NOISE EMISSIONS OF ROAD VEHICLES

EFFECT OF REGULATIONS

Final Report 01-1

by the

I-INCE WORKING PARTY ON NOISE EMISSIONS OF ROAD VEHICLES (WP–NERV)

by Ulf Sandberg
Convener of the I-INCE Working Party on Noise Emissions of Road Vehicles
Swedish National Road and Transport Research Institute
SE-581 95 Linköping, Sweden
E-mail: ulf.sandberg@vti.se

Final report produced with the assistance of Working Party members

International Institute of Noise Control Engineering

2001 July

Table of Contents

Abstract
This report presents a study with the principal objective of obtaining a global view of the effect of the vehicle noise regulations on road traffic noise. The study has included assessments of the development of vehicle noise emission limits over the past 30 years, the most important noise reduction measures on vehicles, changes in vehicle noise emissions over the past 30 years for various categories of road vehicles and for various driving conditions, expected effectiveness of planned changes in vehicle-related noise emission limits, and the reasons why the effectiveness of the regulations have not matched the intended effects. Based on the findings, recommendations for consideration in future noise emission regulations are given.

Foreword
The International INCE General Assembly on 1992-07-22 approved an initiative to review current knowledge and practice concerning *Noise Emission of Road Vehicles -- Effect of Regulations*. The background and work statement for this initiative are described in the main body of the report.

Each member of the Working Party which prepared this report represents a different Member Society that supports the International Institute of Noise Control Engineering; in addition, there was a Convener. Countries and members of the Working Party were as presented at the bottom of this page.

The study started in February 1993 after members of an I-INCE working party to deal with the study had been appointed. Status reports were presented at the INTER-NOISE 93 and INTER-NOISE 94 Congresses [Sandberg, 1993] [Sandberg, 1994]. A draft final report was printed in the June 1995 issue of *Noise/News International* [Sandberg, 1995].

In the balloting of the I-INCE Member Societies (1995), although only one disapproved the report, fewer than 30 % of the Member Societies returned ballots. Therefore, a new ballot was sent out in 1998, but the result was about the same as in 1995. At the I-INCE General Assembly in 1998, a roll call was taken on whether the report should be published with an addendum updating the report. This motion was unanimously approved.

The Convener was requested to produce an updated report, but for several reasons, it was not possible to complete the task until 2001.

The current report is the result of reviewing the report of 1995, and then taking new material and contributions from working party members, as well as from other individuals, into consideration (see the Acknowledgement section).

The report has been reviewed by the working party members, as well as by other individuals who have either made significant contributions or are considered to be recognized “experts” on this important subject.

Members of the Working Party
Ulf Sandberg, Swedish National Road and Transport Research Institute, Sweden (Convener)
Truls Berge, SINTEF Telecom and Informatics, Norway
Ralph K. Hillquist, RKH Consults, Inc., USA
Malcolm Hunt, Malcolm Hunt Associates, New Zealand
Jørgen Kragh, DELTA Acoustics & Vibration, Denmark
Anita Lawrence, Wahroonga, Australia
Michel Maurin, INRETS, France
Alex von Meier/Erik de Graaff[1], M + P Raadgevende Ing., Netherlands
Shinichi Ohno, University of Tokyo/Kanagawa Inst of Technology, Japan
Reiner Stenschke, Umweltbundesamt, Germany
Hideki Tachibana, University of Tokyo, Japan
Mitsuyasu Yamashita, Kobayasi Institute of Physical Research, Japan

[1] Alex von Meier retired in 1995 and was replaced by Erik de Graaff

NOISE EMISSIONS OF ROAD VEHICLES - EFFECT OF REGULATIONS
Final Report by the I-INCE Working Party on the Effect of Regulations on Road Vehicle Noise

by Ulf Sandberg
Convener of the I-INCE Working Party on Noise Emissions of Road Vehicles
Swedish National Road and Transport Research Institute (VTI)
SE-581 95 Linköping, Sweden

2001 July

Executive Summary

The I-INCE Initiative: At the INTER-NOISE 92 conference in Toronto, the International Institute of Noise Control Engineering (I-INCE) decided to undertake a study with the objective of obtaining a global view of the effect of vehicle noise regulations on road traffic noise. This initiative deals with the effect of international, national and regional regulations on noise produced by traffic at the roadside as well as inside buildings near major traffic arteries.

The study started in February 1993, when members of a Working Party[2] had been appointed by national member bodies of I-INCE. WP-NERV has had 13 members coming from 10 countries. Status reports were presented at the INTER-NOISE conferences in 1993 and 1994. A draft of the final report was published in 1995. This report constitutes the final report from the group and is based on the 1995 draft but has been updated and extended in several respects.

Background: Most industrialized countries have introduced regulations regarding maximum noise emissions of road vehicles. The regulations are generally coordinated internationally, both with regard to measuring methods and, to some degree, with respect to noise limits. Such unified methods/limits are, for example, implemented in the European Union (EU) and in countries that have approved regulations of the United Nations Economic Commission for Europe (ECE). The standardized method for measuring the noise emissions of individual vehicles that is most widely accepted is described in the International Standard ISO 362, "Acoustics—Measurement of noise emitted by accelerating road vehicles—Engineering method." Use of a corresponding measurement method is prescribed in the EU and ECE regulations. Although, for example, Japan and USA have slightly different regulations, with respect to each other and to Europe, they participate in the discussions within the ECE in order to promote harmonization and information exchange.

