres and the road surface. These three components occur within different frequency ranges, which do, in part, overlap. The engine components predominate in the lower frequency region from 50 Hz to around 200 Hz. Observed road noise frequencies ranged from 50 Hz to around 1000 Hz, while tyre noise frequencies appeared to be concentrated in the 500-2000 Hz region.

It was observed that the three components interacted in a complex manner to generate the total frequency spectrum for any one particular experimental condition. Importantly, where spectral differences were observed, these tended to be greatest over those regions in the spectra that were controlled mainly by the road surface macrotexture. Also, the road surface components were found to increase with increasing macrotexture coarseness, while the converse was observed for the tyre related components.

2.3 ANALYSIS

In an attempt to quantify the observed roadside noise level effects of road surface macrotexture and tyre tread pattern, a regression analysis was performed on both the linear and the A-weighted coastby data of Fig 3. To do this a simple model utilising air pumping noise generation theory was developed on the basis of previous work on this topic by the author (Samuels 1976, 1978, 1980 and 1982). Air pumping theory attributes tyre/road noise generation to the transient flow of air in the road surface and tyre tread cavities situated within the tyre/road contact zone. Initially therefore, the model required a measure of both the volume and the rate of transient air flow in both the tyre tread and the road surface within each particular tyre/road contact zone for every experimental condition. Measurement of these parameters proved unduly difficult and, as a first approximation, the model was developed utilising the data of Table I once a number of simplifying assumptions had been made.

A complete mathematical derivation of the regression model is given in Samuels (1982), along with explanation of the various assumptions involved. It culminated in eqn (1)

$$SPL = E + B\log V + D\log(M^2 Wl + Q/M) \qquad (1)$$

Where E, B and D are constants,
SPL = Roadside sound pressure level (dB),
V = Vehicle speed (km/h),
M = Macrotexture mean depth (mm)
W = Width of tyre/road contact zone (mm),
l = length of tyre/road contact zone (mm),
Q = Maximum volume of tyre tread enclosed air available for pumping (mm).

A multiple regression analysis, using the SPSS package on the ARRB CYBER 171 computer, was run using eqn (1) on both the linear and the A-weighted coastby data of Fig 3. In Table II the results of these regressions are given, along with the accompanying values of the coefficient of determination, R^2. (The value of R^2 may range from 0 to 1, and the closer it is to 1, the better is the fit of the regression equation to the measured data.) As shown in Table II, eqn (1) represents a reasonable initial descriptor of the measured linear coastby data. Obviously, based on an R^2 value of 0.72 the model is not completely satisfactory, and this was foreshadowed in the preceding discussion concerning the assumptions upon which the model is based and the somewhat suspect tyre and road volume data. However, the model is based on supportable theory and until further data become available, must be regarded as the best linear coastby data descriptor available to date.

Apparently this is not the case for the A-weighted data as reflected in the R^2 value of only 0.44. This may be explained in terms of the A-weighting filter characteristics, which are such that the A-weighted coastby levels would comprise severely attenuated road noise components and some moderately attenuated tyre noise components. It is to be expected, therefore, that a model which in effect assumes that no such attenuations exist is not particularly successful in describing the A-weighted data.

3. NOISE CONTROL APPLICATIONS

3.1 ENGINEERING CONSIDERATIONS

Road Surface

Tyre/road noise control would involve innovative measures aimed at minimising both the road related and the tyre related noise components. For the road components this would generally mean minimising the road surface macrotexture, since the results have revealed a strong relationship between increasing roadside noise and increasing macrotexture coarseness. Two criteria are important. Firstly, the noise generation efficiency of the road noise components should be minimal. Secondly, the surface macrotexture should contribute towards reducing the noise generation efficiency of the tyre components. This involves short circuiting of the air pumping process within the tyre tread.

Unfortunately these two criteria are in conflict, since it has been shown that while road noise decreases, tyre noise increases with decreasing macrotexture coarseness. To resolve this issue, four practical cases were considered on the basis of the regression equation given in Table II for the unweighted data. Two tyre parameters were selected to span the range of commercially available passenger car tyres currently in service throughout Australia. These were combined with two road macrotexture parameters representing a smooth asphaltic concrete surface and a coarse chip seal surface. Results of the calculations for these four combinations are plotted against speed in Fig 4. The curves in Fig 4 suggest that there is generally greater noise control benefit to be obtained by placing most emphasis on reducing the road noise components. There is a limit to this benefit, however, and it ensues from the wide range of tyre related noise levels shown in Fig 4 for the smooth asphaltic concrete surface.

In fact, the upper of the two smooth asphaltic concrete curves in Fig 4 represents an estimate of the upper limit of passenger vehicle tyre/road noise on such a surface. It may also be shown that this curve estimates the lower limit of tyre/road noise on a chip seal surface of macrotexture mean depth 1.68 mm. (This was done by assuming that the curve represented the quieter tyre ($Q = 25 \times 10^3$ mm) operating on a chip seal surface. The mean macrotexture depth was determined by solving Eqn (1) for M for the given curve and tyre.) Therefore it would seem that the noise reduction benefit discussed above which is obtained via minimising the road related components by a reduction of the macrotexture coarseness is limited once the macrotexture mean depth drops below 1.68 mm. That is, below this macrotexture mean depth the tyre related noise components are such that they begin to outweigh the benefits obtained by reducing the road components.

Translation of the above arguments into design criteria depends to some extent on the in-service passenger vehicle tyre population. Estimates of this population are difficult to obtain. Using some of the data of Samuels and Jarvis (1978) as a guide it would appear that this population distribution is approximately normal, but slightly skewed towards the 'quieter' tyres (Q = 25 x 10^3 mm). Applying this information to the Fig 4 trends and to eqn (1) suggests that, as a design guide, the lower limit of chip seal macrotexture mean depth for noise reduction benefit would be around 1.6 mm.

Any further noise minimisation via low noise road design would seem to involve design alternatives to chip seals and smooth asphaltic concrete surfaces. It is here that the open-graded friction course surface is of interest. This type of surface comprises an asphaltic concrete that incorporates large, visually obvious, air voids that serve as water drainage channels (Giffen and Gaughan 1979, Rebbechi 1979). Some local noise data have been collected on such a surface (Samuels 1982) and these indicated that the surface did generate noise levels generally lower than those for the smooth asphaltic concrete. Regressions were not conducted on these data because it was not possible to obtain sandpatch measurements for that surface. To place the effects of this surface in the context of the current argument, results from Tyre 4 (Q = 44 x 10^3mm) and Tyre 5 (Q = 27 x 10^3 mm) have been plotted in Fig 4. These two tyres were chosen for the present purpose since they have tyre tread parameters very similar to those values used in the previous four sets of calculations. As shown in Fig 4, the comparable range of noise levels associated with the open-graded friction course represent a useful additional noise reduction.

Thus from the road surface viewpoint the noise control criteria available to date may be summarised as follows.

(a) Macrotexture mean depth should be minimised to a lower limit of 1.6 mm. Mean depths below this value will not produce substantially different noise levels from those generated on a smooth asphaltic concrete, given the current passenger vehicle tyre population.

(b) To reduce noise below that achieved on a smooth asphaltic concrete, an open-graded friction course should be adopted rather than a smooth asphaltic concrete.

Of course, these criteria must marry with the road design requirements of adequate skid resistance, light reflectance and water drainage properties (Oliver 1979, Bryant 1979). While these requirements are outside the scope of the present paper, it is sufficient to state that they are entirely compatible with the noise control criteria (Samuels 1982).

Tyres

There are several means by which the tyre related noise components may be reduced at the design stage. First among these is the minimisation of pronounced noise frequency spectral peaks that would be heard as annoying whines. Various techniques for achieving this by randomising the spatial repetition order of individual tread elements around a tyre are well known and adopted as a matter of routine throughout the tyre industry. While this practice certainly reduces pronounced peaks, it does not generally have the effect of reducing the sound power generated by a particular tyre. As a result the energy is distributed across the spectrum and this produces a number of (generally smaller) spectral peaks.

