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ROADS AND THE ENVIRONMENT

by

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ABSTRACT

This paper states briefly the benefits that roads and road vehicles render the community and then reviews their adverse effects on the environment in four main fields:- traffic noise, air pollution, vibrations and intrusion. In each of these areas the present state of knowledge is outlined and some indication given of the desirable research and development. Emphasis is placed on the need for some means of assessing environmental benefits in financial terms so that environment factors can be given their fair weight in relation to economic factors when decisions are made.

1. INTRODUCTION

The vehicles on our roads have adverse effects on our environment; they cause noise and vibrations, they pollute the air, and they intrude both physically and visually. So why do we tolerate them? The instinctive answer is that they play a major part in our lives, both economic and social.

The hard statistics prove the point.[1,2,3] The length of public roads in Great Britain in 1968 was about 328,000 km (including some 800 km of motorways, 13,600 km of other trunk roads and 32,500 km of principal roads). There were about 14.4 M vehicles with current licences (including some 10.8 M cars, 1.3 M motorcycles and 1.6 M goods vehicles). These vehicles covered about 191 x 10^9 vehicle-kilometres and in so doing carried 90.7% of the passenger traffic and 83.5% of goods traffic by weight. Even allowing for the longer average journey lengths for rail and sea traffic by considering goods carried on a tonne-km basis, road transport still carried 58.3%. Roads in urban areas comprised in 1966 only 32% of the total length but carried 55% of the vehicle-kilometres.

The estimated total expenditure on road transport in 1968 was £6370 M, ie some 17.4% of the Gross National Product. The cost of new construction, improvement and maintenance of roads was £533 M. The receipts by Central Government for fuel and purchase tax and vehicle licences were £1510 M.

Roads and road vehicles therefore play a massive part in the life of the country and the indications are that the amount of road traffic will increase. Current estimates[4] forecast an increase compared with 1968 of over 70% in vehicles and vehicle-kilometres by 1980 and over 140% by 2000. The construction of new and improved roads has so far been mainly rural and by about the end of 1972 will result in some 1600 km of motorways and another 1600 km of dual carriageway trunk roads. Tentative plans for England given in the White Paper[5] of May 1970 for the late 1970's and 1980's include at least another 3200 km of

new or improved inter-urban roads to motorway and dual-carriageway standard together with numerous improvements to other roads. The total amount to be spent on inter-urban roads in England would be over £4,000 M, including the cost of completing the present programme. With this construction it is anticipated that real congestion on the inter-urban trunk road system as a whole would be virtually eliminated. The urban situation is less easy to describe because road construction in the major urban areas will result from general land use and transportation studies in each of the urban areas involved. However, an increasing proportion of the Roads Programme is being devoted to urban roads. At present under 40% of the total is being spent on urban roads: in the 1980's it is likely to be over half.

We are therefore faced with the prospect of increasing use of road vehicles despite the deterioration of the environment, particularly in urban areas. How then do we balance the benefits of the motor vehicle with its adverse environmental effects? The difficulty is the old one of not being able to compare like with like. The benefits of the motor vehicle can largely be expressed in monetary terms ie the saving in cost of a given journey, or the saving in time which can be expressed as a monetary value. Some disadvantages, eg the cost of accidents, can already be put in monetary terms and taken account of in reaching decisions. There is a need to express environmental values in financial terms, both the benefits of an improved environment and the costs involved in obtaining it. Such information would be of value in assessing the desirable long-term standards and how they may be achieved, and also in the shorter term in giving environmental factors their fair weight in relation to economic ones when particular schemes are assessed.

The aim of this paper is to review four particular aspects of road traffic (noise, air pollution, vibration and intrusion) and to state what is known about their cause, effects and desirable levels; and in particular what is known about what it might be worth spending to reach these levels, and what measures and costs would be involved in so doing.

2. TRAFFIC NOISE

2.1 Introduction

The Working Group on Research into Road Traffic Noise was formed in 1969 and includes scientists and engineers from major organisations doing research in the field. The Group has prepared an authoritative Review of Road Traffic Noise,[6] on which the following summary draws heavily. Readers seeking more detail should refer to the review, its references and the list of research projects.

The final Report of the Committee on the Problem of Noise,[7] which was presented in July 1963, drew attention to the serious problems due to noise, and in particular to the noise caused by road traffic. Since 1963 the number of vehicles on our roads has increased by about 40%, and estimates of the present extent of the noise problem are given below.

Although individual noisy vehicles can be a particular nuisance in quiet areas and at night, the general problem is the fluctuating roar made by streams of traffic on busy roads. This section therefore describes briefly the noise characteristics of individual vehicles, how they combine to form traffic noise, the nature and extent of the effects, the prospects for reduction and the desirable research.

2.2 Noise from individual vehicles

Systematic data are now becoming available on the spectral distribution and overall noise levels due to various types of vehicle and how the noise is affected by the vehicle speed, gear ratio and acceleration.

There is also a good understanding of the contribution to the noise level made by the power unit, the inlet, exhaust, etc and how these contributions are affected by engine design and operating conditions. Figs 1 and 2 show the noise levels produced by a typical saloon car and heavy goods vehicle at various operating conditions. Also shown on the figures are typical test levels for these vehicles obtained by the method of BS 3425 (1966) and the corresponding levels permitted by Regulation 23 of the Motor Vehicles (Construction and Use) Regulations. A complete list of the latter levels is given in Table 1.

TABLE 1

Maximum permitted sound levels – Regulation 23 The Motor Vehicles (Construction and Use) Regulations

	Class or description of vehicle	Maximum Sound Level – dB(A)
1	Motor cycle with a cylinder capacity not exceeding 50 cc	77
2	Motor cycle with a cylinder capacity exceeding 125 cc	86
3	Any other motor cycle	82
4	Goods vehicles with a maximum gross weight exceeding 3½ tons:	
	Motor tractors; Locomotives; Land tractors; Works trucks; Engineering plant; and Passenger vehicles constructed to carry more than 12 passengers, exclusive of the driver	89
5	Any other passenger vehicle ie those constructed to carry not more than 12 passengers, exclusive of the driver	84
6	Goods vehicles with a maximum gross weight not exceeding 3½ tons; and any other vehicles not classified above	85

Most new saloon cars are well under the 84 dB(A) limit, which is only reached by some sports and high performance cars. The heavier goods vehicles, however, are in some difficulty with the 89 dB(A) level.

The main source of noise is the diesel engines of heavy commercial vehicles. In recent years the trend towards larger cylinder bores and higher operating rpm has increased noise levels. A development programme is required not only to achieve some reduction of noise but also just to maintain present levels. In the long term there are prospects for large reductions by radical improvements in the structural design of engines, the design of engine enclosures, and in various detailed developments. Tyre and road surfaces may become the principal vehicle noise source if engine and exhaust noise are reduced, but the mechanism of road-tyre noise generation is not fully understood.

2.3 Traffic noise

The effects of traffic volume and speed on noise levels are fairly well understood, together with the attenuation with the distance of the observer from the road. The influence of the noise of individual vehicles on the overall traffic noise level is less well understood. Further research is required on this as well as on the effects of gradients and intersections. Considerable information is available on the effects of elevated and depressed roads, and to a lesser extent of noise barriers. Some measurements are available on the general

levels of noise in urban areas, which are caused by contributions from numerous individual roads, but again more data are required. There is a reasonable understanding of the attenuation offered by building facades, particularly windows.

Fig 3 shows a representative curve for L_{10} (the sound level exceeded 10% of the time) plotted against traffic flow in vehicles per hour for freely flowing traffic. The levels are approximate ones taken from a number of references; levels in particular circumstances may vary by several dB in either direction. In particular the levels will be substantially higher where there is a contribution from hill climbing, accelerating or braking. To give an indication of the types of road corresponding to the various traffic flows the recommended flows for both rural[8] and urban[9] roads are marked on Fig 3. In general the steady speeds increase on the larger roads with the higher traffic flows.

A point to be noted is the fairly slow increase in L_{10} as traffic flow increases. This implies that the area affected by noise may be minimised by concentrating high flows on a few capacious roads, rather than on a larger number of roads each carrying a moderate flow. Fig 3 also gives an envelope curve for the operating cost in pence per vehicle-kilometre for rural roads, together with an indication of the range of economic flow on representative types of road. This cost takes into account both the capital costs of providing the road and the costs of operating the vehicle. The curve shows that high flows on capacious roads are economic, as well as advantageous from the noise aspect.

2.4 Effects of traffic noise

Our responses to noise are influenced by a multiplicity of factors, and, as a result, are extremely complex. Loudness, temporal variations of loudness, the noise spectrum, our location and activity, who is responsible for the noise, emotive aspects, and so on, all interact to affect our total response. All these factors are themselves complicated by our inherent ability to adapt to a wide variety of environments. Furthermore, the total environment is seldom ideal and noise may be only one of the undersirable factors. The main effects of traffic noise are:-

Annoyance in homes

The London Noise Survey[10] measured noise levels at 540 sites and sought the subjective reactions of 1,300 residents; 30% claimed to be very disturbed by traffic noise. This was the noise most frequently heard and, at more than 80% of the sites, produced the highest levels. Annoyance from traffic noise arises in many ways:- amongst the more obvious are difficulty in going to and remaining asleep, interference with speech communication, having to keep windows closed, and not being able to enjoy listening to music. The resulting dissatisfaction with the noise arises from a complex interaction of psychological and sociological factors. The difficulty is to relate objective measurements of noise in decibels to subjective assessments of annoyance. A number of criteria for the latter have been proposed and include L_{10} (the level of dB(A) exceeded for 10% of the time); L_{eq} (based on the energy mean of the noise level); TNI (the Traffic Noise Index, based upon L_{10} and L_{90}); and L_{NP} (The Noise Pollution Level), based upon the mean and deviation of the noise level). A discussion of the relative merits of these criteria is beyond the scope of this paper and, for the sake of simplicity, only L_{10} is used below.

Speech interference

Speech interference from road traffic occurs in streets, offices, schools, etc, as well as in homes.

There are a number of methods by which speech interference can be rated, ranging from calculation of articulation index, through the simpler Noise Rating, Noise criterion and average band pressure level methods, to appropriately weighted sound level measurements. Speech interference starts at a noise level some 18 dB below the speech level and intelligibility is totally lost when the noise level exceeds the speech level by 12 dB. For example a noise level of about 58 dB(A) allows conversation at 1.3 m at normal voice level and reasonably satisfactory telephone conversation, a minimum requirement for offices but well above that permissible in conference-rooms and class-rooms.

Physiological effects

There is no reason to suppose that exposure under normal conditions to the noise from road traffic is any way harmful to hearing even for protracted durations of exposure, nor that it has any other direct adverse physiological effect. Indirect physiological effects, such as stress syndromes, may exist, but it is impossible to draw a conclusion in the context of traffic noise without further study.

Human performance

There have been numerous studies of the effects of noise on human performance and these indicate that simple task performance is not affected at levels below about 90 dB(C). None of these tests appear to have been conducted under conditions appropriate to road traffic. But this level is much higher than those likely to be caused by road traffic in offices or factories and interference with the performance of routine tasks is unlikely. The main problem, as indicated above, is in communication by sound, and in complex task performance particularly when constructive thought is involved.

Sleep interference

Sleep interference is an element in annoyance in homes. This is a particularly difficult field in which to obtain numerical data but there is evidence that, as in other effects, temporal variations of level are more important than the average level.

2.5 The choice of traffic noise levels

Although there is a fair understanding of the noise levels that constitute annoyance in the home and interference with other activities, the monetary value of eliminating or alleviating these conditions is uncertain. Various techniques, such as social surveys and house valuation, have been tried or proposed and further work in this field is needed. However we must realise that this work may not yield clear answers on desirable noise levels nor, even if it does, will these answers necessarily be the 'right' ones.

People exposed to noise become to some extent conditioned to it and will therefore place less value on a reduction than people used to a quieter environment. If our long term aim is to provide a desirable environment (although by no means a perfect one) we should probably be aiming at quieter levels than those just acceptable to people accustomed to fairly noisy ones.

In principle traffic noise problems can be alleviated by

1. Quietening the individual vehicles
2. Resticting the nature or volume of traffic

3. Designing the road suitably, ie placing in cut (or even in a tunnel) or using noise barriers

4. Using distance as an alleviator

5. Designing buildings suitably both in general layout (ie arranging for areas sensitive to noise to face away from the road) and in detail design (eg use of insulation)

If a new town or urban area is being planned, or an existing one substantially re-developed, all these measures are in principle available and it should therefore be possible to ensure a reasonable environment. But before the roads and buildings can be designed suitably, assumptions have to be made about the probable future characteristics of vehicles and traffic.

However, even if we assume that new developments are well designed, there will remain the massive problem of the present urban fabric. The housing replacement rate is of the order of 1% per annum (the other 1% or so of new houses adding to the total) so that the majority of our present homes may be much the same in 20 or 30 years time as they are today. What can be done to improve their environment?

Apart from the improvement of window insulation to existing buildings, 3, 4 and 5 are not applicable. Even noise barriers will rarely be practicable in an existing situation. Some improvements can be made under 2 (eg by banning commercial vehicles in residential areas at night, and by concentrating flow as much as possible in a few main routes to reduce to the practical minimum the flows in residential areas) but cannot be expected to have a large and general effect, particularly in view of the expected growth of traffic.