Few people question the necessity of stringent vehicle noise limits. However, it is recognized that vehicle noise control may increase vehicle purchase, maintenance and operation costs, and may also in some ways sacrifice some other parameters. For this and other reasons, it is important to assess the effectiveness of the noise control measures that have already been undertaken as a result of the regulations. In this area, I-INCE identified a serious lack of information.

There have been very few investigations dealing with the effectiveness in reducing road traffic noise over the period of time during which the current noise emission limits have been in place, and none of them has been global. The results of these restricted studies generally imply that the regulations have had a much smaller effect than had been anticipated. In some cases, the regulations have been viewed as having been completely ineffective. Regulations which are promulgated without any feedback to assess their effectiveness may be counter-productive and may, in the long run, undermine the credibility of noise control engineering among legislators.

The study presented here is the first and only one that attempts to make a global assessment of the effects of vehicle noise emission regulations in the past.

Extent of the study: The study has included assessments of the development of vehicle noise emission limits over the past 30 years, the most important noise reduction measures applied on vehicles, changes in vehicle noise emissions in actual traffic over the past 30 years for various categories of road vehicles and for various driving conditions, expected effectiveness of near-future regulations, and an analysis of the reasons why the effectiveness of the regulations has been less than intended.

Review of change in limits: Since vehicle noise regulations were first introduced in most industrialized countries 20-30 years ago, the emission limits have been substantially lowered. The latest tightening of the limits in the EU and ECE were made in 1995/96, and in 2001 Japan is tightening some of its limits. Since their introduction, limiting values have been tightened in the EU and ECE by 7-16 dB(A) for various vehicle categories, the lower values for light vehicles and the higher for heavy vehicles (in these values, account has been taken of changes in the measuring procedures which have required or allowed a change in noise reduction). In Japan, corresponding limit reductions have been 8-11 dB(A) and in the USA a 3 dB(A) reduction has been enforced for trucks. These are quite remarkable reductions for all vehicle categories; changes which have not been free of charge. Particularly the heaviest trucks have faced much more stringent requirements; for example the trucks in the EU currently have to meet the same nominal limit as cars had to meet up to 1989, i.e., cars which still represent a considerable fraction of the traffic. Another example is that a new articulated truck in Europe, and the USA as well, which may have a total mass of 40-50 tons, has to comply with a limit which is nominally the same as for a full-size motorcycle, having a mass of less than 1% of the truck.

---

[2] Hereafter called 'WP-NERV', from Working Party on Noise Emissions of Road Vehicles

Vehicle noise emission limits are preferably harmonized internationally. Separate limits and inconsistent regulations from country to country mean extra work, administration and expenditure for vehicle manufacturers and vehicle owners and also for authorities. In the EU and some other European countries having trade agreements with the EU, the vehicle noise regulations are the same in all countries. Also, the ECE tries to harmonize the regulations internationally, and it even provides a forum for harmonization discussions with non-European countries. Nevertheless, one can see three major families of noise emission regulations: those in Europe, USA and Japan. They contain many similar elements; especially the European and Japanese requirements. For the particular objective of this study, such differences are interesting, but in a wide sense a better harmonization is desirable.

Type of tests - review of measuring procedure: Limiting values are generally confined to the approval of vehicles in new condition. A few countries or states have introduced their own requirements regarding in-service vehicles, but globally these can rather be seen as exceptions. The measuring procedure selected for type or conformity of production approval relies on driving conditions that result in high proportions of power unit noise, and up to the mid-1990s in Europe made tire/road noise quite insignificant.

In the testing procedure most commonly used, ISO 362, the vehicle selected for type approval approaches (at constant speed) a line crossing the test track 10 m ahead of the microphone location. At the microphone location there is one microphone on the left side and one on the right side, each one displaced 7.5 m sideways from the centerline of travel. When the line 10 m ahead of the microphones is reached, the vehicle is accelerated with a wide-open throttle (limitations apply in certain cases) until it has passed 10 m beyond the microphone location, when the throttle is closed. The initial constant speed is generally 50 km/h for cars (using 2nd and/or 3rd gears) and in the range of 15-50 km/h for heavy vehicles (using a wide selection of gears). The maximum noise level at the two microphones during the acceleration process is recorded and after some repetition runs and some processing constitutes the final result. The Japanese variant of this is essentially the same, but the US version has twice the distance between the center of the driving lane and the microphones. The details of the driving conditions are also slightly different although the principle is the same.

The intent of this method was originally and is essentially still today to measure the maximum noise a vehicle is capable of creating. During this type of driving, the engine develops maximum or close to maximum power and the resulting noise is dominated by power unit noise (engine, exhaust, transmission, air intake, fan, etc). The other main part of vehicle noise, tire/road noise, has historically been rather unimportant in this method. This has implied, historically, that the method has been a tool to control basically power unit noise, and has left tire/road noise without control. The latter dominates vehicle noise emission during most driving at constant speeds. In recent years, at least in the EU and Japan, as a result of the most recent lowering of limits, power unit noise has become reduced to a level that makes it more or less equivalent to tire/road noise for many vehicles. Consequently, the vehicle manufacturers now have to seriously work with the exterior acoustic properties of tires, i.e., to require “low-noise” tires from the tire manufacturers. This noise reduction is optimized for the very special full-throttle testing condition of the vehicles; a type of running of tires that very rarely occurs in actual traffic.