The important objective is to reduce the transient air flow rate. This may be done either by reducing the volume of air available for pumping or by increasing the time taken for air to be pumped from a particular tread element (noise source) or by a combination of these two. In practice the first of these two requirements involves varying the tyre tread element depths around the tyre. Also, the provision of as many interconnecting channels as possible within the tread will promote the flow of air within the tread itself, thereby reducing the volume of air pumped to atmosphere. In effect this reduces the air available for pumping. Controlling the air pumping time necessitates suitable orientation of the tread elements. If they are as near as possible to parallel to the tread longitudinal centre line, this will have the effect of increasing the times taken for elements to enter and leave the tyre/road contact zone. As a consequence, the air pumping times will increase as required.

Further consideration of tyre noise reduction will not be undertaken herein as the above discussion has summarised the major applications of the current results. However, it is recognised that there exist a number of other well known (within the tyre industry) tyre noise reduction criteria such as avoiding lateral tread elements and avoiding those elements described as individual pockets. These tend to represent extreme opposite examples of the applications discussed above and are, therefore only mentioned for completeness in passing.

3.2 ECONOMIC CONSEQUENCES

Consideration here will be directed primarily at the road surface, since the discussion concerning Fig 3 indicated that this provides generally greater scope for noise control than tyre related options. Furthermore, the noise control possibilities available to tyre manufacturers lie mainly in the design of tread pattern configurations. Given that the costs of alternative tread moulds are comparable, it would appear that the economic advantages to manufacturers of quieter tyres lie not in production cost savings but in increased sales. These might be achieved via suitable marketing strategies in both the original equipment and component replacement sectors. It is beyond the scope of the present paper to estimate these advantages other than to suggest that they may well be substantial, given the sensitive and volatile nature of the automobile and related accessory markets.

For road construction the situation is somewhat different, and it is appropriate to consider some typical economic outcomes of the noise control road surface treatments. This exercise is by no means straightforward as there is a considerable range of road construction practice adopted in Australia. This ensues from the considerable range of traffic, climatic, topographical and geological conditions that exist throughout the country. One indication of the economic effects of minimising road surface macrotexture may be obatined by reference to the three surfaces of Fig 1. Here, Site 1 is an asphaltic concrete while Sites 2 and 3 are what is known as 'spray and chip seals'. Some construction details of these three roads might typically be as shown in Fig 5. Bearing in mind the variety of pavement designs in Australia, the examples of Fig 5 were selected to be reasonably representative of an urban situation where the traffic volumes are such that traffic noise is likely to be a problem. Assming that the costs associated with earthworks and sub-grade preparation are approximately equal for the three cases, the real cost comparison concerns the crushed rock and upper surface (wearing course) components.

It is possible to compare the construction costs as shown in Table III. The costs may be compared as indicated on an area basis or on a length basis for, say, a 7.5 m wide pavement. It appears that there is only a marginal difference between the construction costs of the two chip seal surfaces while these, in turn, cost around 55 per cent of the asphaltic concrete example. This is a substantial difference which translates into around $k30 per kilometre of 7.5 m wide pavement.

In order to place these costs in some context, the 1980/81 road surfacing program of the Country Roads Board of Victoria (CRB) was considered. During that year, the CRB laid 4229 km of chip seal and 151 km of asphaltic concrete pavement at costs of $M25.9 and $M11 respectively (CRB 1981). The comparatively high costs of asphaltic concrete are apparent here, with 3.5 per cent of the constructed length (5.2 per cent of the area) consuming 30 per cent of the total cost of $M36.9. This comparison must be treated somewhat cautiously as asphaltic concrete pavements tend to be employed in situations where traffic and load (weight) levels are relatively high. Under these conditions, the asphaltic concrete thickness may well be substantially greater than the 70 mm of Fig 6 and this will naturally shorten the length of road paved per construction dollar. Also, the chip sealed pavements laid by CRB would not all be of the same design and dimensions as those of Fig 5. Nevertheless, using the CRB figures as a guide reveals that the cost comparisons of Table III may well induce considerable initial construction cost differentials during a given year. From the noise viewpoint, the figures suggest that the 'quieter' chip seals are marginally cheaper to construct than the 'noisier' chip seals. However the asphaltic concrete, which is the quietest surface, is substantially more expensive than the chip seals. (It should be noted also that the costs associated with an open graded friction course would be generally equal to or greater than those of the Site 1 asphaltic concrete. The open graded asphaltic concretes have very little inherent strength and are generally laid over a structural layer of, typically, conventional asphaltic concrete (Lay 1981). This process often results in higher costs.)

The anticipated (or design) life and associated major maintenance costs must also be considered for each of the three cases in Table III. Again a problem arises in cost assessment here as the variety of traffic and pavement loading conditions result in a considerable range of maintenance practices and pavement lives. As a guide however, it is not uncommon in Australia for moderately trafficked chip seal pavements to be resealed at five year intervals and then be reconstructed after 20 years. On the other hand an asphaltic concrete pavement may have its wearing course relaid after ten years and then also be reconstructed after 20 years. If the component costs of Table III are again used as indicative and are indexed at 10 per cent per annum, it is possible to calculate the major maintenance costs over, say, a 20 year design life. This has been done as shown in Table IV where a similar trend to that of Table III is apparent. Note that this calculation has assumed the same minor maintenance (pothole repair and the like) costs for each of the three pavements. At the time of writing this paper, Australian applications of open graded asphaltic concrete (a comparatively recent innovation in road construction technology) have been relatively few. Insufficient data are available on the long term performance of these surfaces and thus it is not possible to make any assessment herein concerning the maintenance costs associated with such pavements (Giffen and Gaughan 1979).

When the initial construction and major maintenance costs of the asphaltic concrete and the chip seals are considered together as in Table V, some general conclusions may be drawn. The asphaltic concrete pavement was substantially more expensive than either of the chip seals where, in turn, the pavement of finer macrotexture was somewhat less costly than that of coarser surface. On the basis of this simplified comparison and given the earlier conclusions regarding the limitations on minimising macrotexture depth for low noise generation, there would seem to be little economic justification for adopting an asphaltic concrete pavement purely on noise control grounds. Furthermore, assuming that a chip seal pavement of adequate strength, skid resistance and light reflectance properties can be provided, then suitable minimisation of the macrotexture depth of such a pavement is likely to result in the least costly low noise pavement.

4. CONCLUSIONS

Roadside noise data were collected for a range of road surface macrotextures and tyre types. Measured roadside noise levels were found to increase with increasing vehicle speed, macrotexture coarseness and, generally, tyre tread coarseness. Further, the low noise properties of an open-graded friction course were observed. A simple regression model, based on the air pumping tyre/road noise generation theory, was successfully applied to the unweighted coastby noise levels. When applied to the A-weighted coastby data the model performed poorly and this expected result was explained via air pumping theory and the effects of the A-weighting filter on the measured noise. It was concluded that low noise road design would generally involve minimising road surface macrotexture mean depth to a lower limit of around 1.6 mm. Mean depths below this value would not produce substantially different noise levels from those generated on a smooth asphaltic concrete, given the current passenger vehicle tyre population. Further, an open-graded friction course will provide generally lower noise levels compared to those produced on a smooth asphaltic concrete surface. Low noise tyre design involves randomising the spatial sequence of tread elements around the tyre, varying tread depth around the tyre, enhancing the longitudinal orientation of tread elements and, where possible, the provision of interconnecting channels between adjacent tread elements.

It was also concluded that minimising macrotexture depth to the 1.6 mm limit is probably the most economical noise control solution, provided a pavement of adequate strength, skid resistance and light reflectance properties may be designed. This conclusion was drawn after comparing the relative costs and noise generation performance of typical chip seals with those of an asphaltic concrete pavement.