There are therefore only two general ways of improving the noise environment in the majority of our houses in the next decade or two. One is to quieten the vehicles and the other is to insulate the houses, which means double glazing plus in many cases a ventilation system. In the short term insulation will have to be used as a palliative in some areas. In the longer term the relative economics of these two alternatives could be assessed but there are two arguments (in addition to the argument in principle that the vehicles make the noise and should therefore be the means of reducing it) in favour of quietening the vehicles. Both of these arguments are relevant to the standards to be adopted for new developments as well as the means of improving existing ones.

The first is the doubt, again as a matter of principle, that people should be forced to protect themselves in their own homes by double glazing. In the winter this does not matter – indeed it could be an advantage when thermal benefits also are considered – but in the summer one should surely be able to sit in one's home with ordinary single glazed windows and with them open.

The second relates to people not in buildings, ie to people in their gardens, walking in urban streets, town centres, parks, etc. Insulating buildings does nothing for them. The only way of producing a significant and general effect is to quieten the vehicles.

But the question is how much to quieten them? A balance has to be struck between environment and vehicle design, and has to be based upon judgement, practicability and cost, even if rigorous cost/benefit analysis is not possible. The following criteria are therefore suggested as targets for detailed investigation:- The majority of the population (say 80 to 90%) when at home in rooms fronting onto the road should be able most (say 90%) of the time during the day to conduct a conversation with ordinary windows open. There are various degrees of speech interference. At the level of 50 dB(A) recommended by the Wilson

Committee for daytime in busy urban areas conversation is comfortable and the background noise, although noticeable, is not intrusive. At 55 dB(A) conversation in a normal voice even at distances of a metre or so is becoming difficult. The achievement of 50 dB(A) is desirable, with 55 dB(A) as an upper limit. Assuming 10 dB insulation for an open window implies a level of 60 to 65 dB(A) at the facade. This is in reasonable agreement with the L_{10} values deduced by BRS from their social survey which indicated that noise is unsatisfactory for L_{10} values above 65 to 70 dB(A) in urban areas. Conditions outside the house would also have to be considered. A level of 55 dB(A) at the front door would be desirable but 60 dB(A) probably acceptable. For houses with gardens an external criterion might also be required, at least for areas used for social purposes. The same levels as indoors would be desirable, but a somewhat higher level, perhaps 55 dB(A) might have to be accepted, and that in areas screened by the house. An internal criterion would also be required for the night-time, based upon a sleep interference level and assuming closed curtains and possibly windows only slightly open.

We should choose a typical distance from the edge of the carriageway to the facade of a house (5–10 m) and aim to arrange vehicle noise levels so that the traffic noise produced at these distances is less than the critical value for this high proportion of the population taking into account the relationship between traffic densities and population densities on the roads of the whole country.

If then a building is a) on a more heavily trafficked road, b) is set nearer the road than the typical value or c) is used for some noise sensitive purpose such as music, teaching or commerce, extra insulation will have to be provided in the building itself. If on the other hand the building is 1) set further back from the road than the typical distance or 2) is situated on a less heavily trafficked road then the occupants will enjoy a quieter environment. An attempt is made below to assess the percentage of residential road mileage now exposed to various noise levels, and how the situation would be affected by changes in vehicle numbers and noise levels.

2.6 The scale of the problem

Approximate estimates of the percentage of the residential lengths of roads in urban areas exposed to various noise levels can be made by combining (1) data on the lengths of residential development on Trunk and other classes of road from Ref 11 (2) data on the traffic flows on the same classes of road from Ref 12 and (3) a relationship between noise level and vehicle flow from various sources including Ref 10 and shown on Fig 4.

The results are shown on Fig 5 both for 1970 and for the forecast situation in 1980, assuming that individual vehicles make the same noise in 1980 as in 1970. Similar estimates have been made assuming certain changes by 1980 in the noise levels of all individual vehicles. The results are summarised in Table 2.

There are uncertainties involved in the estimates of absolute levels given in Table 2, but the size of the percentages calculated for 1970, plus the results of the London Noise Survey, leave little doubt about the widespread nature of the problem. There is a clear need for a substantial survey of current noise levels, and how the public regards them, to provide a more factual basis for planning purposes.

The estimates of the effects of changes in traffic volume and the noise of individual vehicles are however likely to be relatively accurate. By 1980 the percentage of roads affected will increase if present trends continue. A reduction of 5 dB in the noise of all individual vehicles would more than compensate for the expected growth in vehicle numbers. A reduction of 10 dB would bring the majority of urban

roads down to a reasonable level. The next section examines the economic case and technical feasibility of doing this.

TABLE 2

Percentages of urban residential roads exposed to L_{10} of 60 and 65 dB(A)

Situation		60 dB(A)	65 dB(A)
1970		85	47
1980	No change in noise levels of individual vehicles	92	61
	All vehicles 5 dB quieter	61	29
	All vehicles 10 dB quieter	29	11

2.7 Economic aspects

If we accept that a facade level above some datum level of L_{10} is undesirable and wish to represent this dis-benefit financially, we must place some monetary value on the number of decibels above the datum level of L_{10}, at which the dis-benefit is zero. A rough indication of the order of magnitude of the numbers involved may be obtained by selecting an upper limit for L_{10} at which the house is clearly uninhabitable, and therefore a 100% loss, and assuming some plausible shape for the curve joining the two points. Loss of hearing due to long term exposure commences at some 85 to 90 dB(A) and conversation would be impracticable even at lower values. Allowing 10 dB(A) insulation for an open single glazed window suggests a facade level of about 95 dB(A). This may well be too high as some buildings have been evacuated as a result of traffic noise for which the L_{10} would not exceed 85 to 90 dB(A).

Let us assume, therefore, zero penalty at 60 dB(A) or 65 dB(A) and 100% penalty at 90 dB(A) with, for the sake of simplicity, a linear relationship for intermediate levels, and associate these values with the 1970 data of Fig 5. A mean noise level can be determined from Fig 5 for the noisiest 10% of residential roads and converted into a penalty expressed as a percentage loss in the values of the houses along these roads. Corresponding percentage losses can be estimated for the other 90% of the residential roads in 10% bands, and the percentage losses for the 10 bands averaged to give an estimate for the whole urban area in the country. We find that the average loss is 19% for a datum level of 60 dB(A) and 9% for 65 dB(A).

Assuming 15 M houses in urban areas at an average value of £5,000 each the total dis-benefits amount to £14,200 M and £6,750 M respectively. The corresponding annual values would be £1,420 M and £675 M at a 10% interest rate, or £710 M and £338 M at 5%. They might be reduced somewhat on the grounds that only the part of the house facing the road would suffer the estimated percentage loss. Also the accuracy of the cost estimates must be less than that of the percentages given in Table 2.

It is however clear that the sums involved are probably in the order of hundreds, rather than tens, of millions of pounds per annum. Also the estimates refer only to the loss of amenity for homes in urban areas. There will be additional sums for amenity in rural areas and in streets, and for effects on teaching and commerce.

How are the costs of quieter vehicles likely to compare? Ref 6 suggests that the cost of quietening by some 10 dB(A) the commercial vehicles over 1½ tons unladen weight is unlikely to exceed 5% of the cost (excluding wages) of providing and operating them, ie about £50 M per annum. If a similar figure applies to cars and other vehicles the total cost would be about £250 M per annum.

These figures, rough as they are, indicate the case for a serious investigation of the prospects of reducing the noise of individual vehicles.

2.8 Vehicle noise reduction

The time taken for the design, development and production of a new road vehicle is at least five years. Reduced noise levels to take effect for new vehicles in 1975 would just allow reasonable time for the development of known techniques and their incorporation into production vehicles. It would not however, allow time for substantial basic research and the incorporation into production vehicles of radical design changes resulting from research. With these considerations in mind there should be no serious technical problems or economic penalty in reducing the levels for all cars from 84 dB(A) to 80 dB(A) by 1975, except possibly for some sports cars. Indeed as many conventional saloon cars are already within 80 dB(A) an earlier change could be both desirable and necessary to prevent any deterioration in the meantime. For current types of heavy commercial vehicles the lowest practicable target over the next five years is probably a reduction from the present 89 dB(A) to 86 dB(A), as many are now only marginally meeting the 89 dB(A). For the heavier and more powerful commercial vehicles now being developed even the maintenance of 89 dB(A) will be a significant development task particularly since current trends dictated by considerations other than noise (eg low torque, high-speed engines and the reduction of atmospheric pollution) are not necessarily compatible with low-noise design.

Reductions approaching 10 dB(A) will take longer. Assuming that the levels suggested above are implemented by 1975 the next logical date is about 1980, which would allow five years research from 1970 followed by five years for design, development and production. The first target for that date would be to achieve for commercial vehicles a level of 80 dB(A). At urban motorway speeds (circa 80 km/h) coasting noise can currently reach 85 dB(A) and low-noise design will require attention to both the vehicle and the vehicle/road interface.

A reduction for cars to about 75 dB(A) by 1980 could be achieved without serious problems. This represents a 9 dB(A) reduction in current regulations, but, as most saloon cars already achieve about 80 dB(A), only a 5 dB(A) reduction on present conditions. An effective reduction of 10 dB(A) would imply reducing the level to about 70 dB(A). This would be a major research and development task, the feasibility and desirability of which warrants serious consideration.

The foregoing discussion on desirable reductions of vehicle noise levels is written in terms of the BS 3425 test, but assumes equal reductions under practical road conditions in assessing the effects of the reductions. Design trends will have to be studied to ensure that the relationship between test and road conditions does not change significantly.

Research on the reduction of vehicle noise (including an assessment of the effects on the vehicle capital and operating costs) should be pursued in parallel with research on the economic consequences of excessive noise so that by about 1975 a valid economic assessment can be made of the noise levels that it would be desirable to meet by road vehicles. Research should also proceed on the other aspects of road

building and design, traffic control and noise criteria to ensure that an overall economic balance is achieved. When this is acheived and accepted five years notice could then be given for legal levels to take effect in 1980, and this should give reasonable time for the design and development of new vehicles with the then existing technical knowledge on which regulations could be based. Accepting this time scale, the vehicle fleet could then be largely replaced by quieter vehicles by about 1985, except for public service vehicles which have longer service lives. This period of 15 years, although long, is short compared with the lives of roads and buildings. If it is practical and economic substantially to reduce traffic noise at source a decision to this effect by about 1975 would obviate the need to incorporate features in buildings which would outlast the nuisance which led to their presence.

3. AIR POLLUTION

3.1 Introduction

A thorough survey of the present position on air pollution from road traffic has recently been made by Sherwood and Bowers[13] Their paper, and the references in it, can be consulted by those wishing to enlarge upon the summary given below.

3.2 Composition and sources of major pollutants

Losses from the fuel tank, carburetter and crankcase contribute to the hydrocarbons emitted but the exhaust gas is the major contributor to air pollution.

If oxidation were complete, water and carbon dioxide would be the only products of combustion of petrol in an internal combustion engine. In practice carbon monoxide is formed in considerable quantities, some fuel remains unchanged and some is converted into other organic compounds. Also most petrols contain lead 'anti-knock' agents which cause lead compounds in the exhaust, and conditions in the combustion chamber favour the oxidation of the nitrogen in the air so that oxides of nitrogen are also formed.

Petrol engines and diesel engines give rise to similar products but Table 3 shows that the exhaust of diesel engines contains significantly lower concentrations of pollutants than the exhaust gas from petrol engines. However diesel engines emit smoke and make a nauseating smell if they are incorrectly operated or maintained.

TABLE 3

Representative composition of exhaust gases (from Pegg and Ramsden)
(Concentrations in parts per million)

	Pollutant	Idling	Accelerating	Cruising	Deceleration
Petrol engines:	Carbon Monoxide	69000	29000	27000	39000
	Hydrocarbons	5300	1600	1000	10000
	Nitrogen Oxides	30	1020	650	20
	Aldehydes	30	20	10	290
Diesel engines:	Carbon Monoxide	Trace	1000	Trace	Trace
	Hydrocarbons	400	200	100	300
	Nitrogen Oxides	60	350	240	30
	Aldehydes	10	20	10	30

3.3 Effect of pollutants

Unburnt fuel and secondary products

The constituents of unburnt pertrol are not considered to be toxic but some of them have slight anaesthetic effects in fairly high concentrations.

The gaseous products comprise a complex mixture and over 100 compounds have been identified. Most are hydrocarbons and include paraffins, olefins, acetylenes and aromatic hydrocarbons. Aldehydes are also produced and have an irritant action on the eyes and on the mucous membranes of the respiratory system. They can be smelt in very small concentrations and are largely responsible for the unpleasant smell and eye-irritating characteristics of the air in heavily trafficked streets.

Polynuclear aromatic compounds are also emitted and can persist in the air for lengthy periods. Some of them eg benzpyrene are carcinogenic but the extent of the hazard to health from these compounds in the proportions in which they are present in town air is not known. Motor vehicles are not the principal cause of carcinogens in the air and the benzpyrene content in the air even in road tunnels is much less than the content in the air in industrial areas.

Carbon monoxide

The toxic properties of this gas are due to its ability to react with the haemoglobin in the blood to produce carboxy-haemoglobin (COH_b). Carbon monoxide has a greater affinity for haemoglobin than has oxygen and it is preferentially absorbed even when the concentration of carbon monoxide is very low. The degree of absorption depends on the concentration of carbon monoxide in the air, the periods of exposure and the activity of the individual.