The test method was principally developed in the late 1950s after rather extensive and ambitious development work and was found to be very useful for the purposes of that time. When evaluating the results, WP-NERV has found that the limits imposed the first time were adequate to require minor modifications to exceptional vehicles but did not require any extensive modifications to the majority of vehicles being produced.

As the noise limits became more stringent, vehicles were optimized for this situation, so that power unit noise has since been greatly affected by the requirements but tires have been virtually unaffected (until very recently). In Japan, this tire/road noise contribution in the acceleration test became significant a little later than in Europe. But for many years there has been a supplementary Japanese constant-speed test in which tire/road noise dominates.

Results - annoyance and community noise changes: It has been very difficult to find data on how public annoyance due to noise of vehicles has changed over the time period studied.

With reservations for the sparse data available, it may be concluded that the annoyance data suggest that annoyance of road traffic has been reduced in the last 10-15 years, despite increasing traffic. Part of this may no doubt be explained by general noise immission reduction measures being undertaken, but part of it may also be attributable to vehicle noise emission changes after the mid 1980s. In particular, the annoyance seems to have been reduced for the “noisier” vehicle types, such as heavy trucks and motorcycles, the categories for which measures seem to have been most effective. These observations fit well with the observations regarding measured noise reductions. An exception is that the measured noise reductions for motorcycles were rather small, but the observed annoyance effect may be due to changes in the use of illegal exhaust silencers resulting from some anti-tampering regulations.

Some interesting community noise surveys, i.e., noise measurements at a large number of sites spread out over a region or country, have been found. The ones of relevance here make it possible to see development trends over time. These are systematically compared and it is found that they give very different results. However, with some local variations, it appears that essentially they indicate community noise has been rather stable over time. Taking the growth of traffic into account, which has been more than twofold over the time period studied, this means that the improvements in noise emission of individual vehicles have approximately managed to balance the traffic growth.

Results – change of vehicle noise emission values measured during type approval: It is clear from the studies that the mean noise levels of type approval for the vehicle fleet have indeed decreased, although significantly less than the nominal limits. For cars this decrease is rather small, but for heavy vehicles, taking also changes in measurement methods into account, the decrease is substantial. The reason for the discrepancy between nominal limit changes and the recorded effects is that the first limits were so liberal that most vehicles were well below the limits. In recent years the noise levels for most of the vehicles have been just below the limits. This means that the difference between the "noisy" and the "quiet" vehicles has decreased with time.

A regulation-related event that seems to have had a most important effect on noise emission of heavy traffic at low speeds was the ban against nighttime transit traffic in Austria. This was a national regulation with a very limited application, but since it addressed commercial transportation problems that affected several countries, most European truck manufacturers very soon adapted to it and supplied "80-dB-trucks" to most of the European market—a remarkable contrast to the "88-dB-trucks" that were standard a few years earlier.

Results - noise changes in actual traffic: This report extensively and systematically presents results of comparisons between vehicle noise measurements made at different times in different countries, and attempts to obtain a good overview of the development over time.

Very briefly summarized, WP-NERV has found that for accelerating traffic at low speeds, roughly one-half of the nominal changes in noise requirements have been recorded as a reduction of individual vehicle pass-by noise in actual traffic streams. For light vehicle traffic at constant speeds, there has been no significant improvement at all resulting from the regulations. For heavy vehicle traffic at constant speed, an improvement of roughly one-half the nominal change of limits seems to have occurred at low speeds, but very little at high speeds.

Tire/road noise has constituted a lower limit to all improvements at constant speeds. For the current limits in Europe and Japan, tire/road noise is significant also for the type approval conditions for which this type of noise traditionally has been assumed to be negligible.

This all suggests that vehicle noise emission limits have been disappointingly inefficient. But this is not entirely true. For example, there is an "inertia effect" due to the slow exchange of new for older vehicles in traffic, in combination with the noisier vehicles giving disproportionally high contributions to the common community noise indices. It means that the latest European and Japanese lowering of limits has not yet shown its full effect in terms of traffic noise reduction. For example, in Europe one may expect at least one extra dB of noise reduction from already executed limit changes when all old vehicles will have been replaced by modern ones.

When studying the *noisiest* vehicles in a traffic stream, the effects of the limits have been much better and actually rather close to the limit changes. From the noise emission point of view, vehicles of similar ages have become much more uniform, both within each vehicle category and between them. For protection of individuals against maximum level effects, such as awakening at night or sound masking effects, this development is very positive.

Furthermore, there are indications that the regulations have had some more positive effects that are not immediately obvious, such as decreased source height and changes in the noise emission pattern of a temporal as well as of a spectral nature, both which are positive. For example, the noise of vehicle retarders (engine compression brakes, etc.), which sometimes are perceived as the worst vehicle noise offenders, as well as brake squeal and compressed air noise, seem to have been reduced over the period studied.