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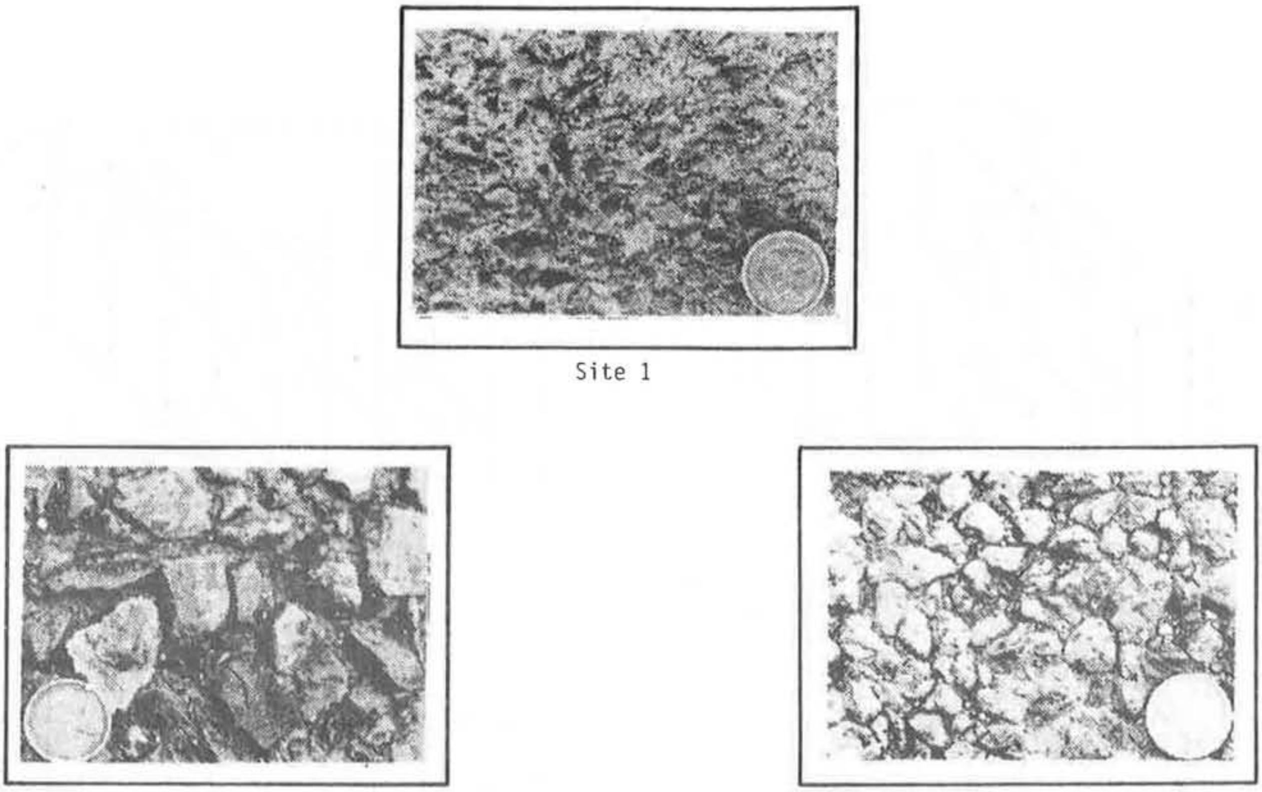
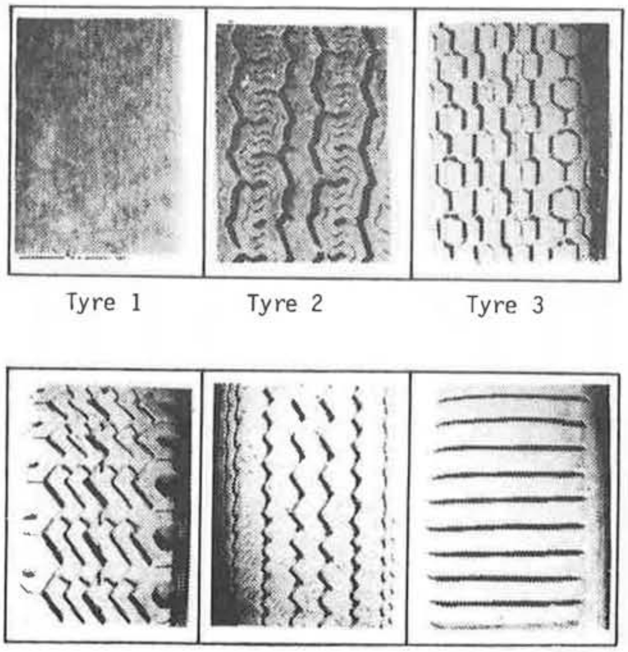