A recent survey of the concentration of carbon monoxide in busy city streets in Great Britain over a 15 month period showed that the proportion of time when the concentration of carbon monoxide exceeded 30 ppm was less than 2 per cent, and a concentration of more than 50 ppm was exceeded only in very isolated occasions. Other workers have found much higher concentrations than this but it seems likely that in this country a concentration of 30 ppm is only being exceeded for short periods.

Although this seems to indicate that in Great Britain carbon monoxide is not likely to leave any permanent effects or cause any acute physical discomfort its effects cannot be entirely discounted. In addition to temporary physical discomfort on particularly susceptible people, there is some evidence to show that quite small amounts of carboxy-haemoglobin in the blood may impair temporarily mental ability. However even these levels are only likely to occur in Britain to pedestrians and motorists under bad conditions eg still weather in traffic jams for periods over an hour, and to people where work requires them to be exposed for longer periods.

Oxides of nitrogen

Oxides of nitrogen are produced by the combination of atmospheric nitrogen with oxygen at high temperature and pressure such as are produced in the internal combustion engine.

Little information is available on the effects of oxides of nitrogen on the health of humans, but experiments have been made on mice and monkeys.

As the concentration of nitrogen oxides found in city streets is less than 10 per cent of that required to affect laboratory animals and the exposure is only intermittent it seems unlikely that the nitrogen oxides emitted from cars are a real danger to health, but the effect is clearly adverse and more permanent than the effect of carbon monoxide and the possibility of long-term effects from continuous exposure to very low levels of pollutants remains a worry.

Lead compounds

Vehicle exhaust gases are the major source of lead in urban areas. The lead compounds in the exhaust gas originate from the 'anti-knock' agents added to the fuel. About 2 g of the metal are present in each gallon of petrol and 25–50 per cent of this becomes air-borne in the form of a fairly stable aerosol of lead halides and oxides. The concentration of lead in the air of city streets is about 2–4 $\mu g/m^3$. This is more than 20 times the background level found in remote areas but is well below any toxic limits (the MAC for 3 hours daily exposure is 200 $\mu g/m^3$). Whether or not the levels measured are of themselves dangerous to health such increase above the natural level may result in the concentration of lead in some biological chains leading ultimately to toxic doses in some of the foods eaten by man.

Smoke

The smoke consists mainly of very fine particles of carbon. Smoke is not considered to be a health hazard in itself but carbon particles may act as nuclei both for haze formation and for the absorption of gases eg sulphur dioxide and nitrogen oxides. The latter are likely to cause damage to the lungs. Little is known about this phenomenon and as studies of air-pollution from motor-vehicles use analytical methods which require the removal of particles by air-filtration before the gases are analysed it may be a more important medical problem than has previously been suspected.

Other particulate matter

Vehicles also produce finely divided rubber from the tyres and asbestos dust from the brake-linings and clutch-plates. Prolonged exposure to asbestos dust gives rise to asbestosis and some varieties are carcinogenic. However, the amount from road vehicles is small and there is no evidence of a hazard to health.

Amenity and safety aspects of air pollution

The major components contributing to the unpleasant character of roadside air are smoke and hydrocarbons. Beacuse their emissions can be seen diesel engined vehicles get the most blame for amenity effects. The smoke from a badly maintained diesel engine is also a safety hazard because of the reduction in visibility. Diesel vehicles are also blamed for oily deposits on windscreens but these are probably caused by all types of vehicle.

Weight for weight the smoke from diesel engined vehicles produces three times as dark a stain on fabrics as smoke from industrial sources. A study of smoke from vehicles in Archway Road (a road carrying a large number of heavy commercial vehicles) showed that the concentration of particulates at the building line, although not particularly high, would have a soiling potential roughly equivalent to that existing as a background level in industrial areas.

3.4 Methods of reducing air pollution

Air pollution from road vehicles mainly affects people and things on or near the road. In general, therefore, the only feasible method of reducing the nuisance is by reducing the emissions from the actual vehicles.

By engine modifications

Pollutants in exhaust gases may be reduced by:-

a) Catalytic converters in the exhaust system

b) Direct flame after-burners in the exhaust system

c) Modifications to the carburettor and combustion chamber

d) Air injection into the exhaust manifold

e) Basic changes in engine design such as petrol injection in place of carburation

Early work was concentrated on the first two methods. Most control systems in use at present make use of a combination of (c) and (d). These involve the use of leaner mixtures – Fig 6 shows that as the air/fuel ratio is increased the concentration of both carbon monoxide and hydrocarbons is decreased but the emission of nitrogen oxides is increased. A careful balance has therefore to be kept and emission cannot be controlled solely by carburation. After the gases have left the combustion chamber air is injected as close as possible to the exhaust valve where any carbon monoxide and hydrocarbons present are hot enough to ignite immediately and their oxidation is thus completed.

Apart from their possible toxic effects lead compounds in the exhaust gases present problems because they can prevent the control devices from functioning properly. It is probable that in the near future oil companies will feel obliged to reduce the use of lead-based 'anti-knock' agents. This can be done by changes in engines so that they will run on lower octane fuels but this may well increase the emission of other pollutants. Alternative means of increasing the octane rating exist but they are likely to increase the price of petrol by about 2d per gallon.

Crank-case blow-by can be controlled by feeding the gases back into the combustion chamber.

Evaporative losses can be reduced by trapping and storing the evaporated fraction, then returning it to the engine.

Smoke from petrol engines is usually a sign that the engine is badly worn and that oil is being burnt. However in a diesel the production of smoke is more fundamental. The weight of air inducted into the cylinder on each cycle is more or less constant. To obtain an increasing output of power an increasing amount of fuel is injected and this will therefore be accompanied by a reduction in the air:fuel ratio. Eventually a point is reached where there will be insufficient air for the fuel to burn completely and smoke is produced. Fig 7 shows how the power output is balanced against smoke production. All diesel engines are fitted with a stop to limit the maximum quantity of fuel used by the engine and when the vehicle is in sound condition the exhaust smoke at this limit is invisible. The setting of the maximum fuel stop is laid down in a British Standard AU 141 and is a built-in feature of the engine. Criticisms have however been made that the smoke level in this standard is much too high.

Smoking of a diesel engine under operating conditions will occur if the maximum fuel stop becomes worn or through faults in the fuel injection system. It also occurs when a vehicle is started from the cold as diesel engines have an excess fuel device which permits the fuel input to be increased to allow for an easier start. Control of smoke in diesel engines is thus a question both of engine design and of the manner in which the vehicle is operated. Investigations into the use of additives to the fuel to prevent smoke are being made. Most of these additives contain barium compounds and significant reductions in smoke can be obtained at an additional cost of about 1d per gallon on the fuel bill. The barium in the fuel could be a potential hazard but as most of it is converted to the insoluble non-toxic barium sulphate the amounts of barium carbonate and barium nitrate produced are generally considered to be too small to have any harmful effects.

Use of alternative fuels

Liquified petroleum gas (LPG) which is a mixture of propane (C_3H_8) and butane (C_4H_{10}) stored under pressure can be used as an alternative to petrol and it is commercially available. Pollution from engines running on LPG is much less and several other advantages over petrol are claimed. The selling price of LPG is about 1/3 of petrol but the cost of petrol includes a high proportion of tax and if the untaxed costs are compared petrol is considerably cheaper. The cost of converting a car to run on LPG is about £150 but this would not be an additional item of cost if engines were specifically designed to run on LPG. However, it is not known whether LPG could become a serious competitor to petrol if it were produced on a massive scale.

Alternative methods of propulsion

Of the two types of internal combustion engines not already considered, rotary (Wankel) engines are said to emit much the same amount of carbon monoxide but rather less hydrocarbons than reciprocating petrol engines, and gas turbines to emit rather more carbon monoxide and hydrocarbons but less nitrogen oxides than a well maintained diesel engine.

The pioneer work on steam propulsion has been carried out in America by the Lear Motor Corporation who for many years have been trying to develop a steam engine suitable for cars. However, at a meeting of the Society of Automobile Engineers in November 1969 the Chairman of the Company announced that he believed that the mechanical complexity and maintenance problems were too great for such a car to be practical. In his view the only possible adaption of steam propulsion was in buses or other large road vehicles. If a steam engine were badly maintained it might emit carbon monoxide but the emission of other pollutants is very low.

The major problem at present with electric cars is their range. Electric motors are unlikely to gain acceptance as a normal replacement for an internal combustion engine until a major breakthrough in battery design or in the development of a fuel cell is achieved.

3.5 Legal aspects

Because of the acute problems presented by the Los Angeles 'smog' California has led the way in restricting the emissions from motor vehicles. Californian standards (1970) are that for the specified driving cycle the exhaust emission should not be greater than 180 ppm for hydrocarbons and 1.0 per cent by volume of carbon monoxide.

Californian legislation also requires control of crankcase emissions and evaporation from the fuel tank and carburettor. Restriction of nitrogen oxide emission is proposed.

US Federal Standards (1970) for hydrocarbons and carbon monoxide are similar to the Californian but are expressed as 2.2 and 23 g/mile respectively. Further controls are proposed in future years. Nitrogen oxides will be limited to 3 g/mile after 1973 and to 1 g/mile after 1975. Also from 1975 the emission of particulate matter will be limited to 100 mg/mile. Even with these controls it is estimated that by 1985 the levels of pollution will reach a minimum and then start to rise again because of the increase in the number of cars. At the estimated 1985 level the amount of carbon monoxide emitted will be 175 per cent of the estimated amount that was emitted in 1940.

Europe

Several European countries including Great Britain, West Germany, France, Italy, Holland, Belgium, Sweden, Hungary, Czechoslovakia, Spain and Yugoslavia have agreed to use common standard test requirements if and when legislation is introduced into their respective countries. The test procedure will consist of three types of test:-

Type I test – This restricts the amount of carbon monoxide and hydrocarbons emitted by the exhaust when tested by a test cycle. The quantity of gas allowed in the exhaust depends on the weight of the vehicle.

The restrictions proposed are, in fact, quite modest. Work at the Motor Industries Research Association has shown that the average emissions of British cars when tested in the European test cycle were 169 g for carbon monoxide and 11 g for hydrocarbons. Most British cars are in the 850–1020 kg weight range for which the limits would be 117 g and 8.7 g respectively so that the proposed limits would reduce the carbon monoxide emission by about 30 per cent and the hydrocarbon emission by about 20 per cent.

The 117 g of carbon monoxide allowed for a vehicle in the range 850 – 1020 kg is approximately equivalent to 46 g/mile which compares with the US Federal 1970 limit of 23 g/mile. The corresponding figure of 8.7 g of hydrocarbons is approximately equal to 3.5 g/mile which compares with the US Federal 1970 limit of 2.2 g/mile.

Type II test – This test consists of measuring the carbon monoxide content of the exhaust gas when the engine is idling. The quantity of carbon monoxide allowed under test conditions must not exceed 4.5 per cent of the total volume of gas emitted. This compares with a figure of 6.9 per cent for a typical vehicle without control devices.

Type III test – This relates to crank-case emission and requires that the mass of hydrocarbons contained in the crank-case gases and not re-cycled by the engine must be less than 0.15 per cent of the mass of the fuel consumed by the engine.

Great Britain

At present no legislation exists in this country for the control of invisible emissions from motor vehicles and the legislation relates only to the control of visible emissions. This has meant that the main concern has been with the reduction of smoke from diesel engines. The United Kingdom (Construction and Use) Regulations 1966 require that 'Every motor vehicle shall be so constructed that no avoidable smoke or visible vapour is emitted therefrom'. They also require that 'No person shall cause or permit to be used on a road any motor vehicle from which any smoke, visible vapour, grit, sparks, ashes, cinders or oily

substance is emitted if the emission thereof causes or is likely to cause damage to any property or injury to any person who is actually at the time or who reasonably may be expected on the road or is likely to cause danger to any such person as aforesaid'. Further aspects of the regulations are concerned with ensuring that the excess fuel device which is used in starting the engine is properly maintained and cannot be readily operated by the driver when the vehicle is in motion.

Enforcement of legislation

Existing procedures for checking invisible emissions are far too involved for the regular checking of all vehicles or even of random checks on selected samples. The method adopted in America has been to type test each model produced by each manufacturer.

There are obvious weaknesses in this system, particularly as the manufacturer selects the vehicle for test, and there have been strong criticisms in the USA that enforcement ignores the fact that poor maintenance will generally give rise to an increase in the emissions of a vehicle that was originally satisfactory. The manufacturers claim that if proper maintenance procedures are followed emission control systems will continue to perform at the required levels. However, even quite small deviations from the proper setting of the various adjustments can create an increase in emissions.

Adequate methods for checking the emissions of vehicles in use are therefore needed if legislation is to achieve the desired effect. This is fully recognised in America and work is in progress with the development of rapid methods of assessment; one such method which it is claimed can be completed within one minute at a cost of 50 cents has already been developed for use in the State of New Jersey.

European proposals for the checking of vehicles follow the American pattern of type testing models in the country where the model is made. It is proposed that the certificate, if granted, would then be acceptable in other countries party to the European agreement.

Legislation for the control of smoke and the means of measurement already exist in this country. Really blatant cases of smoke emission can be dealt with by the police without any need for the use of smokemeters. However smoke emissions are mainly dealt with by spot checks carried out by Ministry of Transport Examiners in conjunction with the police. In the case of really bad smoking the offending vehicle is forbidden to proceed and has to be unloaded and towed away by the owner. This is a much greater deterrent than fines. Less extreme cases are permitted to proceed but the owner is warned to carry out remedial work and the Ministry of Transport check to ensure that this is done.