Speculation regarding the situation if no noise regulations had existed suggests that noise levels would then not have decreased to any significant degree. Some development towards quieter vehicles would have been driven by market forces (although sport cars and motorcycles would have developed in a contrary direction), but it is doubtful whether this would have more than matched the increased performances of most vehicles that have taken place, such as increased power, increased speed capacity, increased weight, and higher load capacity. This would probably have meant that compensation for the noise of increased traffic volume would not have occurred and in total the situation would have been extremely unfavorable.

Results - comparison of Japanese experience with the experience of other countries: There are indications that the Japanese experience is more positive than others; there are at least four reasons for this. Firstly, in Japan, type approval has been based on a measuring method which is modified from ISO 362 but more representative of actual traffic than in Europe and Australia. In fact, it has been a general observation in this study that noise emission during type approval based on ISO 362 correlates poorly with noise emission in actual traffic. Secondly, in Japan there is a long tradition of control of in-service vehicles. Thirdly, the tolerances between actually measured noise levels and limits are much stricter in Japan than in Europe. Finally, Japan has had a separate limit for vehicles driven at constant high speeds. It is possible that this could have encouraged a certain tire selection.

Reasons for limited effectiveness: The Working Party has analyzed the reasons for the limited success of the emission limits and arrived at the following conclusions.

- The most important reason for the poor efficiency of the limits is that the lack of any significant effect on tire/road noise of the type approval procedure for vehicles (until recently) has left tire/road noise uncontrolled over the time period studied. Exterior tire/road noise from individual vehicles has not been reduced over the past 30 years; possibly it may instead have increased somewhat. In too many cases, tire/road noise has put a lower floor to achievable overall noise reductions, since no matter how much power unit noise has been reduced, there is still tire/road noise remaining and unaffected, and human perception concentrates on the dominating noise. Generally speaking, one can say that for the modern vehicles, tire/road noise and not power unit noise is the determining factor for all constant-speed driving conditions. Heavy vehicles driving at speeds lower than 50 km/h would be the exception, but constant-speed operation is rare at such low speeds. This does not by any means make power unit noise reductions unnecessary, since many of the noisiest situations involve stop-and-go operation and in congested traffic, power unit noise will be the important factor. But it is important to realize that power unit noise reductions must be supplemented by measures affecting tire/road noise.

- The second important reason is that limits were not sufficiently strict during the first years; at least in Europe and Japan, it took a decade or more until they reached a level where they really seemed to affect the vehicle population significantly.
- The third important reason is what may be called the “inertia effect,” i.e., the relatively slow exchange rate from old to new vehicles makes noise reduction lag behind the limit changes. This time lag in noise reduction may be greater than most people have expected. This is aggravated because the old noisier vehicles maintain a presence in the fleet that affects equivalent as well as maximum noise levels for a disproportionally long time.
- The fourth important reason is that over the time period studied, at least for heavy vehicles, there has been a general trend towards bigger and more powerful vehicles having more tires and being more optimally loaded. In the time period studied, in general, new vehicles have been equipped with more powerful engines. This does not necessarily mean more noise, but the risk is evident. Particularly for the heavy vehicle class, larger vehicles have been introduced. Loads have increased. These changes have required the use of more tires on individual vehicles than earlier. More tires mean more tire/road noise. The trends are caused by requirements for more efficient and economical freight and passenger transportation and increasing road transportation needs in general, but it should be recognized that some restraining effects have been imposed by limitation of fuel consumption. For example, during the 1970-98 time period, freight transportation expressed as overall ton-km for 16 European countries has increased by a factor 3.0 and passenger transportation in passenger-km by a factor 2.3. Figures for Japan and USA are higher or comparable. More vehicles are now utilizing the maximum size and weight limits. It is difficult to avoid that the trend towards increasing size, load and power results in higher noise generation. This has counteracted the lowering of noise emission limits.
- Among other important effects that have limited the efficiency of the limits can be mentioned the lack of realism and representativeness of driving conditions in the measuring method on which type approval is based. For example, in Europe and most other countries, vehicles are tested unloaded. In combination with the extreme power now available and the driving condition, this often results in extreme testing conditions very unrepresentative of actual traffic. This probably results in sub-optimizations of noise reduction measures. In Japan, the test method is somewhat different, which may be one explanation for the apparently better effect of the regulations in Japan than in Europe. Another effect is that vehicles in service are not generally controlled with respect to noise. Type approval mainly controls vehicles in new condition, often differently constructed than the “same” vehicles used in traffic.

Recommendations: Based on this report and assuming that society needs a considerable traffic noise reduction, WP-NERV offers the following recommendations for consideration in future vehicle noise emission policies (additional recommendations can be found in the main body of this report):