Site 1

Site 2

Site 3

Fig 1 - Road surfaces



Tyre 1

Tyre 2

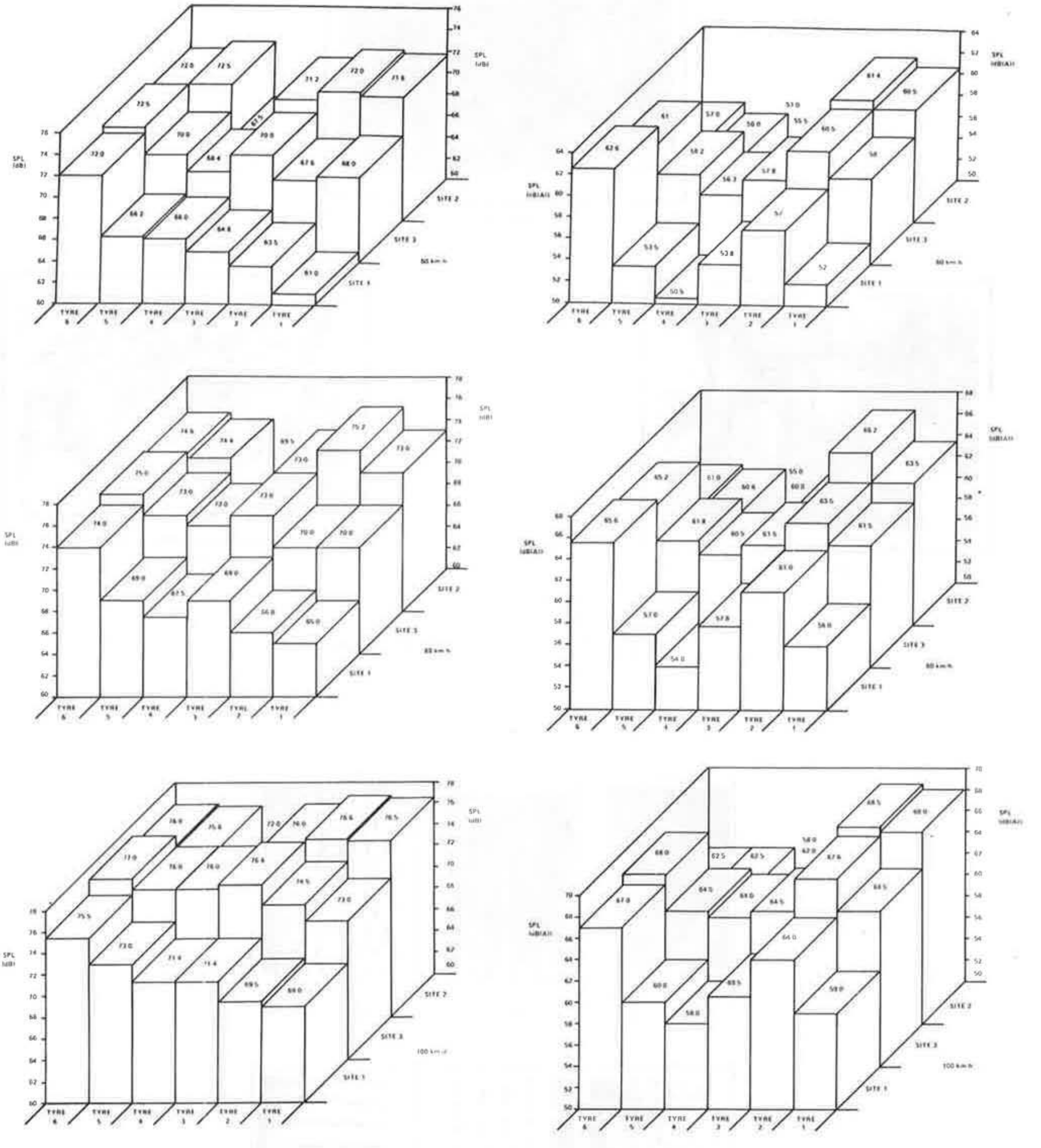
Tyre 3

Tyre 4

Tyre 5

Tyre 6

Fig 2 - Tyres



Linear A-weighted

Fig 3 - Coastby data

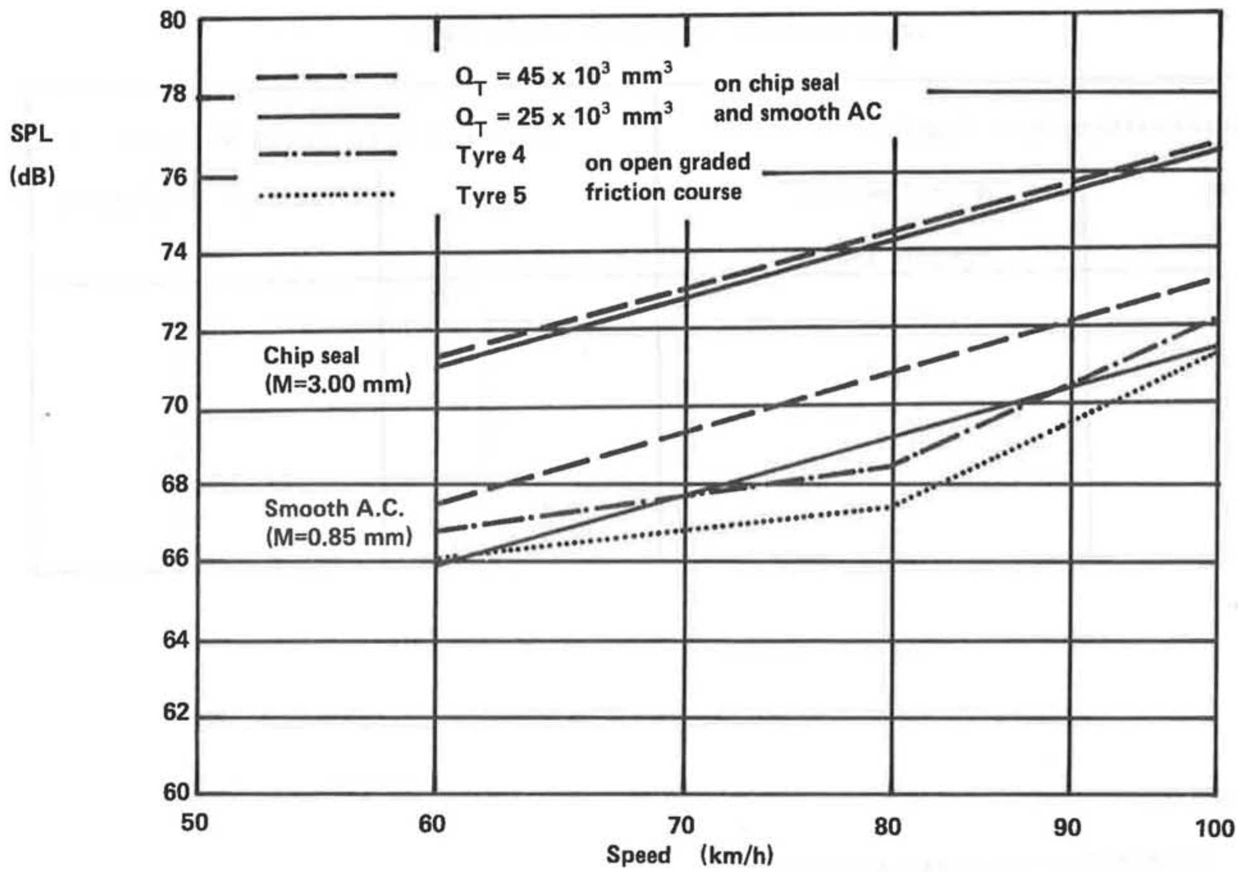


Fig 4 - Calculated passby noise levels. Also shown are measured data on a friction course

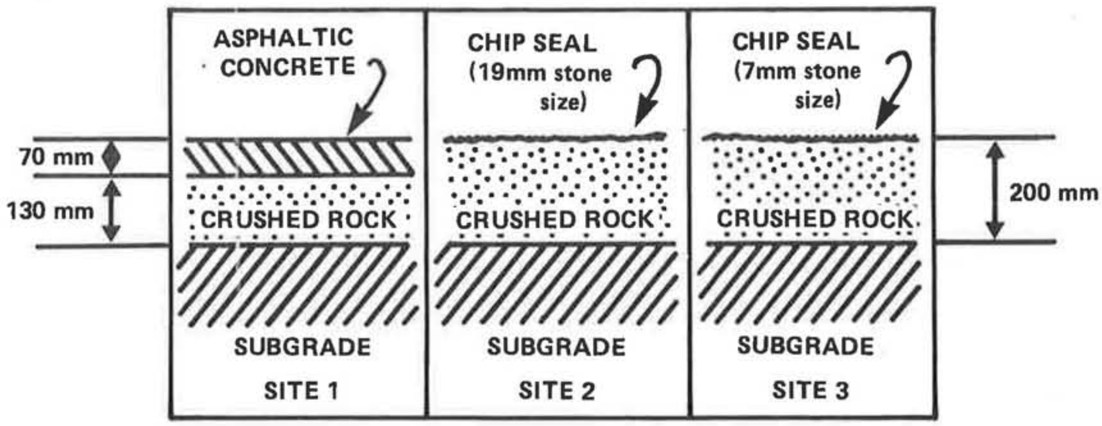


Fig 5 - Typical construction possibilities

TABLE I

ROAD SURFACE AND TYRE TREAD DATA

Macrotexture Mean Depths		Measured Tyre Tread Volumes	
Site	Macrotexture Mean Depth (mm)	Tyre	Volume ($mm^3 x10^3$)
1	0.84	1	0
2	2.86	2	36
3	2.01	3	42
		4	44
		5	27
		6	48
		7	40

TABLE II

REGRESSION ANALYSIS RESULTS

$SPL = E + B\log V + D\log(M^2WI + Q_T/M)$

	E	B	D	R^2
Linear	-17.1	25.1	8.3	0.72
A-Wt	-16.4	30.3	3.9	0.44

TABLE III

CONSTRUCTION COST COMPARISON
(A$ - 1981)

Site	Component Costs*($/m²)			Total Costs	
	Crushed Rock	Sprayed or Chip Seal	Asphaltic Concrete	$/m²	$/km**
1	2.28	0	6.72	9.00	67500
2	3.50	1.60	0	5.10	38250
3	3.50	1.16	0	4.66	34950

*Cost data are extracted from CRB (1981)
**7.5 m width x 1 km length of pavement.

TABLE IV

MAJOR MAINTENANCE COSTS COMPARISON OVER 20 YEARS
($A - 1981)

Site	Maintenance Operation	Year at Which Operation is Performed	Indicative Initial Cost (i.e. cost of operation in year 1) ($/m²)	Total Cost Over 20 Year Design Life	
				$/m²	$/km**
1	Relay wearing course	10	6.27	17.40	130500
2	Reseal	5,10,15	1.60	13.41	100575
3	Reseal	5,10,15	1.16	9.72	72900

TABLE V

OVERALL MAJOR COSTS OVER 20 YEAR DESIGN LIFE
(A$ - 1981)

Site	Initial Construction Cost ($/km)**	Major Maintenance Costs ($/km)**	Total Major Costs ($/km)**
1	67500	130500	198000
2	38250	100575	138825
3	34950	72900	107850

REDUCTION OF TRAFFIC NOISE BY FACADES CONTAINING WINDOWS

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ABSTRACT

Windows provide light and are often the only means of providing fresh air in many buildings, particularly domestic buildings. While a double-glazed window would be expected to give a better noise reduction than a single-glazed window, the effective noise reduction of the total facade must be taken into consideration. If the windows are opened to allow for natural ventilation the attenuation of the building envelope may be severely reduced.

An experimental building has been used to investigate the reduction of traffic noise by a range of single- and double- glazed windows in lightweight and masonry facades. The reduction in traffic noise for various open window areas and the effect of staggering the opening sashes in a double-glazed window have also been measured. These results can lead to recommendations as to the most efficient means of providing satisfactory noise reduction for buildings exposed to traffic noise.

INTRODUCTION

One of several methods of reducing the impact of road traffic noise on nearby residents is to improve the attenuation of the external envelope of the buildings. The cost of such improvements may be partially or totally borne by the community at large (in the case of traffic noise compensation payments) or it may be totally borne by the householder. In both cases it is very important that the methods chosen in new and existing buildings are cost-effective, i.e. that sufficient improvement is noise reduction is obtained for a reasonable money cost.

In this paper, the results of some measurements of traffic noise attenuation provided by different walls and windows are presented and suggestions are made regarding the most effective methods to be used.