In 1965 about 10 per cent of the vehicles observed in spot checks were smoking sufficiently for action to be taken. The Heavy Goods Vehicle testing scheme is meant to ensure that vehicles are maintained in road-worthy condition and thus smoke emission should be reduced.

3.6 Research

A number of organisations in Great Britain have been engaged on relevant research. These include the Warren Spring Laboratory of the Ministry of Technology, the Motor Industries Research Association and the Air Pollution Research Unit of the Medical Research Council.

Further research is clearly required in several areas:-

Human health and behaviour

The identification of permanent effects that can be attributed to pollution from traffic is a difficult and complex problem and is being investigated in a large number of institutions throughout the world. The investigation of the effects of polluted air on driver behaviour has, rather surprisingly, not received much attention and there is a clear need for research in this area. Also more investigation is required on the attitude of the public towards fumes from road vehicles.

Control systems

A large amount of research on this subject is being done in America where the manufacturers are under increasing pressure to reduce emissions from their vehicles and where the limitations are already much more severe than any proposed in Europe. The possibility of more basic research, which would be complementary to the American programme, being done at a suitable laboratory should be examined.

Levels of pollution

The aim of more stringent controls on individual vehicles is to reduce the pollution levels due to traffic (ie streams of vehicles) in busy streets. We therefore need to develop a better understanding of how the levels in streets are affected by the characteristics of individual vehicles and also take regular samples of the major pollutants at a range of sites to monitor the levels and how they are affected by changes in vehicle design and other developments.

Analytical techniques

There is a need for a rapid means of evaluating whether a vehicle complies with any standards that might be set. As far as invisible emissions are concerned this is, at the moment, a very involved procedure which is quite unsuitable for checking as part of the annual inspection of vehicles. Research is therefore required to develop a rapid means of assessing the invisible emissions of vehicles.

3.7 Discussion

The general consensus of opinion among the authorities in this country in a position to judge is that air pollution from road traffic is not a serious health hazard. This conclusion has been reached because nobody has demonstrated that, in the proportions that they are found in town air, any of the pollutants have permanent harmful effects. This does not, however, mean that the possibility of long-term effects can be entirely discounted, particularly when the expected growth in vehicle usage is considered, and the possible contamination with low-level pollutants from other sources, and possible synergistic effects between various pollutants. Another point to be kept in mind when considering the introduction or modification of vehicle regulations is that it will be many years before they are fully effective.

Traffic fumes are certainly unpleasant and dirty. They cause transient health effects, aggravate chronic complaints and may affect task performance. They soil buildings and clothing. So far there has been no indication in Britain of the widespread and serious photochemical smog that has been common in Los Angeles for years, or of conditions comparable to those recently reported from New York and Tokyo. There is however a report of photochemical smog from as near home as Delft, in Holland.

In recent years road vehicles have been a minor contributor to air pollution in Britain in terms of fuel usage (the total coal and oil consumed in Great Britain in 1965 was 276 million tons coal equivalent and only

26 million tons of this was used in connection with road and rail transport). But since the Clean Air Act of 1956 there has been a noticeable decrease in air pollution due to the reduction in coal consumption for industrial and domestic purposes. Meanwhile the pollution from road traffic has been increasing and, particularly as the pollution is emitted at ground level, is likely to become increasingly significant unless action is taken to reduce emissions of pollutants from vehicles. For example, road traffic is already the major source of carbon monoxide in the atmosphere, the amount produced from petrol engines during 1965 being estimated at 5 million tons compared with 12 million from all other sources.

Estimates of financial costs of air pollution as a whole are difficult, and estimates of the contribution from a particular source such as motor vehicles even more so. Such estimates should include not only the direct economic costs (such as cleaning and medical charges, and damage to crops) but also the social ones (such as suffering due to poor health, and loss of amenity due to dirty surroundings when cleaning is impracticable). However the Programmes Analysis Unit, which is a joint Atomic Energy Authority/Ministry of Technology body, has been studying the economic aspects of air pollution from all sources, and this study should help in assessing the magnitude of the problem.

Meanwhile an indication can be given of the probable cost of air pollution due to road vehicles. Scorer in 1956 estimated the direct costs to be £16 M per annum, and since then the number of vehicles in Britain has approximately doubled. The current total of direct and social costs of air pollution due to road traffic in Britain could well be about £50 M per annum, possible somewhat less, possibly considerably more, depending particularly on the extent and valuation of the social aspects. Whatever the figure it must be expected to increase with the number of vehicles unless the characteristics of the individual vehicles are improved.

How does this rough estimate of £50 M per annum compare with the probable cost of improving the situation?

Most of the hydrocarbons and carbon monoxide comes from petrol engines. The estimated cost of meeting the proposed European controls is £8 –£10 per car ie for Britain with about 1¼ M new cars annually, say £11 M. Fuel consumption should not be adversely affected. However to improve on our present environment in the face of increasing traffic one feels that the 1970 US levels will be necessary (quite apart from export considerations) rather than the European ones. The estimated increase in the price of a new car is about £40, giving a total of some £50 M per annum, assuming no change in fuel costs.

If lead is removed from petrol cars would have to be de-rated, or the octane value of petrol uprated in another way. The latter would cost about 2d per gallon. On a consumption of some 4.5×10^9 gallons the annual cost would be £37 M per annum.

Smoke from diesel engines can be reduced by de-rating or by a barium-based fuel additive. The latter would cost about 1d per gallon which, for a consumption of 3.5×10^9 gallons, would cost £15 M per annum.

The total increase in vehicle capital and running costs could therefore, depending upon the level of improvement chosen, range up to £100 M per annum and would increase with the number of vehicles.

The costs and the benefits, bearing in mind the rough nature of the above figures, are of the same order and therefore warrant careful investigation before decisions are made.

4. VIBRATIONS

4.1 Introduction

The dynamic response of vehicles to irregularities in the surfaces of roads and bridges generates vibrations in the road structures. The transmission of these vibrations may have adverse effects on people, buildings and scientific equipment within buildings. The following summary of these topics is based upon a recent survey by Whiffin and Leonard.[14]

4.2 The generation and transmission of vibrations from road vehicles

New road pavements are required to have no irregularities exceeding 10 mm in a 3 m length. However road surfaces in time develop defects such as uneven deformation, potholes and, for concrete pavements, steps between adjacent slabs. Trenches are often cut for access to services and reinstatement is imperfect. Also many older roads were not built to current standards. Irregularities up to 25 mm are not uncommon and larger ones may occur. The impact load due to a wheel passing over an irregularity is a complex function of the size and shape of the irregularity, the vehicle speed, the vehicle size, weight and layout, and the dynamic properties of the vehicle tyres, springs and dampers. Each axle encounters the irregularity in turn and causes two or three successive blows on the road surface, which generate vibrations. The impacts due to successive vehicles will often be repeatedly applied to the same spots along the road, causing further deformation and vibration. This process, once started, can cause rapid deterioration of the surface and increasing vibration, particularly when heavy goods vehicles use a road not designed for such traffic.

Table 4 shows the vibrations recorded when a two-axled lorry was run over sections of the pavement design experiment on Trunk Road A1 at Alconbury Hill. The tests were made in 1960–1, when the surface was in good condition, but included runs over an artificial irregularity of 21 mm. The values from the flexible and concrete sections were broadly similar: for the normal surface the maximum amplitude of vibration (half peak-to-peak) was 1.8 μm and the maximum peak particle velocity was 0.25 mm/s at 3.65 m from the edge of the road: with the 21 mm irregularity the corresponding figures were several times larger, 12.4 μm and 14.7 mm/s respectively. In a further measurement without the artificial irregularity the rear wheel of the test vehicle, when passing over an expansion joint in a 200 mm concrete slab on a 76 mm hoggin base, generated an amplitude of 1.8 μm at 44 Hz (peak velocity 0.49 mm/s).

The above values may well be representative of fairly strong and stiff pavements with good surfaces and with fairly severe irregularities respectively. Corresponding data are needed for less stiff pavements for which the vibrations might be rather larger for a given surface condition. Also the above data were obtained from tests with two-axled lorries. Recently the RRL has been testing heavy articulated vehicles, which have pairs of axles with inter-connected suspension systems. When some of these vehicles travel over irregularities there appears to be a transfer of load from one axle to its companion which gives substantially higher impact factors than simple axle systems. Research is in hand to ascertain the causes of this unwelcome behaviour.

For bridges, as for pavements, the vehicle has to receive an initial disturbance, such as an irregularity in the road surface, to cause significant vibrations. The problem is however more complicated than for pavements as the response of the bridge may be important, and the vehicle and the bridge have to be considered as a combined dynamic system. The worst conditions are likely to occur when the natural frequencies of the vehicle and the bridge are similar. Most present bridges have stiff structures with adequate damping, and the dead weight is usually large compared with the vehicle weight, so that vibrations in bridges are small.

TABLE 4

Results of measurements of traffic-induced vibrations on Trunk Road A1 at Alconbury Hill (Hunts)

Flexible road sections had a surface 100 mm thick, a road base 150 mm thick and a sand sub-base 480 mm thick at the point of test
Load on rear axle of two-axled test lorry = 7.21 Mg
Vehicle speed 48 km/h
Artificial road surface irregularity was a wedge-shaped piece of timber 230 mm wide and 21 mm thick at the trailing edge.

Details of road construction	Surface Deflection measurement by Deflection Beam	*Tests on normal running surface of road*				*Test with artificial road surface irregularity in path of vehicle*							
		Vibration 3.65 m from edge of road				Vibration recorded on road surface close to irregularity				Vibration 3.65 m from edge of road			
		Accel	Ampl	Freq	Particle velocity	Accel	Ampl	Freq	Particle velocity	Accel	Ampl	Freq	Particle velocity
	μm (microns)	g	μm	Hz	mm/s	g	μm	Hz	mm/s	g	μm	Hz	mm/s
Bituminous road sections													
Asphalt surface, lean concrete base	300	0.003	1.3	23.7	0.19	0.132	71.1	21.6	9.64	0.020	10.7	21.6	1.45
Asphalt surface, rolled asphalt base	460	0.004	1.0	29.8	0.19	0.053	35.6	19.3	4.31	0.012	8.1	19.3	0.98
Asphalt surface, tar-coated stone base	480	0.001	0.4	26.0	0.06	0.077	53.3	18.9	6.33	0.009	5.8	18.9	0.69
Asphalt surface, stabilised soil base	510	0.002	0.5	30.4	0.10	0.110	71.1	19.5	8.71	0.014	9;9	19.5	1.21
Asphalt surface, dry stone base	610	0.004	1.5	26.5	0.25	0.117	73.7	20.1	9.30	0.015	9.1	20.1	1.15
Bitumen macadam surface, lean concrete base	610	0.004	1.3	22.2	0.18	0.121	68.6	23.2	9.99	0.018	7.9	23.2	1.15
Concrete roads													
250 mm slab on 76 mm hoggin		0.002	0.5	30.0	0.10					0.007	5.8	22.2	0.81
200 mm slab on 76 mm hoggin		0.002	0.5	30.0	0.10					0.016	7.6	22.4	1.07
125 mm slab on 76 mm hoggin		0.004	1.3	25.8	0.21					0.018	12.4	18.9	1.47
200 mm slab on 225 mm lean concrete		0.003	1.8	18.3	0.20					0.015	8.4	21.1	1.11

However the current trend towards lighter and more slender bridges increases the probability of significant vibrations.

There are numerous publications on the transmission of waves through elastic media and layers in connection with seismology, geophysics and non-destructive testing, but few dealing with the attenuation of vibrations over distances relevant to the transmission of vibrations from roads to buildings. However a paper to be published by T E Frydenlund of the Norges Geotekniske Institutt gives results of driving at speeds of 30 and 50 km/h a lorry with a rear axle carrying 8 Mg over eight different roads. All the roads except one had asphalt surfaces but were of less robust construction than those at Alconbury. The maximum peak velocity of the vertical vibration at the same distance from the edge of the road as the Alconbury Hill measurements (3.65 m) was about 1 mm/s, ie about four times the Alconbury Hill value. This difference may be due to several factors including the lighter construction and, possibly, a lower standard of surface smoothness. Measurements were also made with artificial irregularities in the form of wedges as at Alconbury, but of height 50 and 100 mm. The maximum peak velocities measured at 3.65 m were about 4 and 8 mm/s for the 50 and 100 mm wedges respectively, and appear consistent with 1.47 mm/s for the 21 mm wedge at Alconbury. An indication of the general rate of attenuation with distance is given by the following examples:-

At edge of road	5 mm/s
12.5 mm from edge of road	1 mm/s
25 m from edge of road	0.5 mm/s
50 m from edge of road	0.2 mm/s

Frydenlund's results also indicated some reduction in frequency with increasing distance from the road. In one case the reduction was from some 40 Hz at 20 m to 12 Hz at 100 m.

Taking the RRL and Frydenlund's results together it appears that for surfaced pavements in Britain in reasonable condition the maximum peak particle velocity at 3 to 5 m from the edge of the road lies in the range 0.1 to 1 mm/s, increasing to 2 to 3 mm/s for roads in poor condition with irregularities up to 25 mm. Values might rise to 5 mm/s for the occasional pothole, but one would not expect this to remain unrepaired for long.