- Noise emission from tires during “normal” driving must be substantially reduced. As long as this is not done, vehicle noise regulations are likely to be ineffective.
- Tire/road noise reductions may be achieved by use of a regulation similar to the amendment to the EU tire directive, but the limits must be substantially reduced to have any effect. Furthermore, it is important that such regulations do not exempt significant parts of the tire market, such as retreaded tires, since any remaining noisy tires will have a disproportionally large influence on noise levels.
- Since noise emission from in-service tires may be quite different from that of new tires, it is important to determine means to ensure that worn tires do not become significantly noisier than when they were new.
- Not only should tires be subject to noise limitations, but the role of the road surface in excitation or otherwise affecting tire/road noise emission should also be limited, which is the responsibility of road or environmental authorities. Preparations and plans for such measures have already been made, but it is important that they be followed-up. As for tires, it is important that in-service characteristics are also controlled.
- A new measuring procedure for use during type approval of vehicles should be developed. It should require that the major noise events of a vehicle are controlled, i.e., these that are expected to be perceived as noisy by the exposed people. A project is under way in a Working Group of the International Organization for Standardization (ISO).
- This Working Party does not take a position on the question of whether power unit noise and tire noise should be separated in such a new method. But if they are separated, tire/road noise may be controlled by the separate tire noise regulation discussed above. In such a case, it is recommended that a speed lower than the test speeds required in the EU tire directive be added in the tire noise regulation.
- Vehicles in service should be checked with respect to noise (this may possibly not need to be applied to cars). With regard to in-service motorcycle noise and “anti-tampering” measures regarding exhaust silencers, this is of extremely high importance in order to reduce public annoyance.
- Limiting values should be chosen to be sufficiently stringent in order to really affect the vehicle or tire population and not only a very few of the noisiest vehicles or tires. Otherwise, the public will not perceive any positive effects

of the regulations. It is important to avoid repeating the mistakes in this respect in the earlier noise regulation policies.

- The “bonus” of one dB in limiting values for light vehicles with diesel engines should be removed.
- Substantial effects in terms of noise reduction may be achieved if the extra decibels of allowance for sport utility vehicles and light trucks and vans (<3.5 tons) are removed to make them meet the same requirements as other light vehicles (cars). This vehicle category is rapidly increasing in popularity and will soon be the dominating noise[3] source if nothing is done to avoid it. Many of these vehicles are operated with particularly “noisy” tires.
- Vehicle noise emission, in particular public annoyance, may also be affected by change of driving behavior. With regard to noise, this is most important concerning motorcycle and moped drivers.
- The “Boom car” problem of in-service vehicles needs to be addressed in some way. The use of high-power music reproduction systems may create sound that far exceeds the noise emission during normal vehicle operation and constitutes a new type of nuisance that is rapidly increasing.
- It would be favorable if a means of affecting the noise levels of the vehicles that emit medium and low noise levels can be found and applied. Introduction of some means of commercial arguments for lower exterior noise emission would be beneficial. Means for encouraging the use of vehicles that are as quiet as possible may include tax incentives connected to noise levels, exemption from toll for low-noise vehicles, limitation of travel based on a quota system with “environment-affecting” points, as well as permits (connected with noise classification) to travel in restricted low-noise areas, on restricted roads or at restricted times.
- It is important that development trends be assessed at frequent intervals, in order to be able to correct undesirable development without too much time inertia. Assessments are dependent on the availability of comparable measuring data from time to time, and authorities are encouraged to establish programs that aim at collection of such data.

Concluding remarks: It should be emphasized that, although the vehicle noise reductions in actual traffic have been less than anticipated, there have been many and major positive effects from them. The discrepancy between anticipated effect and actual effect is not due to failure of the industry or a lack of technical competence or knowledge. In fact, one can say that the regulations in at least Europe and Japan have essentially succeeded in reducing power unit noise in traffic as much as one could reasonably demand. It is mainly our *expectations* that have been wrong. These expectations, except perhaps within the vehicle industry and researchers in the area, have been unrealistic in that they have neglected for too long that tire/road noise is important and not subject to any regulations—combined with a selection of noise limits during the first time period that were too conservative and were tightened too slowly.

The work of the Working Party has shown that it is very important to monitor the effect of regulations, in order that poor effectiveness and other problems be identified at an early stage and corrective actions be taken without too much time inertia. Had this been done, one would have realized much earlier that the present regulations must be supplemented with a limitation directed towards the tire/road system and that the measuring method, based on ISO 362, should be replaced or modified. Authorities are therefore advised to engage independent technical and scientific expertise to estimate in advance the effects of new noise legislative actions, and then to monitor and evaluate regularly the actual effect!

The need to go further: The rather modest reductions in actual traffic noise that have been identified should be put into context with the very significant reductions necessary if people living near busy roads are to enjoy anything like the recommended community noise levels. For example, to meet a criterion of L_{eq} of 55 dB(A) from a road carrying 2000 vehicles/h (10% heavies) a road-dwelling separation distance of about 80 m is required. This is not often possible and may require either the acceptance of a poor environment or the achievement of the reduction by alternative and very expensive means. To put it very simply, if vehicle noise emission could be reduced by 3 dB(A) it is generally equivalent to cutting separation distances to half for the same noise level at the dwelling. The reductions one would wish ideally would be more like 10-20 dB(A) than the few dB which have been recorded. Although such reductions do not seem realistic in our lifetime, it is important to try to achieve as much as is practical/economical in order to relax the needs for other noise reduction measures.

The challenge is now to create a sustainable acoustical environment around roads and streets, in a time of continued traffic growth, building of more roads and streets, and with a likely continued trend towards larger and more powerful vehicles on the roads. It is difficult to imagine a development in that direction without the use of more stringent vehicle and tire/road noise emission limits. It is hoped that this report will aid in designing a system of efficient and economical regulations.