EXPERIMENTAL BUILDING

An experimental building has been constructed adjacent to a road in an industrial suburb of Sydney.[1,2] The building contains two test rooms, one measuring 4 x 5 x 2.4m high and the other 3 x 5 x 2.4m high, which are similar in size to a normal living room and bedroom respectively. There is a control/storage room to the rear. The walls, except for the street facade, are of concrete block masonry and all dividing walls are carried up to the underside of the pitched roof tiles, to minimise flanking transmission via the suspended plasterboard ceiling. The street facades are non-structural to permit different wall and window combinations to be tested.

A concrete slab floor has been provided for all three rooms and the two test rooms currently have suspended timber floors independently supported on masonry piers, again to minimise flanking transmission. At a later stage, the timber floors will be removed and the concrete slab will be the basic floor, thus representing the upper level of a multi-storey domestic building.

The first experimental facade comprised timber framing with asbestos cement sheeting externally and 13mm gypsum plasterboard internally, called "timber stud walling". Later, openings were formed in the facades and a series of aluminium framed windows, having double- and single-glazing arrangements was installed. The external asbestos cement sheeting was then removed and a second, masonry skin constructed outside, to represent brick-veneer construction. At a later stage the timber stud walling will be removed and replaced with a skin of masonry, so the facade will be representative of cavity brick walling.

MEASUREMENT PROCEDURES

Noise from traffic using the road was recorded simultaneously outside and inside the rooms. The sampling duration was typically five or ten minutes. Results were analysed in terms of overall dB(A) levels as well as in one-third octave band levels (to permit comparison with laboratory data). For most tests the outside microphone was located at 1 metre from the facade (opposite the blockwork dividing the two rooms). The internal microphone was either placed centrally in the room or in up to five independent positions in which case the results were subsequently averaged. Tests were performed with the rooms either empty or furnished and all results have been normalised to take into account facade areas and room absorption.

RESULTS

1. Traffic noise reduction by a timber stud wall without windows

Although the majority of new domestic buildings now appear to have brick-veneer or brick cavity walls, there are still many dwellings, particularly in country areas, which have timber stud walls lined with asbestos cement or timber boarding. Thus tests were carried out to determine the traffic noise attenuation provided by such walls. As shown in Table I, the overall normalised noise reduction was 21 to 22 dB(A). in terms of the L_{10} traffic noise levels. (L_{eq} values were similar).

2. Traffic noise reduction by closed windows in a timber stud wall

Aluminium framed domestic quality windows were provided by two manufacturers. One brand (here called the Type A window) was provided with good flexible seals, designed to withstand cyclonic wind forces, although the glazing was the standard 3mm thickness. The windows were provided with wide timber reveal linings to allow for a second, internal window to be fitted with the air space between the glazing variable between 50 and 190mm.

In the larger, North room, the window size was 1200mm high and 2710mm wide and it was of the sliding- fixed light- sliding sash configuration. In the South room, the window size was 1200mm high and 1800mm wide and there was one fixed and one openable light.

In the smaller, South room a second set of windows was also tested (Type B). These were of normal domestic quality (i.e. no special seals. One was a horizontal sliding type, similar to the Type A window; one was a double hung (vertically sliding) window and the third was a factory-sealed double-glazed awning type window with 3mm spacing between the panes.

The traffic noise reduction provided by these windows is also shown on Table I, for the case when the windows were closed. It can be seen that there is little benefit in using a well-sealed double-glazed window in a facade that itself has a poor acoustic performance. For example, for the Type A windows in both North and South rooms, there was no improvement in overall attenuation when the second, internal windows were installed with a spacing between the glazing of 50mm. (The slightly poorer performance of the North room window could be due to the increased perimeter of the opening sashes, compared to window area, vis a vis the two-light South room window.) When the air space between the windows was increased to 100mm an improvement of 2 to 3 dB(A) was obtained, compared to the single-glazed window.

As the poor performance of a timber stud wall might be improved in practice by the addition of a second layer of plasterboard inside, this was carried out in the North room. An increase of 3 dB(A) in the performance of the 100mm spaced double-glazed window was obtained, thus confirming that it was the wall rather than the window that had determined the overall performance of the facade before.

The horizontal sliding and double hung Type B windows show a marginally poorer performance than the Type A windows in the timber stud wall. The factory-sealed double-glazed awning window gave comparable results to the Type A single-glazed window.

3. Traffic noise reduction by partially open windows in a timber stud wall.

Since windows are required to provided natural ventilation as well as daylight in domestic buildings, the effect of opening the windows on traffic noise reduction was also investigated. Table II shows some results, again, in terms of the normalised noise reduction of L_{10} traffic noise levels, dB(A). (Again, L_{eq} results show a similar trend.)The windows were each opened for 50% of their openable area, which represents different percentages of the overall facade areas; these percentages are also shown on the Table.

It can be seen that whilst there was no difference between the performance of the single-glazed and double-glazed Type A windows with 50mm air space when closed, the double-glazed windows were 1 to 2 dB(A) better than single-glazed windows when open. For the 100mm spacing, the improvement of 2 to 3 dB(A) when closed (compared to single-glazing) increased to 4 dB(A) when open. When the opening sashes in the 100mm spaced double-glazed windows were staggered (the inside right-hand sash opened 50% and the outside left-hand sash opened 50%) the noise reduction increased considerably, and an improvement of 10 dB(A) compared to the single-glazed open window was found. However, the effective open area of the facade and hence the amount of natural ventilation provided is less for this arrangement. There was no absorbent material lining the reveals and it would be expected that a further improvement would occur if this was to be applied. Kerry and Ford[3] also found an improvement using staggered openings in double-glazed windows, compared to open windows (although in their case one window slid vertically and the other horizontally); they recommended using 25mm polyurethane foam reveal linings.

A comparison between Type A and Type B windows in the timber stud wall is shown on Fig.1. for open areas representing different percentages of the total facade area. They both show a rapid decline in attenuation for quite small percentage open areas.

On Fig.2 are shown the results for the various alternative versions of the Type B window, i.e. horizontal sliding, double-hung and awning type. The latter two configurations appear to give an improved performance compared to the horizontal sliding window for nearly all percentages of open area. The double hung window has a smaller pane size than the other types, and perhaps better sealing between sashes in the 'open' configuration. In the case of the awning window, it could be expected to reflect some of the incident sound away in its open configuration.

4. Traffic noise reduction by closed windows in a brick-veneer facade.

Table I shows the results obtained for windows installed in the brick-veneer facades. In the North room the improvement in performance of the Type A windows, either single- or double-glazed was 4 dB(A). However, when the 100mm spaced double-glazed window in the improved timber stud wall (with the extra layer of plasterboard)is compared with the result in the brick-veneer wall, the overall increase for the latter is only 1 dB(A). This indicates that the window has again become the limiting factor in overall attenuation.

The Type A window in the South wall also shows only a 1 dB(A) improvement in the brick-veneer wall, although the less well-sealed Type B window showed an improvement of 5 dB(A). Although all obvious gaps have been sealed it is possible that some flanking transmission is affecting the performance of the Type A window in this room.

5. Traffic noise reduction, partially open windows, brick-veneer facade.

Table II shows an improvement of 2 to 4 dB(A) for the single-glazed Type A window in a brick-veneer facade, when partially open, compared to its performance in the timber stud wall. However, there was little or no improvement in the case of partially opened double-glazed windows in the brick-veneer facades. Fig. 3 shows a comparison between the Type A windows for various opening percentages in the timber stud and brick-veneer facades. There is a marginally better performance in the case of the larger percentage openings in the brick veneer facade.

In both cases, the greatest reduction in attenuation occurs for very small percentage openings.

DISCUSSION

It can be seen from the results presented here that great care must be taken to select the most cost-effective system of window/facade elements. Since the basic attenuation of the timber stud facade is only of the order of 21 to 22 dB(A) there is little point in installing double-glazing, or even domestic quality windows with improved seals, since the overall improvement, with typically sized windows is a marginal 2 or 3 decibels.

If the performance of the timber stud facade is improved by adding a second layer of gypsum board lining, an additional 3 dB(A) attenuation was obtained (for the double glazed window situation). Again, this is scarcely cost-effective.