4.3 Effects on buildings

A number of measurements of vibrations in buildings have been made in Britain by the Building Research Station, RRL and other organisations, usually as a result of complaints from property-owners of minor damage (such as cracking of plaster, brickwork or glass, and loosening of tiles) from some particular source of vibration. As a result of these investigations, (which included vibrations from forge hammers, machinery, blasting, pile-driving, aircraft, church-bells and domestic activities, as well as road traffic) the BRS concluded that in no case was any serious damage directly attributable to the effects of vibration alone. Cracks are common in buildings where there is no vibration. The addition of vibration may exploit an existing crack or, when for instance plaster is under stress from temperature or moisture changes, some vibration although small in itself may be sufficient to initiate a crack, particularly when repeated continually.

Fig 8, taken from BRS Digest No 117[15] shows the relation between vibration frequency and peak particle amplitude at which various levels of damage to buildings are likely to occur. Lines of peak particle velocity are also shown on Fig 8 as this has been shown to correlate well with damage to buildings.

Frydenlund suggests that the vibration velocities in the 3 principal directions be added vectorially and the resultant compared with the following limiting velocities suggested in the German Standard of September 1969:-

	Maximum vibration velocity mm/s
Buildings of historic interest, ruins, etc	2
Slightly defective buildings, cracked walls, etc	5
Buildings free from plaster cracks	10
Industrial buildings	10 – 40

If the velocities in the 3 principal directions are equal, then $\sqrt{3}$ times the vertical velocity should not exceed the values quoted. In general there is reasonable agreement between this Standard and Fig 8, but the Standard makes the point that buildings of historic value should not be subjected to vibrations as great as those tolerated by other buildings.

Both Digest 117 and the German Standard relate to continuous vibrations of the type caused by road traffic. For a small number of repetitions, as might occur from blasting, the threshold of damage is higher, serious damage being likely only above 50 mm/s.

The data quoted in 4.2 for ground vibrations 3 to 4 m from the edge of the road indicated peak particle velocities up to 1 mm/s for surfaces in reasonable condition and say 5 mm/s for an exceptional irregularity. Assuming that the ground vibration is transmitted to the building without significant attenuation or amplification, and bearing in mind that most traffic vibrations are between 15 and 30 Hz, Fig 8 indicates that surfaces in a reasonable condition should cause no structural damage at all, and that roads in a bad condition could give rise to minor cracks, but nothing more serious. The data from measurements of vibrations near roads and from buildings suffering damage therefore appear to be in good agreement.

4.4 Effects on people

People are very sensitive to vibration and the literature on the subject, although by no means comprehensive, is extensive. Guignard, of Southampton University's Institute of Sound and Vibration Research has recently made an extensive survey of the literature.

The scales of human sensitivity to vibration provided over 30 years ago by Reiher and Meister are still widely accepted for steady state vibrations. The values for sensitivity of standing people to vertical vibration are given in Fig 9 in terms of frequency and amplitude. Lines of peak particle velocity are superimposed to aid comparison with the values quoted above. The threshold of perception corresponds to a peak particle velocity of 0.3 mm/s and a vibration is annoying if the velocity exceeds 2.5 mm/s. These values refer to continuous vibrations. For transient vibrations, like those produced by heavy road vehicles, it is likely that greater velocities are required to produce a given sensation. Recalling again the values quoted in 4.2 for a distance of 3 – 4 m from the edge of the road the indication is that the range of vibration velocities from a pavement in reasonable condition (up to 1 mm/s) will be imperceptible or just perceptible, and that the range due to a pavement in poor condition (up to 2 – 3 mm/s) will be clearly perceptible and possibly annoying. Exceptional potholes causing 5 mm/s would be in the unpleasant category.

The numerical data are therefore in good agreement with the subjective impressions that in particular conditions vibrations from road traffic are objectionable to people. They also emphasise that people are

more sensitive to vibrations than buildings and explain why vibrations that are tolerable to the occupants rarely cause damage to the buildings.

4.5 Effects on instruments

Sensitive instruments in laboratories may be mounted on special frames attached to a solid wall of the building or mounted on a piled foundation to protect them from vibrations generated in the building, even from people walking and shutting doors. These methods would not be satisfactory in the presence of significant ground vibrations due to traffic or other sources, and in such cases other precautions, possibly housing the equipment away from roads, would be needed.

In 1961, the Instrument Society of America recommended the following limiting values of acceleration:-

(i) 0.001 for dimensional and electrical-physical reference standards (0.001 g = 6.2 μm at 20 Hz, particle velocity 0.78 mm/s)

(ii) 0.002 g for dimensional working standards (= 12 μm at 20 Hz and particle velocity = 1.56 mm/s)

(iii) 0.003 g for electrical physical working standards (= 19 μm at 20 Hz and particle velocity = 2.34 mm/s)

Steffens[16] also quotes the information given in Table 5 which is attributed to White. The information given in Table 6 was obtained recently by the RRL.

If the road is of reasonably good riding quality (eg the Alconbury Hill standard,less than 2 μm amplitude and 0.25 mm/s velocity) it will be seen that many laboratory instruments are unlikely to be disturbed even if quite close to the road. But a more remote situation or special precautions in mounting are needed for the more sensitive equipment.

4.6 Conclusion

Vibrations due to road traffic on pavements with reasonably smooth surfaces should be barely perceptible to people even at distances of 3 to 4 m from the edge of the road, and should cause no harm at all to buildings, although sensitive scientific equipment might be affected. Vibrations from roads in poor condition can certainly be annoying to people and cause or aggravate minor damage in buildings.

More quantitative data are needed on the effects of various road and vehicle characteristics on the generation and transmission of vibrations. This applies particularly to the characteristics of coupled suspension systems, and to the sizes and shapes of irregularities which cause vibrations on the threshold of human perception at various distances from the road.

New roads in Britain are among the smoothest in the world and it is doubtful if there is a case for higher standards to reduce the generation of vibrations. The problem is one of maintenance, both of the older roads, and of the more recent ones as they deteriorate under traffic or are disturbed for access to services beneath them. The extent of the effects of vibration on people and buildings is uncertain, but is probably a collection of local conditions (eg particular areas of poor surfacing, very heavy traffic or sensitive buildings) rather than a general one like noise. A systematic survey is desirable to establish the scale of the nuisance and help estimate the financial benefits of improved standards of maintenance. The sum spent on maintenance of road surfaces in urban areas in Britain is probably about £20 M per annum, but this includes

TABLE 5

Sensitivity of some laboratory instruments to vibrations

Type of instrument	Displacement μm	
	Satisfactory	Excessive
Nettler analytical balance	R	0.1
Sartorius analytical balance	0.2	0.8
Leeds-Northrup reflective galvanometer	0.02	0.1
Zeiss interferometer microscope	R	0.1
Electron microscope	0.5	12.0
Photo-microscope	1.25	11.5
Watts microptic autocollimator	0.05	0.07
Haas standard barometer	0.25	0.7

R indicates that the instrument can be used only during periods of little vibration

TABLE 6

Additional information on the sensitivity of laboratory instruments to vibrations

Instrument	Notes on behaviour supplied by user	Corresponding values of	
		Amplitude μm	Peak particle velocity mm/s
Phillips EM300 electron microscope	Makers state that maximum permissible vibratory speed on floor is 35 μm per second. (If frequency of ground vibration were 20 Hz amplitude would be 0.28 μm)	0.28 (Limiting value)	0.0035 (Limiting value)
Electronic apparatus of general character	Undisturbed by vibrations of the order of 60 micro inches at 10 to 20 Hz caused by road and rail traffic	Not disturbed by:- 1.5	0.19
Perkin Elmer RMV7 mass spectrometer	Could not be used when vibrations of 500 micro inches at 500 Hz were present. Pump equipment had to be mounted separately from base of instrument.	Made unusable by:- 13	40
EM6G electron microscope	Made unusable by a vertical vibration of 0.02 inches at 10 Hz	Made unusable by:- 510	32
Apparatus unaffected by vibrations due to traffic close to building			
AEI MS2H mass spectrometer			
Phillips X-ray crystallographic apparatus			
Contact potential measuring apparatus			
Optical extensometers used with creep apparatus, associated testing machines were mounted on isolated plinths	Readings became impossible under vertical vibrations of 0.02 inches at 50 Hz	Made unusable by:- 510	160

work done for structural repair and restoration of skid resistance as well as improvement of surface smoothness. Local authorities have recently been under pressure to reduce expenditure on road maintenance and there have been complaints of deterioration in surface conditions.

5. INTRUSION

5.1 Introduction

This section deals mainly with physical and visual intrusion. The discussion is confined largely to roads, without drifting into the wider questions of urban planning and land use.

5.2 Community separation

At the strategic level physical intrusion raises the whole question of the presence of major traffic routes in an urban area. A highway which fulfills its primary function of passing large volumes of traffic at an efficient speed in its own direction is a potential barrier to travel traffic across it. The direct economic penalty of increased journey lengths and times for people whose business or pleasure takes them from one side to the other can be costed and will presumably be offset against the economic gains of the people travelling along the road. But there is also the less tangible effects of the possible severance of one part of a community from another. These effects will clearly depend upon the location of the road and the size of the areas left after the division. One usually pictures the effect as an adverse one but it can be harmless eg in confirming the demarkation between an industrial and a residential area, and could even be of benefit, eg in protecting a high-quality area from creeping decay from an adjacent one of lower quality.

The adverse effects of separation can be minimised by the provision of adequate ways of crossing the major road. The practicability and cost of such crossings depends not only on the location of the road but also on its level. If the road is at ground level the crossings (except for access points which will usually be 1 or 2 km apart even in urban areas) have to be either underpasses or overbridges which are expensive both in terms of space and construction cost. If the road is an elevated viaduct the construction cost is high and, although the ground level pattern of local streets may be almost undisturbed, the sight of the viaduct may not blend with the environment, be it residential or city centre. The full impact of elevated roads and their complicated junctions is barely reaching Britain. There are numerous examples abroad, particularly in the USA. Sunken roads are an attractive alternative; the visual problem is less and the cross-roads can be carried on ground-level bridges.

The next logical step is to put the road in a tunnel and thus absolve the surface level from intrusion except at access points. So far tunnels have usually only been used to carry highways under particular obstacles, usually rivers.

Their more general use for roads depends critically on the costs. In recent years the costs of tunnelling have been decreasing due to improvements in excavation and lining techniques, and a study is being made of the probable cost of tunnels in relation to the costs of various types of surface roads. The present indications are that for construction costs alone a highway tunnel, even in favourable ground such as a soft competent rock or a firm clay, will be more expensive than an elevated road. However when land acquisition costs exceed about £100,000 per acre the total construction and land cost of an elevated road might well exceed that of a tunnel. The inclusion of environmental values would favour the tunnel even more. Further away from city centres and in ground less favourable to tunnelling the position is less clear. In many cases plans

for surface roads take full advantage of 'soft' areas either due for re-development or 'blighted' by the knowledge of long-term plans for a new road. In either case the current acquisition cost of the land is low enough not to justify a tunnel. But if a tunnel were to be built this land could be developed and in say 10 years time would have a very high value – perhaps high enough to justify the tunnel rather than the surface road. In such circumstances what land value should be used in choosing between a surface road and a tunnel, the current one or the potential future one? The instinctive answer is the latter, but this raises aspects of economics and policy which would require careful study by the public authority concerned.

Various aspects of highway tunnels require further investigation before their use on a substantial scale in Britain could be firmly advocated. These aspects include the design and cost of junctions, running costs, breakdown and other emergency procedures, ventilation, and the effects on surface traffic during construction. But it is relevant that the recent OECD Conference on Tunnelling in Washington anticipated a substantial increase in tunnelling for roads and other urban developments and urged member governments to expedite research, education and other preparations to this end.

5.3 Pedestrian/vehicle conflict

At the tactical level physical intrusion involves the presence of both people and vehicles at the same time and place, and this raises the whole question of the status of the pedestrian and the quality of his environment.

This environment, in addition to noise and pollution, includes safety and delays and the less tangible effects such as pleasant surroundings, weather protection and the mental pressures of the need for constant vigilance, which will increase as vehicles get quieter. Crossing many roads is not easy for the physically fit and mentally determined. It is often an ordeal for the old and the young, the infirm and those carrying shopping and other loads, and even more generally in bad weather or at night. Current trends seem to be moving against the pedestrian. When roads and junctions are designed or modified to improve traffic flow the safety aspects of both pedestrians and motorists are fully considered, but in some cases the pedestrian has to follow a longer path. Pedestrian delay and amenity should be given their fair weight in an overall optimum design. The old and infirm are particularly affected as many of them do not own cars, and the bus services are reducing.

The only feasible solution appears to be separation of the pedestrians from the motorists, to their mutual advantage. This requires the provision of pedestrian streets, precincts and walkways, including full use of grade separation from vehicles, particularly at road crossings. The walkways must connect the centres of residences, shops, workplaces and transport centres; they must cater for the infirm and the use of perambulators, etc; and should desirably offer some protection from the weather. A fair knowledge is available of the requirements of such pedestrian facilities.[17,18] However much more information is needed on pedestrian habits and motivations and the RRL is tackling some projects in this field. Assessment is also needed of the circumstances in which various types of pedestrian facilities are economic, taking into account the amenity aspects of this environment as well as the more easily calculated costs of delays and accidents. Fig 10, taken from Ref 19, shows that pedestrian delays and accident risk are both increasing rapidly at flows of about 500 vehicles/hour, and that vehicles' journey speeds are also starting to fall. This flow, at which noise is also starting to become serious, has been mentioned by other writers. However the critical flow will depend on both vehicle and pedestrian flow, the use of the road, etc and guidelines would be valuable.