[3] This may already be the case in some countries

Final Report

1. Background and Problem Statement

Most industrialized countries have introduced regulations regarding maximum noise emissions of road vehicles. The regulations are generally coordinated internationally, both with regard to measuring methods and, to some degree, with respect to noise limits. Such unified methods/limits are, for example, implemented in the European Union (EU) and in countries that have approved regulations of the United Nations Economic Commission for Europe (ECE). The standardized method for measuring the noise emissions of individual vehicles that is most widely accepted is described in International Standard ISO 362, “Acoustics - Measurement of noise emitted by accelerating road vehicles - Engineering method.” Use of a corresponding measurement method is prescribed in the EU and ECE regulations. With a few exceptions, the noise emission regulations are based on the type approval system for new vehicles.

A section on “Vehicle noise regulation history” has already appeared in a publication by Sandberg [Sandberg, 2001-1]. As reported there, some countries had vehicle noise regulations in the 1930s. For example, Germany had its first regulation in 1937—which was later updated in 1953, 1957 and 1966 [Kemper, 1979]. However, regulations of this type were not common, and never coordinated internationally, until the 1970s. This report concentrates on this “post-regulation” period.

Since vehicle noise regulations were first introduced on a worldwide scale some 30 years ago, the emission limits have been substantially lowered. For example, the latest tightening was made in the EU in 1995/96 and in Japan some vehicle types face stricter regulations from this year (2001).

The period studied (1970-2000) covers a time of rapid development in the transportation sector, despite oil crises, recessions, etc. For example, between 1970 and 1998, road passenger transport (in passenger-km) increased by a factor 2.3 in the 16 ECMT/WEST countries of Europe, and the road freight transport (ton-km) increased by a factor of 3.0. For the same period, the corresponding increases were a factor of 4.9 and 2.3 in Japan, and 2.3 and 2.6 in the USA. One may expect that if no countermeasures were undertaken or other changes occurred, this would have led to much more than a doubling of the sound power emitted on roads and streets in the 30-year-period. It is obvious that this has put increased pressure on the acoustical environment that, by 1970, was already a very serious problem.

Few people question the necessity of stringent vehicle noise limits. However, it is recognized that vehicle noise control may increase vehicle purchase, maintenance, and operation costs, and may also, in some ways, sacrifice some other parameters. For example, the weight of a vehicle may increase—something that may affect fuel consumption. For this and other reasons, it is important to assess the effectiveness of the noise control measures that have already been undertaken as a result of the regulations. In this area, I-INCE identified a serious lack of information.

Some studies of changes of vehicle noise emission with time have been made [Sandberg, 1989], [Berge, 1994], and [de Graaff, 2001]. These have, however, attempted neither to look at the problem in-depth, nor globally. Simply stated, there have been very few investigations dealing with the effectiveness in reducing road traffic noise over the period of time during which the current noise emission limits have been in place, and none of them has been global. The results of these restricted studies, some of which have been presented at recent INTER-NOISE congresses, generally imply that the regulations have had a much smaller effect than had been anticipated. In some cases, the regulations are viewed as having been completely ineffective. Regulations that are promulgated without any feedback to assess their effectiveness may be counter-productive and may, in the long run, undermine the credibility of noise control engineering among legislators. To date, international organizations have failed either to identify the problem or to take appropriate action.

At the INTER-NOISE 92 Congress in Toronto, Canada, I-INCE decided to undertake a study with the objective of obtaining a global view of the effect of vehicle noise regulations on road traffic noise. A working party under I-INCE was established to conduct the work[4]. This report constitutes the final result of this study.

2. Objective and Method

This initiative deals with the effect of national and regional regulations on noise produced by traffic at the roadside as well as inside buildings near major traffic arteries.

The principal objective has been to obtain a global view of the effect of the vehicle noise regulations on road traffic noise. In agreement with the initially given objectives and an action plan [Sandberg, 1993], the study has been conducted as follows:

1. The development of vehicle noise emission limits over the past 30 years has been studied.
2. The most important noise reduction measures that have been implemented on vehicles as a result of the legislation have been identified.
3. Data regarding changes in vehicle noise emissions over the past 30 years have been collected; wherever possible, separately for various categories of road vehicles and for various driving conditions (interrupted-flow and constant speed traffic at various speeds).
4. Information regarding the expected effectiveness over the next few years of the latest lowering of vehicle noise emissions has been collected.
5. Wherever possible, the study has been expanded to include not only outdoor mean A-weighted levels but also indoor noise levels as well as maximum noise levels.

---

[4] Hereafter called “WP-NERV from Working Party on Noise Emissions of Road Vehicles

6. WP-NERV has tried to identify the reasons why the effectiveness of the regulations has been less than intended.

Most of the work has been done by correspondence, although WP-NERV had one-day meetings in connection with the INTER-NOISE congresses in 1993 and 1994.

3. Development of Vehicle Noise Emission Limits Over the Past 30 Years

3.1 For New Vehicles

Control of vehicle noise by legislation can be based on two main principles:

- Setting limits which new vehicle models must meet, subdivided into

  (a) Type approval tests, i.e., approval for the entire type of vehicle based on a test of a representative vehicle, often supplemented with a conformity of production (COP) test, and
  (b) Production standard and COP tests; i.e., a new vehicle must meet a certain production standard (noise limit), which is then checked at random by COP.

- Checking noise emission of vehicles in use, either taken from the traffic or tested during annual inspection.

The type approval principle is applied in most regulations, such as the ones of the EU, the ECE, Japan and Australia; whereas the production standard and COP principle is applied in the USA.