Unfortunately, the performance of the brick-veneer facade without windows has not yet been measured, however, the 100mm spaced double-glazed window gave an overall attenuation of only 25 dB(A), a mere 1 dB(A) improvement over the same window system in the improved stud wall.

It might be thought that better results would be obtained with thicker glazing, however, a change from 3mm to 6mm glazing in the brick veneer wall gave an improvement of only about 1 dB(A) - again, not a worthwhile expense.

It must be remembered that the eaves, under floor construction, etc. are typical of normal domestic buildings and it could be that flanking transmission through such paths are a limiting factor to the overall traffic noise reduction obtained. The windows tested so far have also been typical domestic quality, and it is possible, that if windows can be permanently closed and sealed, it may be worthwhile installing heavy duty commercial type frames and glazing.

When windows have to be partially open to provide ventilation there is no point in using other than normal domestic quality frames and glazing. Gains of about 2 to 4 dB(A) can be obtained (50% open area) either by using brick-veneer walling, rather than timber stud, or by using a double-glazed system. The most effective arrangement with open windows was to use double-glazed horizontally sliding windows with staggered openings. Even without absorbent linings in the cavity reveals, the attenuation reached 16 dB(A) in the timber stud wall.

FUTURE STUDIES

It is intended to brick up the openings so that the potential performance of the brick veneer facade can be determined. If it is found to be significantly better than the results obtained with windows inserted, further, improved windows will be tested. Otherwise the project will continue with the cavity brick facade version.

ACKNOWLEDGEMENTS

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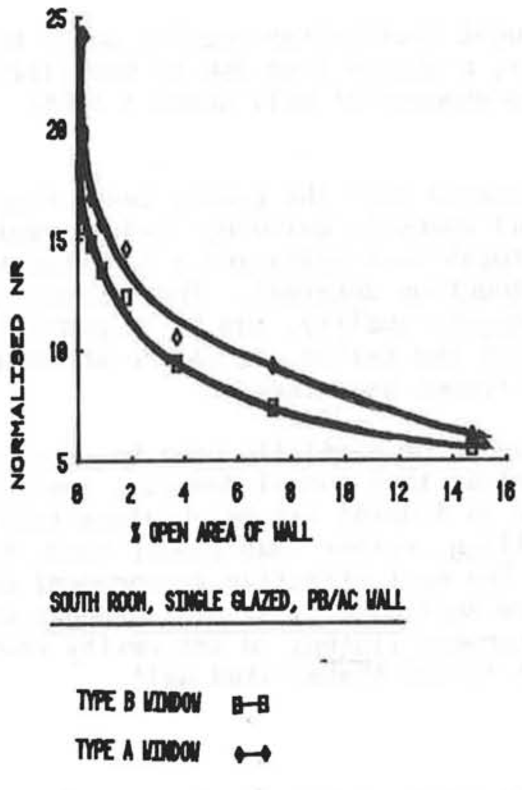

FIGURE 1: NORMALISED NOISE REDUCTION, L_{10}, dB(A), OF PARTIALLY OPENED TYPE A AND TYPE B WINDOWS IN A TIMBER STUD WALL

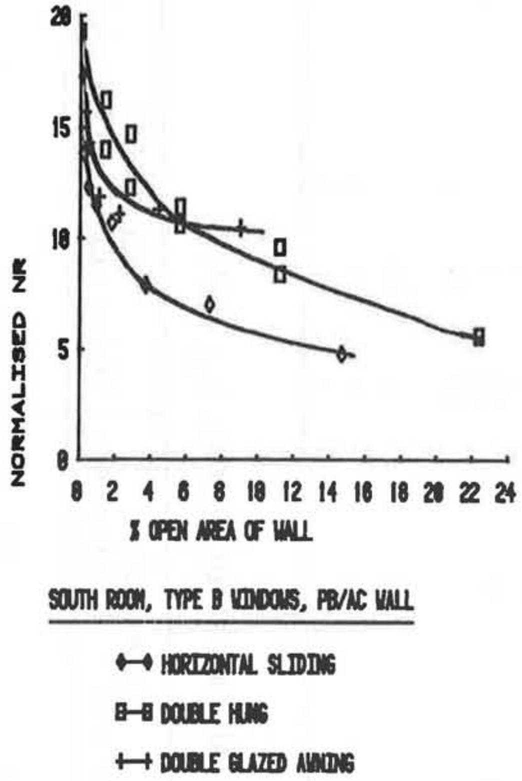

FIGURE 2: NORMALISED NOISE REDUCTION, L_{10} dB(A) OF PARTIALLY OPENED TYPE B WINDOWS IN A TIMBER STUD WALL

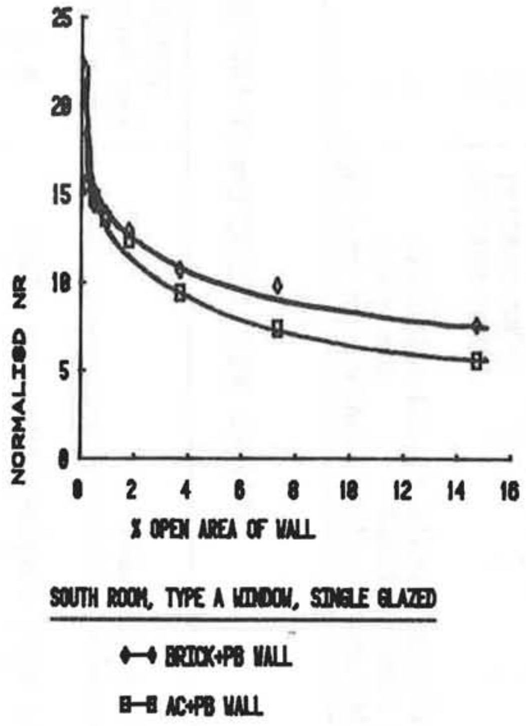

FIGURE 3: NORMALISED NOISE REDUCTION, L_{10} dB(A) OF PARTIALLY OPENED TYPE A WINDOWS IN TIMBER STUD & BRICK VENEER WALLS

TABLE I

TRAFFIC NOISE REDUCTION OF CLOSED ALUMINIUM FRAMED WINDOWS, L_{10} dB(A)

WINDOW / FACADE	TIMBER STUD North	TIMBER STUD South	TIMBER STUD + PL.BD. North	TIMBER STUD + PL.BD. South	BRICK VENEER North*	BRICK VENEER South	
No window	22	21	-	-	26	26	* with extra layer of plasterboard
TYPE A							
Horizontal sliding single-glazed 3mm glass	19	21	-	-	23	21-22	
" " " " 6mm glass	-	-	-	-	-	22	
" " double-glazed 50mm spacing	19	21	-	-	-	-	
" " " " 100mm spacing	22	23	25	-	26	-	
" " " " 190mm spacing	-	-	-	-	25	24	
TYPE B							
Horizontal sliding single-glazed 3mm glass	-	19	-	-	-	24	
Double hung single-glazed 3mm glass	-	19	-	-	-	-	
Factory sealed double glazed awning 3mm spacing	-	21	-	-	-	-	

TABLE II

TRAFFIC NOISE REDUCTION OF PARTIALLY OPENED ALUMINIUM FRAMED WINDOWS, L_{10} dB(A)

WINDOW (50% openable area open)	OPENING % (re facade)	NORTH ROOM Timber stud	NORTH ROOM Brick-veneer	SOUTH ROOM Timber stud	SOUTH ROOM Brick-veneer
TYPE A					
Horizontal sliding single-glazed, 3mm glass	8.3	6	10	-	-
" " " " " "	7.3	-	-	7	9
" " double-glazed, 50mm spacing	8.3	7	-	-	-
" " " " " "	7.3	-	-	9	-
" " " " 100mm spacing	8.3	10	11	-	-
" " " " " "	7.3	-	-	11	11
" " " "staggered opening	4.2	16	-	-	-
TYPE B					
Horizontal sliding single-glazed 3mm glass	7.3	-	-	7	-
Double hung single-glazed 3mm glass	11.2	-	-	10	-
Factory-sealed double glazed awning 3mm spacing	4.0	-	-	11	-

WHY IS IT DONE THAT WAY?