No estimates are given of the benefits or costs of improving the pedestrian environment, but it may well be comparable to traffic noise in importance.

Separation of vehicles and pedestrians is mainly a long-term policy. New or re-built towns (eg in Britain, Cumbernauld and Coventry) offer great scope but are limited in number. Modifications to existing situations are more difficult but improvements can be made (eg at Norwich) where the layout permits.

5.4 Visual intrusion

The extent of visual intrusion will depend upon the taste and occupation of the individual; the size, the distance and character of the object viewed; and so on. It is possible to envisage some subjective scale of visual intrusion based upon a set of ground rules deduced from the opinions of a number of people, but the development of such a scale and the attachment to it of monetary values is indeed a daunting task.

The discomfort caused by vehicle headlights at night in urban areas is presumably also visual intrusion but is probably best cured by vehicle/pedestrian separation, unless we can achieve a standard of street lighting in which the use of car headlights can be banned.

6. SUMMARY AND DISCUSSION

Consideration of the adverse environmental effects of road vehicles involves the technical aspects of the generation and transmission of the effects, of their consequences and of means of alleviation. Policies are needed on the desirable or acceptable levels and how they should be achieved. To aid these decisions data are required on the financial benefits, both physical and amenity, of improved environments and of the financial costs of achieving them.

Our knowledge of the technical aspects is extensive but by no means complete. Our knowledge of the effects on people, and the attitudes of people, is less satisfactory. Our knowledge of the financial aspects is inadequate. Considerable research is required, in particular on the human and financial aspects. To this end a substantial social survey, together with associated physical measurements, is being planned.

When assessing the financial benefits of improved environments particular attention should be paid to the physical aspects (eg working efficiency for noise, cleaning costs for pollution). This is not to be taken as a denigration of the financial values of amenity aspects but as a recognition of the fact that the latter are not quite comparable to the increased costs of vehicles and vehicle operation incurred in reducing noise and pollution. The latter are hard economic costs which will affect the distribution of effective incomes in Britain, the prices in the shops, and possibly even export prices. The benefits of reducing the physical aspects of pollution are also hard economic costs which can be directly offset against the costs of reducing the pollution. If the cost/benefit of reduced pollution is reasonable even on the physical aspects, with the amenity ones so to say as a bonus, the case will be much stronger than one based solely on the valuation of amenity.

The main conclusions reached about particular effects are:-

Traffic noise is a widespread and increasing nuisance, although not a significant threat to health. The bulk of the urban noise problem lies in the present roads, together with the residential and other property along them, which will be much the same in 10 or 20 years time as they are now. The means of improvement in

the near future are largely limited to sound insulation of windows and measures of traffic control. The latter would involve concentration of traffic into a small number of heavily trafficked roads, and restrictions on the use of heavy goods and other noisy vehicles, particularly at night. Sound barriers may help at a few locations and experiments with barriers are in hand on M1 and M4, but in most places they will be neither practicable nor acceptable. In the longer term the main prospect for substantial alleviation is reducing the noise of individual vehicles to a level which will allow reasonable living conditions for most of the community. This is likely to take 10 – 20 years to become effective, and will then in some places leave a residual noise problem which will have to be cured by building layout and construction.

Air pollution from road traffic is also a nuisance, although not so widespread as noise. Adverse effects on health are unproven but cannot be ruled out. Steps to contain, and preferably reduce, air pollution due to road vehicles are desirable and can only be obtained by reducing the output of individual vehicles. Such steps will again take many years to become effective.

Vibrations should not be a nuisance provided that the road surfaces are kept reasonably smooth, except possibly for very sensitive buildings such as ancient monuments or scientific laboratories. However the maintenance of adequate smoothness is a substantial problem to highway authorities.

Intrusion is widespread and ranges in character from community severence to pedestrian problems. The cure lies largely with the road and town planner. Guidance is needed on the circumstances in which vehicles and pedestrians should be separated.

Acknowledgement

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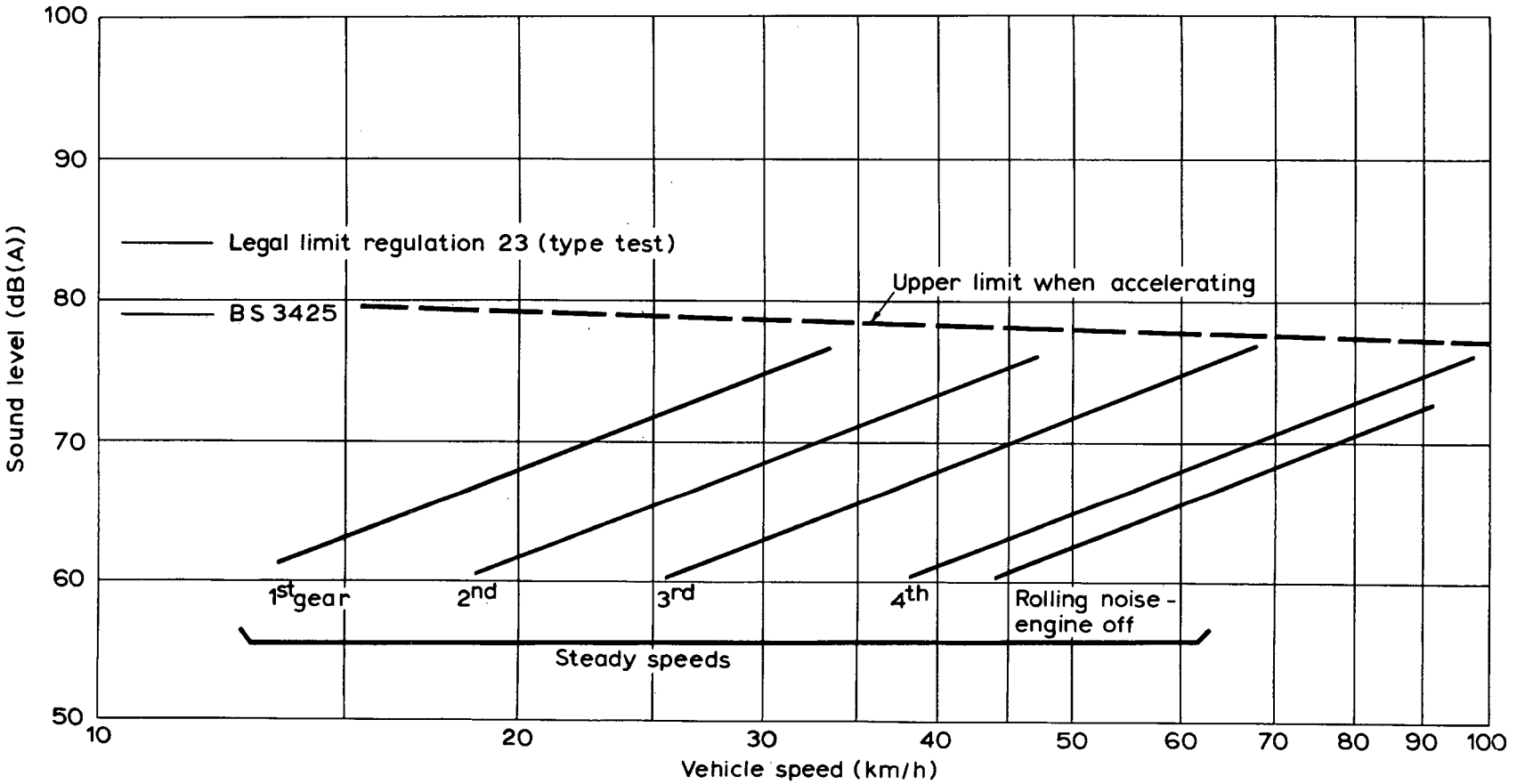