With regard to type testing of new vehicle models, Fig. 1 illustrates the rather radical tightening of vehicle noise emission limits that have occurred over the years in the EU, USA and Japan. There are several more vehicle categories; the ones shown here are examples of perhaps the most interesting ones. Most industrialized countries have similar limits, but their application usually differs in the year in which they were first enforced.

The reader should be careful in interpreting the figure. Please note that the noise limits in different countries are always based on a certain measuring method. Since the methods and the data processing differ between the illustrated countries or areas, the limiting levels are not entirely comparable from one to the other. For example, it seems that Europe has more stringent requirements than Japan. In reality they are almost the same, since there are small differences in testing and treatment of the data that balance out the noise level differences. The great diversity in measuring standards and limits is illustrated in an excellent comparison in Table 13 of Close [Close, 2001].

It appears that the limits, since they were introduced in 1970, have been lowered in the EU by 8 dB(A) for cars, 11 dB(A) for heavy trucks and 2-6 dB(A) for motorcycles. These are nominal changes; in addition, some alterations in the measuring method have, in practice, meant a further tightening of limits of heavy vehicles by 2-4 dB(A) while they meant less stringent limits for cars of approximately 2 dB(A). Conformity of Production (COP) requirements of 1996 did not change nominal limits but in practice forced vehicle manufacturers to meet 1 dB(A) stricter limits. The possibilities after 1995 to use worn tires during type approval tests, may have enabled some manufacturers to increase vehicle noise by 1-2 dB(A). The net limit reduction in the EU from the 1970s until the present time is therefore approximately 7 dB(A) for cars and 13-16 dB(A) for the heaviest trucks.

The figure also shows that requirements in the USA differ considerably from those in the EU and Japan, especially since there are no federal requirements for light vehicles. However, some states and local jurisdictions have limits for light vehicles that are either 80 or 84 dB(A), originally measured according to SAE J986. This standard makes use of a 15 m measuring distance and the limits then would correspond to 86 and 90 dB(A) at the 7.5 m distance used in most standards outside North America. However, unlike the ISO 362-related standards, the lowest gear is used for testing, and it is the experience of the US manufacturers that this approximately balances the 6 dB distance correction [Cherne, 1993]. This makes the 80 dB(A) limit according to SAE J986 roughly equivalent to an 80 dB(A) limit according to the ISO 362. An agreement has been reached between the US manufacturers and the state and local jurisdictions that the ISO 362 standard be used as an alternative, at the discretion of the manufacturers. Therefore, in practice and for domestic use, all US manufacturers comply with the 80 dB(A) limit measured according to the ISO 362 standard, which means that the practical limit is comparable to the European limits in the 1980s. However, in order to comply with regulations in Europe and Asia, many vehicles meet even the most stringent of the European and Asian regulations, such as the European 74 dB(A) limit. See further [Cherne, 1993] for a thorough discussion of these issues.

The current US limit for trucks is 80 dB(A), which is equivalent to 86 dB(A) with the European measuring distance, and this is considered by many as corresponding fairly well with the EU and ECE limit of 84 dB(A) before 1996. At least, European trucks meeting the old 84 dB(A) limit were said to have no problem passing the US limit. A same-day measurement on a MAN truck using the US (SAE J366) and the EU standards gave 5 dB lower level with the US standard [Drewitz & Stiglmaier, 1989]. The US Environmental Protection Agency planned to lower the limit to 75 dB(A), which would have brought the US limit close to that of the current EU/ECE limit, but these plans were never implemented.

Limits in Australia have not been modified since 1989, but are currently being reviewed [Close, 2001]. They basically correspond to the European limits valid between 1989 and 1996. An exception is that Australian limits allow up to an extra 3 dB(A) for some heavier truck categories, “B-doubles” and “road trains” that are typical of long-distance transportation in Australia (where trucks sometimes may have a total weight of 100 tons).

A thorough review of noise regulation history in Japan has been published [Anon., 1999]. Regulations on exhaust noise (stationary test) and “steady running noise” (constant speed) were in place beginning in 1952, but the modern set of standards came into existence in 1971.

For motorcycles, the development of limits is shown in Fig. 1 for two examples of motorcycle size. The intermediate sizes show intermediate level changes. Although the first limits were already introduced in Germany in 1937 [Stenschke, 1994], the first limits for motorcycles in the EEC (now the European Union) were introduced as late as 1980. As can be seen in the figure, the development in Japan for motorcycles has been going on for a much longer time than in Europe and has been much more progressive. Note, however, that the driving condition during testing in Japan is somewhat less aggressive than in the EU; thus the nominal levels cannot be directly compared.