P. Knowland, MAAS

An Acoustician when confronted with a noise problem, usually goes through a disiplined process in evaluating a solution to the noise problem. Typically for some workers, the process runs similar to this:

1. What is the sound pressure levels and frequency content of the noise?

2. What is the required noise level to satisfy the particular environment?

3. Item 1 minus Item 2 plus correction for ambient is the noise reduction that should be achieved?

4. What is the mechanics of the noise generation?

5. Can I treat it by absorptive means?

6. Can I place a barrier between the source and the receiver?

7. Can the noise radiation be cut down by vibration damping treatment?

8. Is vibration isolation required?

9. Do I have to enclose the device?

   (a) Does it need operator access?

   (b) Does the device give off heat and therefore need ventilation?

   (c) Is frequent maintenance required of the device?

The above listings are a simplification of the thought process required in generally coming to a solution to a noise problem.

An important aspect which is rarely considered by an Acoustician, is the question "why is it done that way". It is imperative to question why the noise is generated in the first place and why are people affected by it. If this process is carried out then in many cases a simple and cheap solution can be obtained to the problem. In particular it means that the appendage type treatment so common with acoustic advice is not carried out.

This lateral thinking process must be an essential part of the Acoustician's kit when looking at a noise problem. The question processes are essentially as follows:-

1. Why is the process carried out in this manner?

2. Why is the person or persons affected by this noise?

3. Can the process be carried out differently and more effectively?

The number of case histories are now considered to illustrate examples of how noise problems can be solved more economically and in some case with an improvement of efficiency of the original process that gave rise to the noise problem.

CASE NO. 1
THE VIBRATING HOPPER

The particular problem involved a tall chemical tower some 80 metres above the ground causing a noise problem for a distance of 3/4 of a kilometre away effecting a large number of people in an adjacent residential area. The noise was generated by a magnetic vibrator which was attached directly to the bottom of a steel hopper located at the top of the tower. The hopper contained a white chemical powder very similar in appearance and consistency to that of flour. The purpose of the magnetic vibrator was to prevent compaction of the chemical powder at the outlet throat to the hopper. The hopper was of steel construction approximately 3-4mm thick and was vibrated by a large vibrator operating on 50 Hertz AC input. The radiation area of the hopper was quite large which resulted in a high and annoying sound pressure level within the residential area. Treatment of the hopper looked to be a very difficult exercise as application of damping to steel of this thickness was a major problem at the time this problem existed. Enclosing the hopper was also a horrific problem. The tower which was some 80 metres in the air made it extremely difficult to apply barrier type materials to limit the radiation from the hopper.

We put the problem back to the client. Why is it done this way? In conjunction with the client a number of alternative methods of preventing compaction was examined. The solution agreed on by all parties was to use compressed air in an air lance located within the powder and just near the throat. This solution provided a more than adequate reduction of noise to eliminate the noise problem and at the same time improved the efficiency of the process.

CASE NO. 2
LAMINATE SHEET CUTTING MACHINE

This was a hearing conservation problem which existed with a process line where sheet laminate was finally cut to size. The noise level at the operator's ear close to a finishing saw, was 98 dBA. The process generally was highly automated and the operator was normally able to be well away from the noise level during the process. However, as frequent jamming occured from waste material it was necessary for the operator to be close on hand to quickly remove the source of the jam so that the process was not held up. Because of operator access, treatment to the machine proved to be extremely difficult. We spent some time watching the entire process of how the sheet came from where it was made up to the cutting process. It was determined that by slightly changing the process it was possible to get the operator well away from the high noise level. The suggestions were put forward to the client who subsequently implimented the changes to the process line. This resulted in an improved efficiency of their process line with no jamming occurring and thus removed the operator from the vicinity of the high noise source. It was then possible to apply some acoustic barriers well away from the noise source so that the noise level over the general area of the factory was reduced.

CASE NO. 3
COOLING TOWER NOISE LEVELS

The particular problem here that a large cooling tower was to be placed at the rear of a large regional shopping centre development. Unfortunately this would place the tower in close proximity to an existing residential area. The development had a two-fold effect on the residential area. Firstly, it provided a substantial acoustic barrier between the residents and an existing busy main thoroughfare. This would result in a drop of ambient sound level for the residents. This was one of the positive features of the development. The negative feature was that the existing traffic noise level would be replaced by a large cooling tower. The cooling tower was required to operate right through the night at reduced capacity. A common source of irritation with cooling tower noise during night time operation is the frequent cutting in and cutting out of the fan and pumps as the load is applied in appropriately to the cooling towers capacity.

The capacity of the tower was 500 tonnes and the costing exercise of the tower and attenuators was as follows:-

The cost of a 500 tonne cooling tower is $18,000.

Due to the inability of these fans to take high static resistance very large sound attenuators together with transformed sections and supporting structure is required. The cost of silencing was $14,500 making a total cost of $32,500.

The approach adopted in this case, was to ask why is it necessary for the fans in the tower to cut in and out for the night time conditions. The reason was that the cooling load is significantly down on the normal day time load, as a principal cause and a secondary cause is that the ambient temperature is also lower making for more cooling efficiency. The exercise was then looked at on the basis of 2 speed operation of the fan between night and day time with the night time operation to be continuous and the cooling load to be adjusted by the water flow through the tower rather than cutting off bringing the tower into or out of operation. To achieve the required cooling capacity for evening and the overall noise reduction it was necessary to increase the initial size of the cooling tower so that the capacity of the tower on low speed operation would be adequate. The nominal duty was changed from 500 tonnes to 750 tonnes and the cooling tower equipped with 2 speed axial fans running at either 425 RPM or 212 RPM. Control equipment was provided which sensed the temperature requirements of the refrigeration chillers and ran the tower at the appropriate speed. The cost for this approach was as follows:

Cost of 750 tonne tower $27,000.
Cost of 2 speed motors and controlling equipment $6,200.
Total amount $33,200.

This system had a number of advantages:-

1. The over capacity of the tower allowed low speed operation during the day time for a major portion of the year. This resulted on a 5 year basis savings in power which paid for the cost of the 2 speed motors and control equipment. Therefore the cost on a 5 year basis was $27,000 as against $32,500 plus.

2. The noise reduction achieved by the 2 speed operation was greater than that which could have been achieved by the particular attenuators for the frequencies of 63 and 125 Hz. The following table is the noise level which should be the sound pressure level measured 30 metres from the tower at normal speed and at low speed operation.

	Octave Band Sound Pressure Levels							
	63	125	250	500	1k	2k	4k	8k
Normal Speed (420RPM	72	76	70	68	60	57	50	39
Low Speed (212RPM)	60	60	52	46	42	36	31	20

3. Maintenance of the tower was unhindered as there were no attenuators restricting access to the fans. Maintenance on an attenuated tower can be a significant cost.

Three illustrations have been given where noise reduction with overall cost effectiveness is achieved by questioning the whole process of the noise generation. This questioning process should be one of the major tools when considering a noise control problem.

ENERGY CONSERVATION VERSUS NOISE CONTROL IN MECHANICAL SERVICES

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INTRODUCTION

During the late 1970's, the oil crisis throughout the world led to the reappraisal of energy use. This has, in turn, spawned a whole new industry of energy conservation consultants and/or experts and led to a keen awareness of the implications of energy use. Motor cars previously commonly equipped with "gas-guzzling" V8's or big 6's are now "aerodynamically" designed with 2 litre four cylinder engines. 800cc type town cars are common and the number of 2 stroke mopeds is increasing.

Current day houses are designed to be passively heated and cooled. Home insulation is the "norm" rather than an "extra" or a luxury. Substitution of fuel oil heating with other less expensive sources of energy is a high priority. Industry too, has responded to these changing times - energy conservation programs are commonplace and waste heat recovery and solar energy are now two further alternative sources of energy to be considered. Probably the industry segment greatest affected has been the commercial office building area where the costs of both acquisition and maintenance of energy consuming systems especially air conditioning systems is closely monitored. Similarly the change in construction materials and building techniques brought about by the adoption of energy optimisation has resulted in a whole new breed of architectural solutions. In all these areas, the emphasis on energy performance has resulted in considerable implications for the noise environment.