Fig. 1. SOUND LEVELS - TYPICAL SALOON CAR (PETROL ENGINE) ON A SMOOTH DRY ROAD

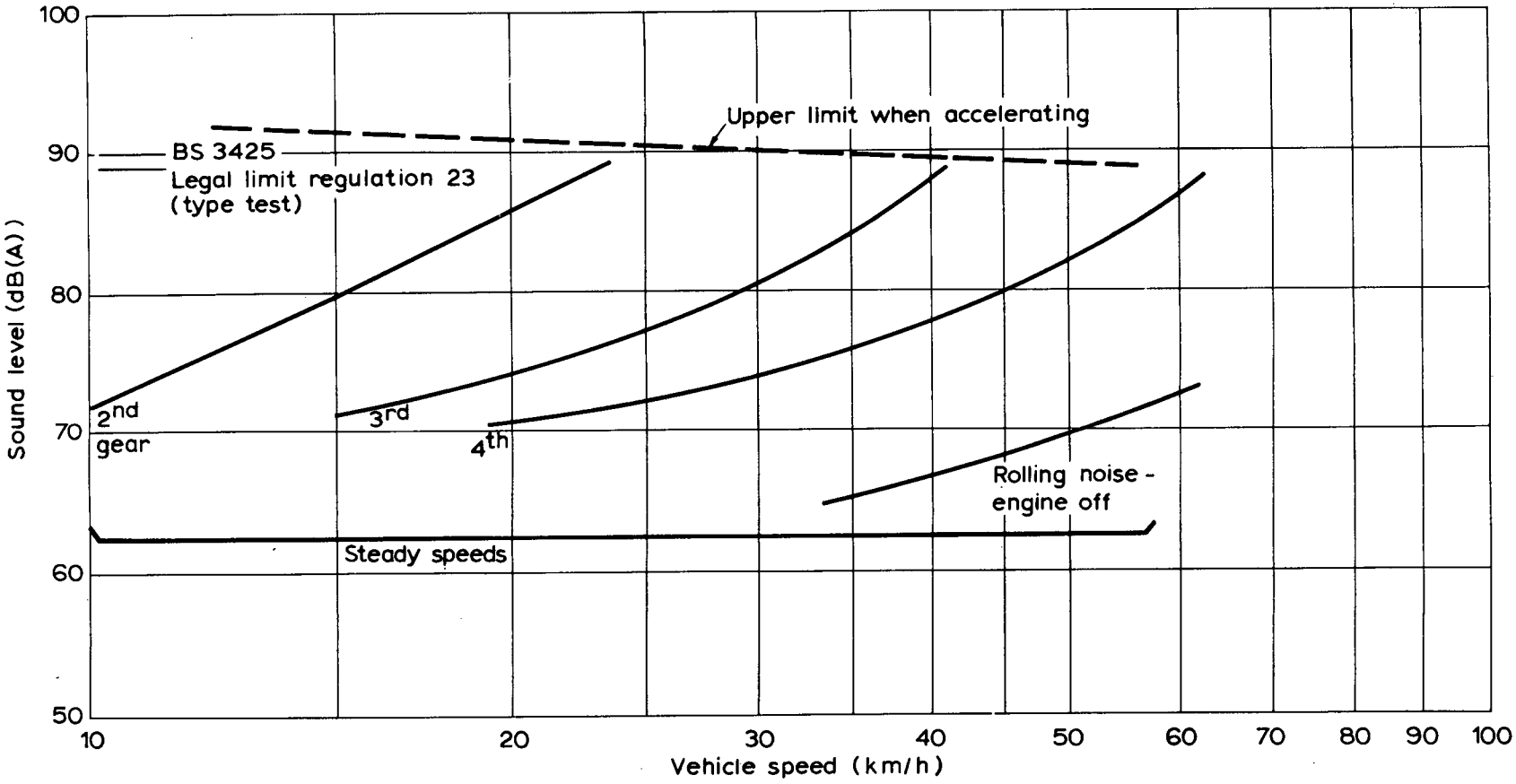

Fig. 2. SOUND LEVELS - TYPICAL HEAVY LORRY (DIESEL ENGINE) ON A SMOOTH DRY ROAD

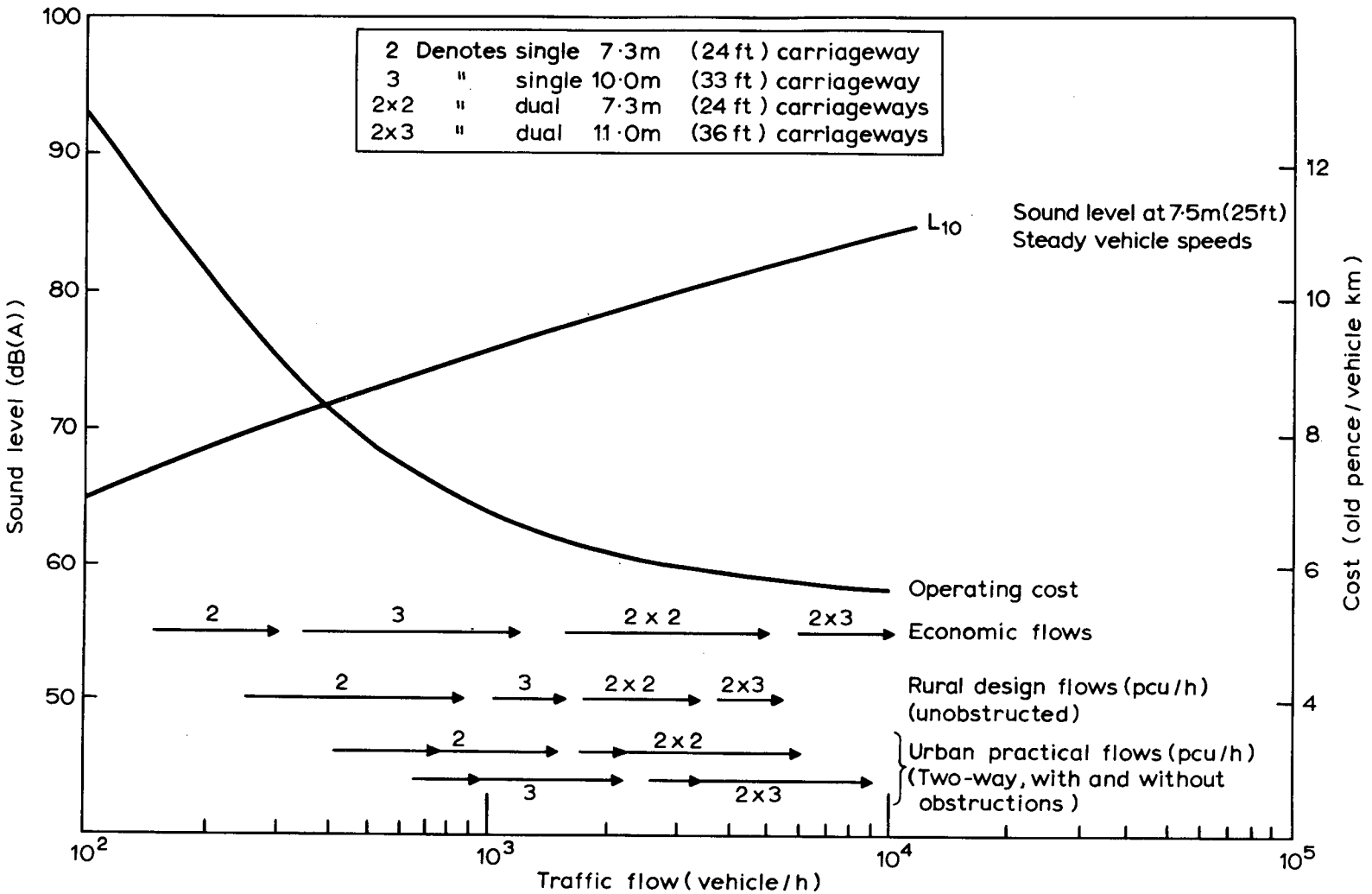

Fig. 3. TRAFFIC NOISE AND OPERATING COSTS

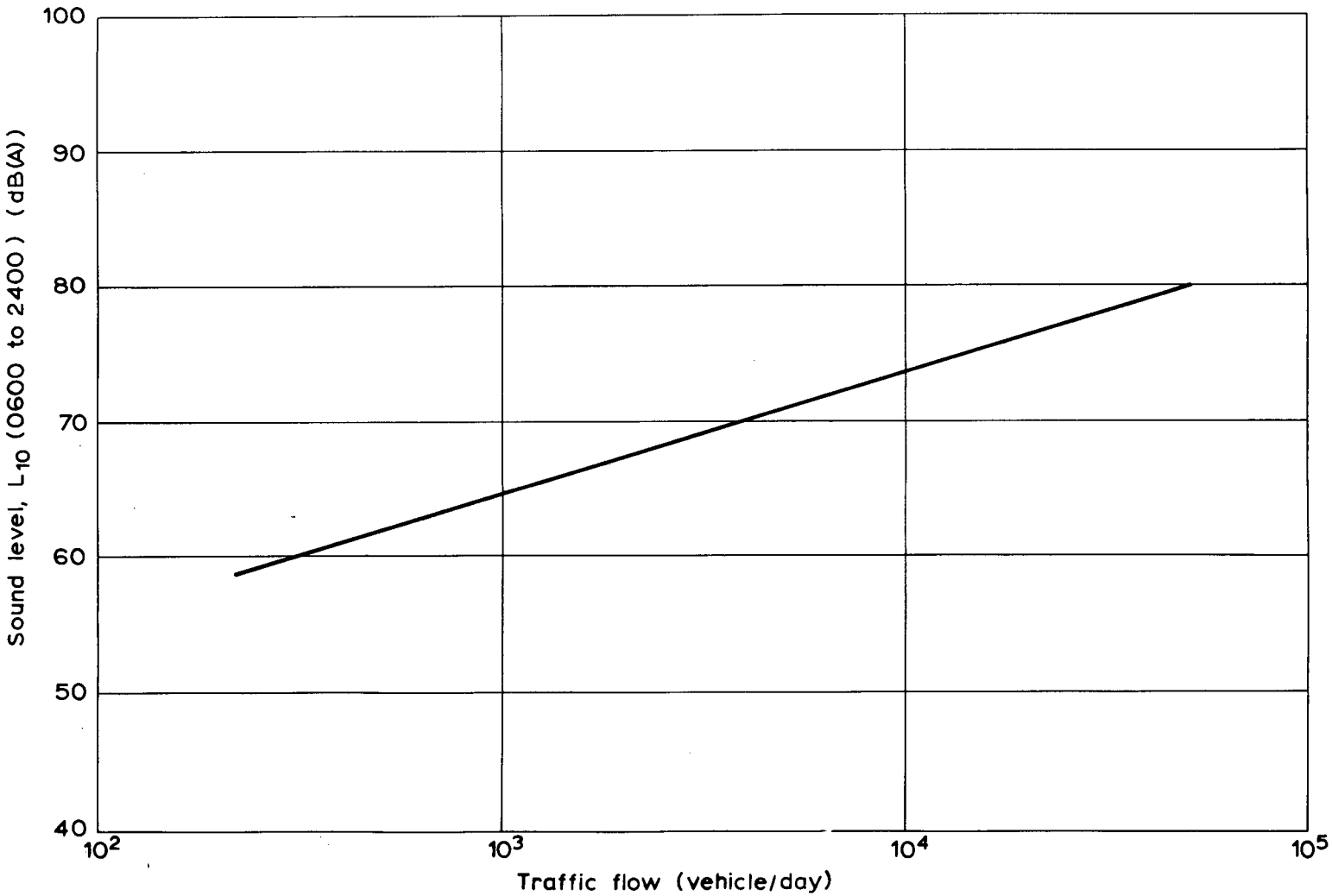

Fig. 4. SOUND LEVEL AND TRAFFIC FLOW

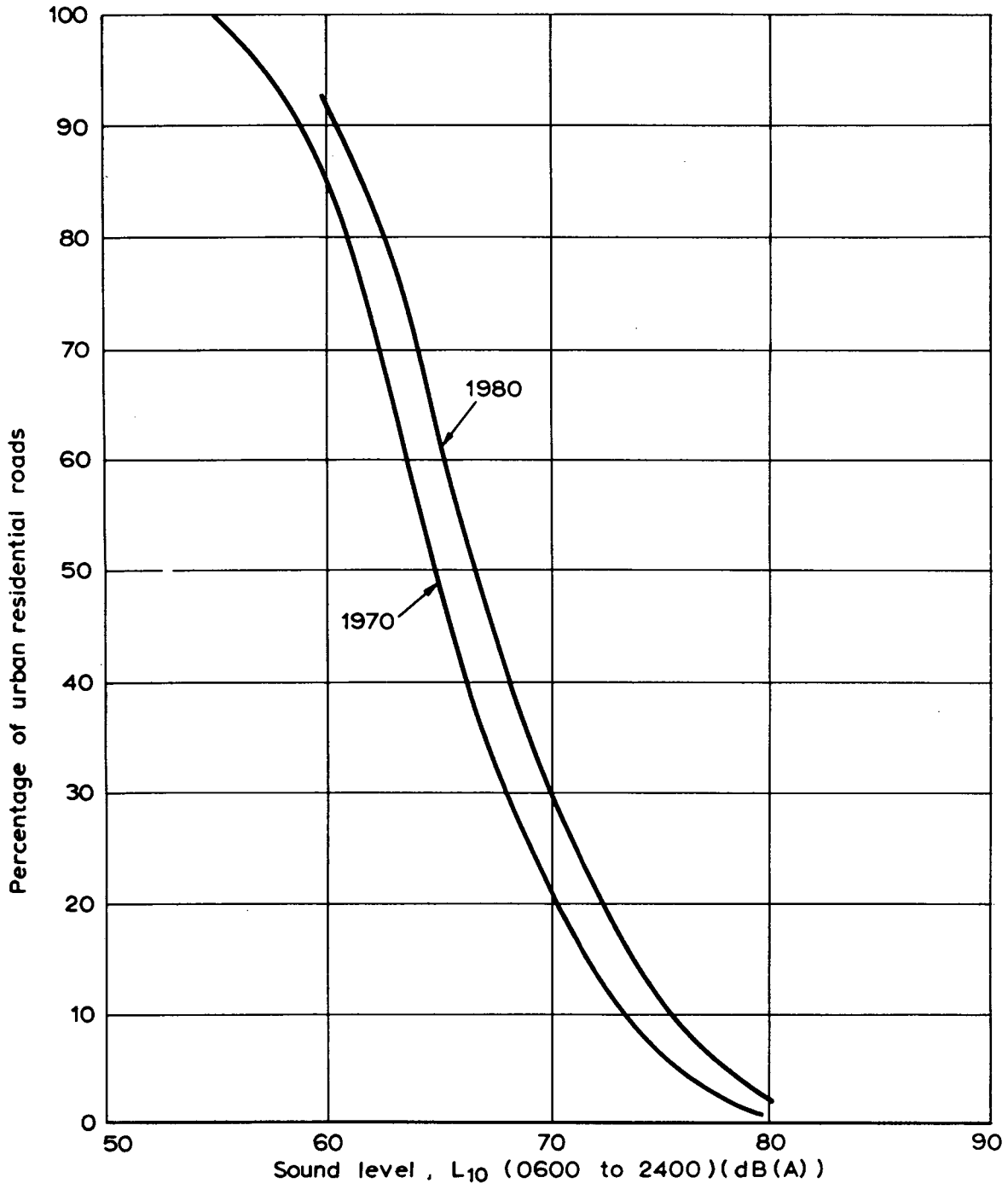

Fig. 5. PERCENTAGES OF URBAN RESIDENTIAL ROADS EXPOSED TO VARIOUS LEVELS OF L_{10}

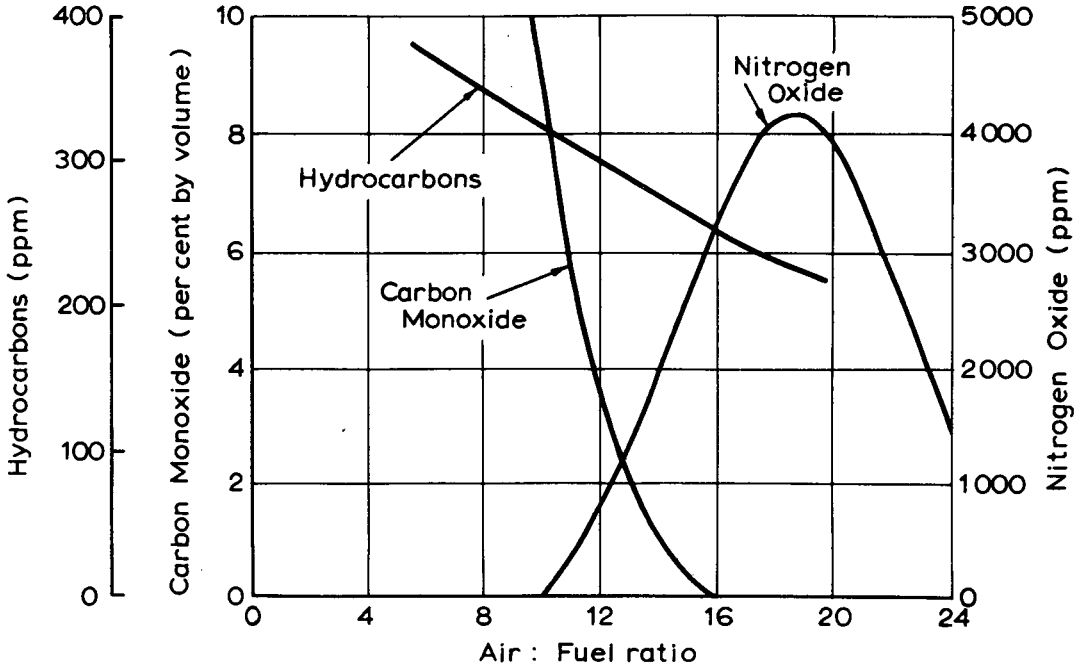

Fig. 6. EFFECT OF AIR : FUEL RATIO ON THE CONCENTRATIONS OF THREE OF THE POLLUTANTS THAT OCCUR IN PETROL ENGINE EXHAUST GASES

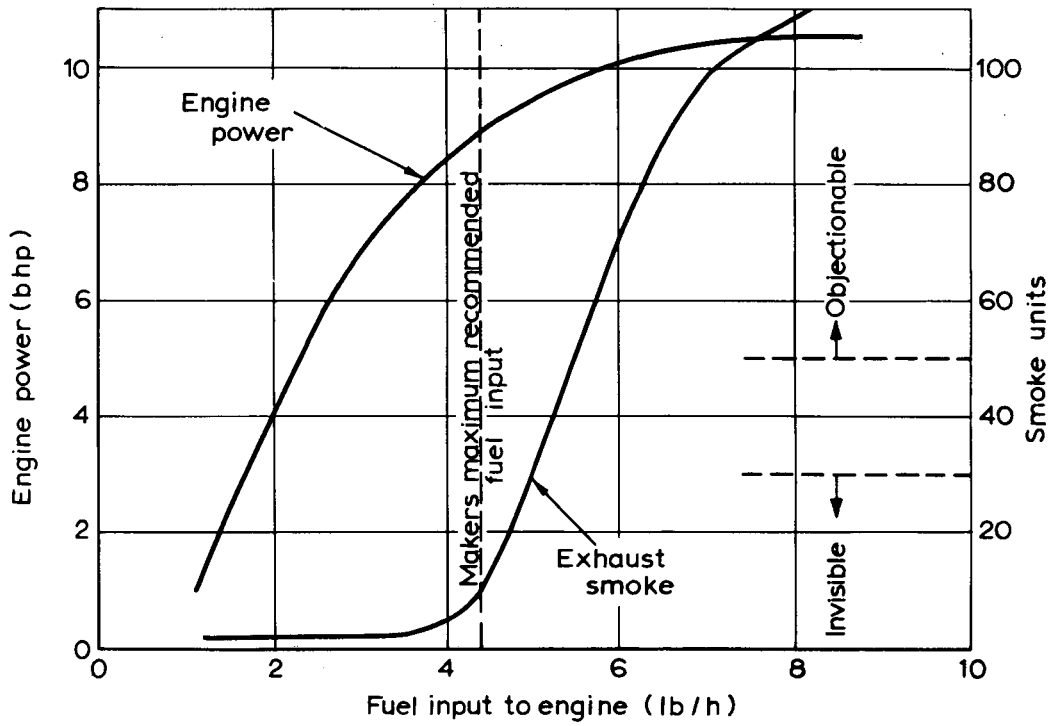

Fig. 7. EFFECT OF FUEL INPUT ON POWER AND EXHAUST SMOKE OF DIESEL ENGINES

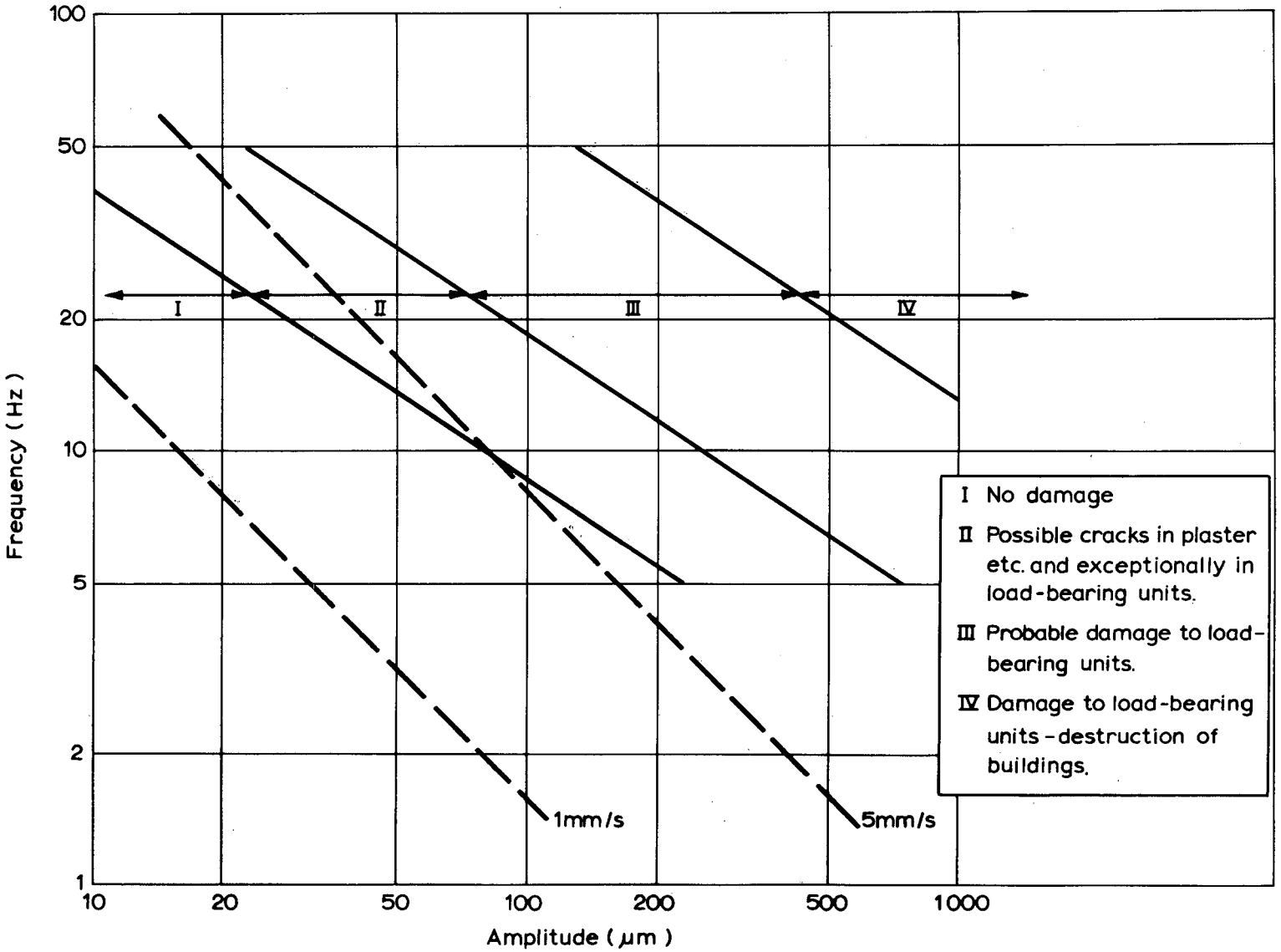

Fig.8. VIBRATION DAMAGE TO BUILDINGS

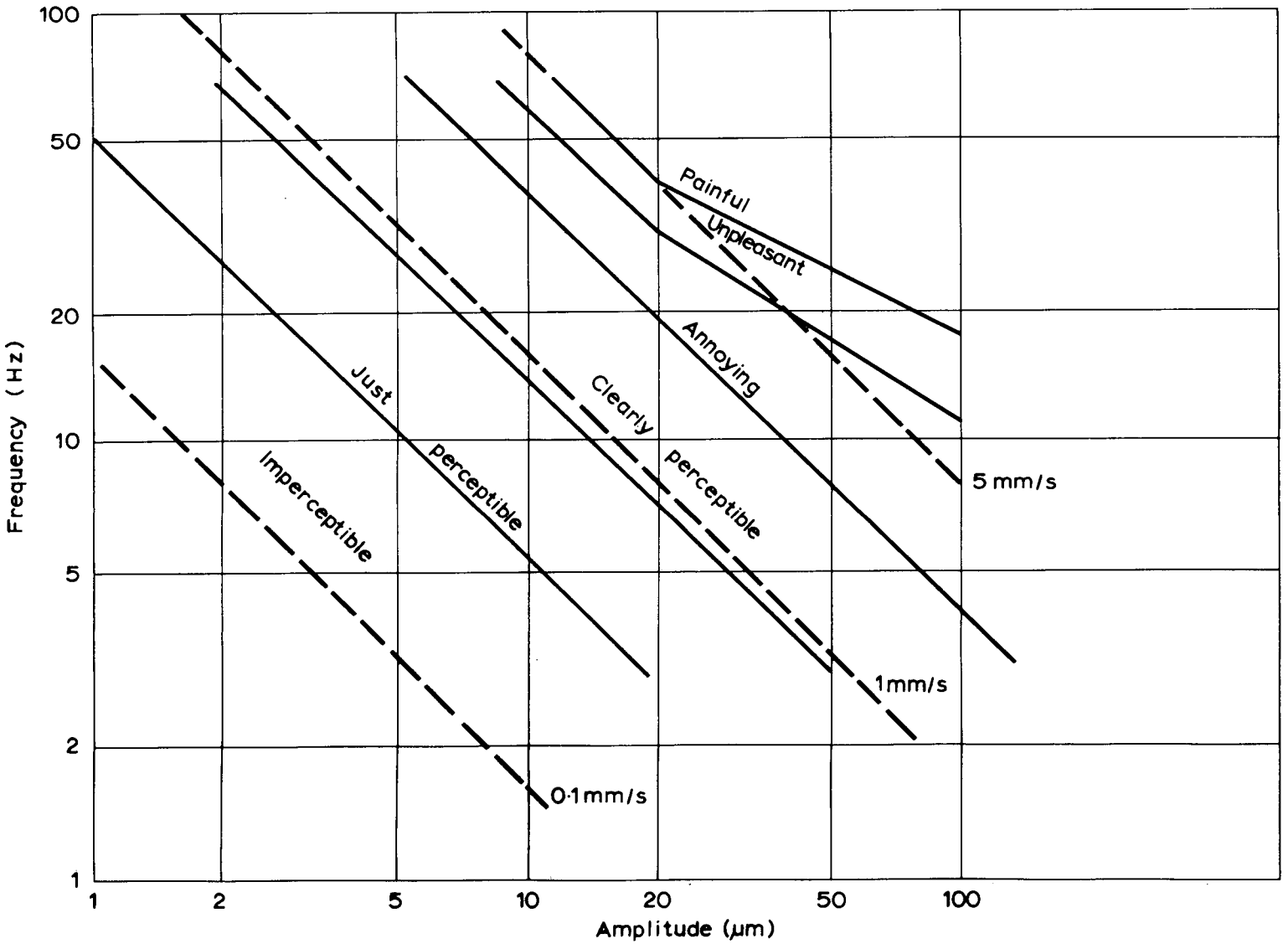

Fig. 9. HUMAN SENSITIVITY TO VIBRATIONS

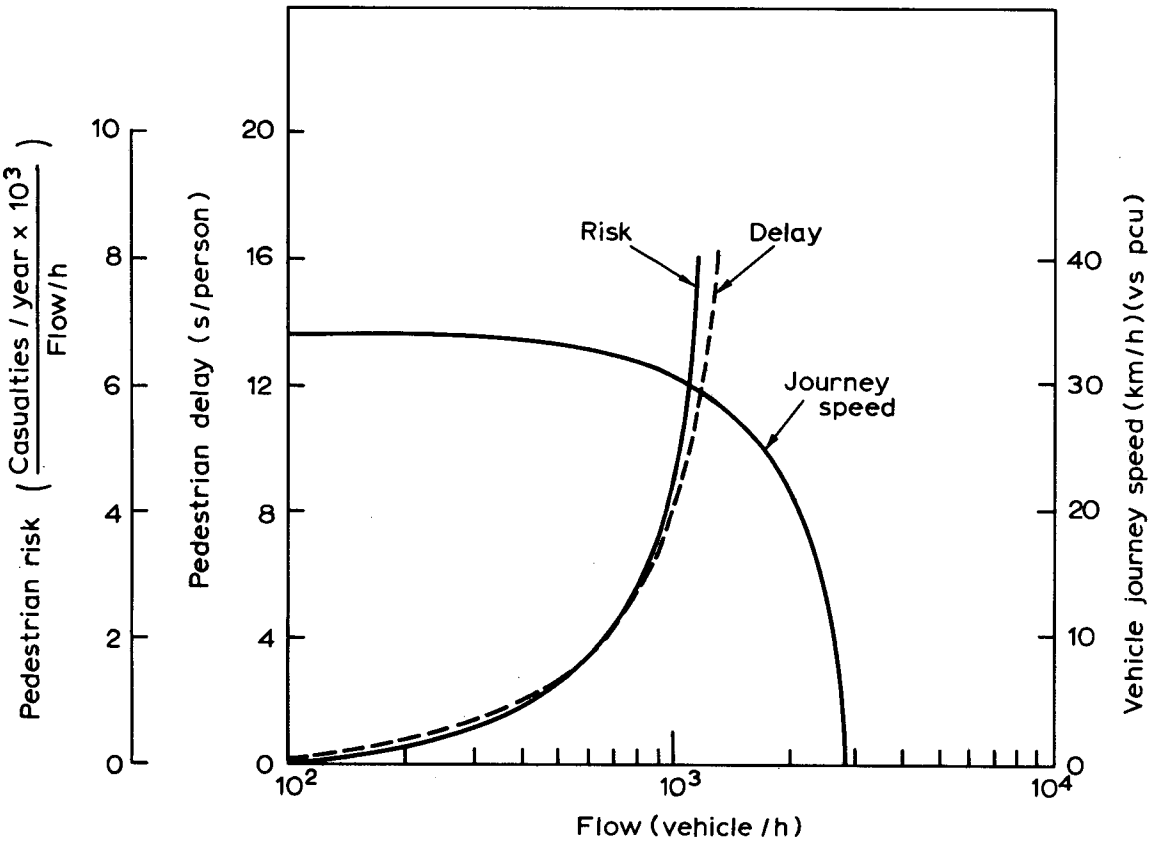

Fig. 10. PEDESTRIAN RISK AND DELAY

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ABSTRACT

Roads and the environment: M E BURT BA(Hons) CEng, FRAeS, MICE: Department of the Environment, TRRL Report LR 441: Crowthorne, 1972 (Transport and Road Research Laboratory). This paper states briefly the benefits that roads and road vehicles render the community and then reviews their adverse effects on the environment in four main fields:- traffic noise, air pollution, vibrations and intrusion. In each of these areas the present state of knowledge is outlined and some indication given of the desirable research and development. Emphasis is placed on the need for some means of assessing environmental benefits in financial terms so that environment factors can be given their fair weight in relation to economic factors when decisions are made.

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