IMPLICATIONS FOR THE NOISE ENVIRONMENT

Almost without exception, the urgent application of energy optimisation techniques has resulted in a considerable deterioration in our noise climate. Quiet slow-revving cars have been replaced by high-revving mini-engines and in some areas of the world now pose a major environmental noise problem. Houses and apartments with ceramic floor tiles to trap the heat from the northern exposures result in reverberant spaces and high levels of footfall noise. Conversely the widespread use of insulation materials in roofs and walls tends to enhance sound insulation properties and thus improve the internal acoustic amenity of most new houses as also does the more common use of double glazing.

Industrial energy conservation programs have resulted in both improvement and deterioration of the noise climate. Steam leaks in process plants and the reduction in air pressures in pneumatic systems has done much to improve the acoustic environment. On the other hand some waste heat recovery systems and process burners tend to deteriorate their local noise environment.

In the commercial building area the implications have been even greater. Even today's architects - inundated by salesman for energy efficient building materials - have succumbed to the temptation and the "rash" of reflective glass curtain wall buildings appearing in all of our cities is a result. Admittedly the heat rejection and absorption characteristics of these laminated glass systems is impressive but the degradation of the sound insulation properties of building facades using this system has created a whole new series of problems. In many cases the cost of retrofit work to solve the latter problem has greatly outweighed the energy cost savings of the former. The noise control engineer in these situations is also faced with making decisions on facade systems upon which little noise insulation data is available. With Australia's building research capability seriously decimated it is important that, we the noise control engineers, either pool our resources to get this information or demand it of the suppliers and keep our clients informed of the risks associated in proceeding without accurate data.

It is in the mechanical services field however that the implications are most serious. The use of variable volume terminal devices "spans the tightrope" between being marginally acceptable as an air distribution system on the one hand and an acoustical nightmare on the other. These VAV systems will normally also include adjustable inlet guide vanes on the main conditioner fans, a factor which can greatly increase fan noise and which is often overlooked. The use of the more efficient screw compressors for air conditioning applications also creates noise and structural vibration the rectification costs of which can easily outweigh any savings gained from energy efficiency. In an effort to apportion energy costs to actual users and enable partial occupancy of commercial office buildings the use of packaged plant rooms on each floor is now widely used. Most of these systems, unless very carefully engineered, result in very considerable noise control costs. In summary, energy conservation measures in new buildings have generated a new need for the noise control expertise in the development of a new building.

This paper aims to examine the compromises made in assessing the balance between energy conservation in mechanical services and the need for a good acoustic environment.

ENERGY CONSERVATION MEASURES IN COMMERCIAL BUILDINGS

Architectural Design

The oil crisis and the resultant dramatic increase in energy costs has forced architects to re-appraise their design philosophy on new commercial buildings. Now more than ever building orientation, shade effects and the potential for natural lighting are examined to ensure energy efficiency.

Building facade development has been considerable - both to capitalise on energy efficiency and on new more efficient construction techniques. In some areas, government regulations are limiting the heat transfer across facade elements e.g. a minimum of 45 watts/square metre is mandatory for new buildings in Singapore. This further promotes the use of new facade constructions most commonly glass curtain walls and light aluminium facade elements. Whilst the use of small windows and large concrete spandrel panels would be a more acceptable solution to both services engineer and acoustics engineer, this does not allow for high levels of daylighting - a high priority in modern buildings. As most commercial buildings are built either within the central business distinct or along major arterial roads the acoustic performance of the facade elements is significant and considerable attention to detail is required in all these so-called energy efficient systems to ensure that reasonable internal noise levels are achieved.

Electrical Services

Energy optimisation is also affecting the design and operation of electrical services within commercial office buildings. Lighting design changes reflect the dramatic improvements in energy use per light output being achieved in modern fluorescent and discharge lamps. Of serious concern to the noise control engineer is the often demanded requirement for relief air to pass over the main heat generating elements in these new fittings, and hence degrading what ceiling transmission loss is available.

Similarly the more widespread installation of auxiliary power plants to guard against unplanned black-outs or to smooth supplies for critical data processing equipment also has very serious implications for the noise control engineer. Even more difficult to counter is the use of diesel generating equipment located evenly throughout a buidling to keep power cabling reticulation costs low. This approach inevitably means that occupied office space borders the auxiliary power plant room with mammoth noise control treatment implications.

Mechanical Services

All the elements which make up an air conditioning system are sources of noise. Acoustical considerations are an important design element and should be considered along with the selection of equipment for energy optimisation. This means that it is vital to involve the acoustical engineer at the earliest possible stage of a new project if only to have his experienced input in planning the air conditioning system.

Central Plant Equipment

In a design involving a central plant the selection of plant items can have considerable acoustical implications. Energy optimisation approaches are now dictating plant selections with often severe implications for the noise control engineers. In the selection of chillers for instance considerable running cost savings can be made by the use of centrifugal or screw compressors not requiring vibration isolating inertia bases. However whilst the noise levels of the latter are generally lower the tonality of both the airborne sound and the structural vibration mitigate against their widespread use.

Variable volume air conditioning systems are designed to maximise cost savings by reducing air quantities. This is done on the occupied floors with the use of VAV terminal units or air valves and in the plant room by fitting variable inlet guide vanes to main conditioner fan. This can in some instances mean that fan noise levels increase dramatically due to the turbulent interaction of the vanes with the impeller. This noise is often transmitted via both supply and return air ducts to occupied spaces. Attenuation selection needs to take this into account if the final system is to be acoustically satisfactory.

Single duct variable volume systems which incorporate induction capability generate a whole new series of problems. Their operation is similar to the standard single duct VAV system but rely on drawing warm air from the ceiling space to mix with cold primary air for winter operation. This means that radiated noise levels are much higher (as there is an open port to the ceiling space) and thus the suspended ceiling system construction and performance become an important parameter. Again noise level variations of up to 10 dB during normal operation are common. Also radiated noise levels are so high that in general it becomes impossible to locate these terminals over occupied spaces.

The most recent VAV terminal system to be released and used in Australian projects is a single duct VAV box with both induction capability and including a small forward-curved blower to maintain air circulation after the main central plant is switched off. This system has all the inherent noise problems of the previous one but with additional blower noise source. These systems also require considerable care in design and in placement to ensure that radiated and discharge noise levels are not excessive.

A further complicating factor of terminal units which induce air from the warm centrezone area is that sound rated partitions require slab-to-slab type construction. This is not possible with this sort of system where warm air from the air conditioning system's centre zone is the source of heating for the building perimeter during winter warm-up periods. No only do high and variable noise levels result but also poor privacy conditions between offices are guaranteed. So for energy awards!

Packaged air conditioning units located on each floor can also be a problem unless very careful attention to detail is undertaken. Discharge supply and return air ducts are common problem areas but the structure borne noise and even airborne noise of these plants transmitted straight through very light weight plant room walls are often overlooked.

The final element in the air conditioning system and often the one blamed for generating excess noise levels is the air diffuser. This device designed primarily to diffuse air evenly throughout a space is really just a flow disturbance in an airstream - a standard dipole source. As such the designer aims to achieve good airflow pattern at a <u>set</u> optimum condition. No diffuser currently available in

Australia is able to vary its profile to take account of varying flow conditions. Hence the selection of the diffuser is a compromise:-

- select diffuser to handle maximum flow at PWL specified
- check airflow pattern (normally OK)
- check noise level at low flow condition (generally 10 dB down) and a little too quiet
- check airflow pattern at low flow condition and handling cold air (normally very marginal because of the reduced kinetic energy of the airjet)
- check airflow pattern at low flow condition and handling hot air (almost always unsatisfactory)

In this paper examples of installations highlighting these difficulties will be shown.

CONCLUSION

The adoption of energy usage as a critical design factor in air conditioning system design is welcomed. Lack of appreciation of the acoustical implications of these energy efficient designs will however guarantee unsatisfactory space conditions the retrofit costs of which greatly outweigh the operational cost savings achieved.

COMMUNITY COST OF NOISE CONTROL

by A.Hewett & J.Mazlin

Abstract

Any noise reduction campaign relating to industrial noise emmissions should take into consideration social, environmental and economic costs and benefits. The paper reviews the philosophical approach of the Commission to noise control, and then looks at some of the economic views expressed by economists about life and the environment.It examines industries where noise control has been implemented before and after commencement of operations.

The paper stresses the need for consideration of noise emissions and controls at the planning stages for any planned activity and supports the view that noise control for industrial premises is not as expensive as many industrialists would have us believe.

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