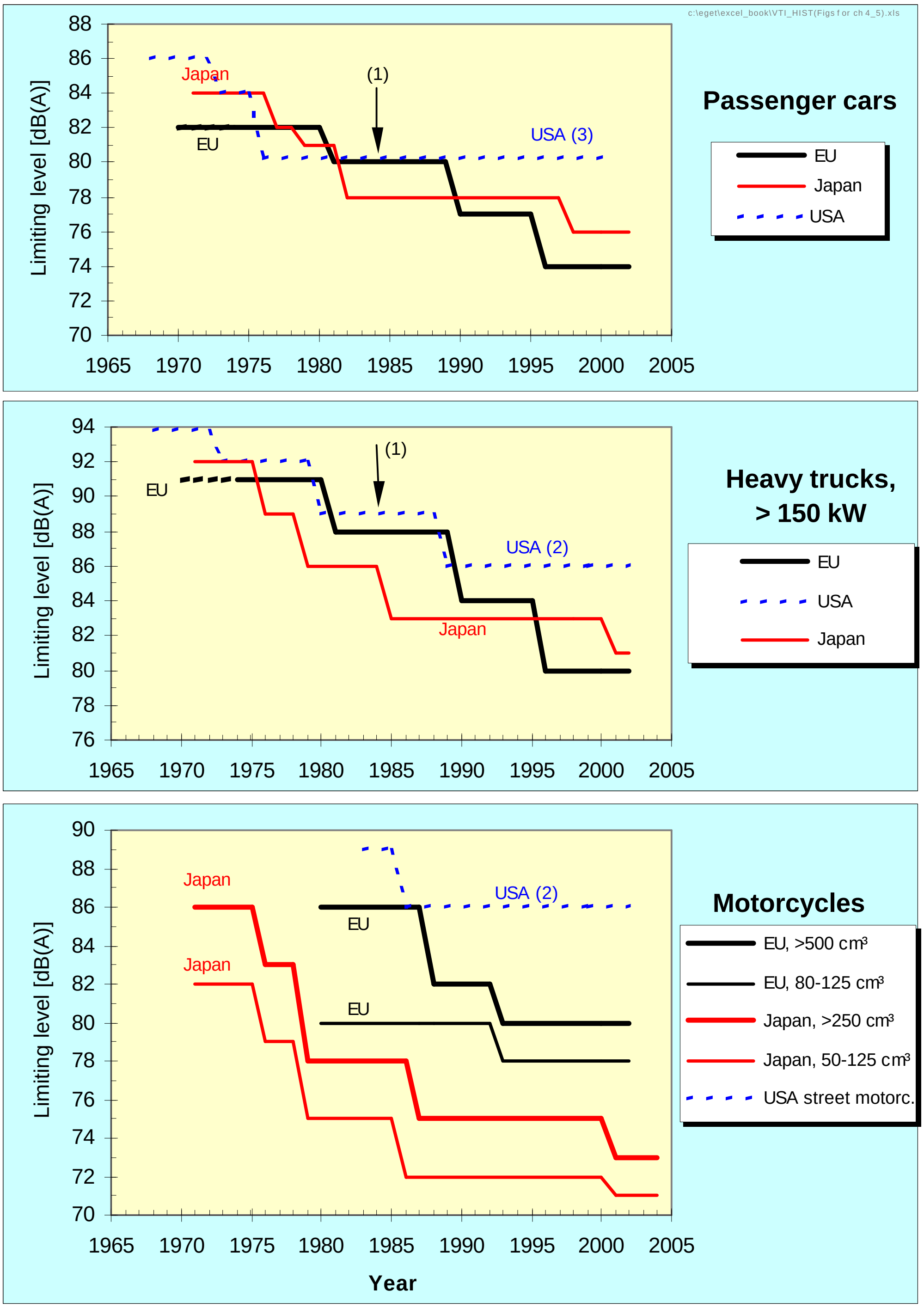


Fig. 1. Examples of the development of vehicle noise emission limits over the years, including some projected limits.

Notes:

(1) The arrow indicates that in the EU there was a change in measuring procedure in 1985. For trucks, this corresponded to 2-4 dB of stricter requirements on top of the other changes; but for cars it corresponded to approx. 2 dB of less stringent requirements

(2) Truck values for USA increased 6 dB to compensate for twice as large measuring distance (values before 1980 are for California)

(3) In the USA there are no federal noise requirements for cars, but some states have limits of either 80 or 84 dB (see the text)

(4) In the EU, COP requirements established in 1996 in practice meant another 1 dB of stricter requirements for both cars and trucks but the possibility to use worn tires may have counteracted this effect (not shown in figure)

3.2 For Vehicles in Use

It is generally assumed that the noise emission of vehicles increases with age, tear and wear. If this is a correct assumption, it is important to also control the noise emission of vehicles in service. In particular, the more noise control measures that are applied, the more one may expect that a lack of such control may affect overall road traffic noise. Consequently, a combination of both the type approval and in-service control options would be desirable. However, only a few countries have employed limits regarding vehicles in use.

It may, furthermore, be assumed that the regulation of noise from new vehicles (i.e. based on type approval tests) mainly affects "average-type" noise descriptors such as L_{eq}, whereas the regulation of in-service noise affects maximum levels in traffic, such as L_{max}.

Probably the most ambitious attempts have been made in the Australian state of New South Wales (NSW), where used vehicles have been subject to an exhaust noise control since 1979-80 [Eiser & Scott, 1994]. The first limits were set high to ensure that most of the older vehicles in normal condition would comply, but to ensure that vehicles with clearly faulty or tampered-with exhaust systems would be rejected. The present limits seem to be the same as the national Australian limits [Close, 2001], and are measured on stationary vehicles either at 0.525 m (mainly for cars) or 1.05 m (mainly for heavy vehicles) from the exhaust outlet. They are differentiated with respect to type of vehicle and position of exhaust outlet and range between 85 and 103 dB(A) for the latest models. These levels have been lowered by up to 6 dB(A) since their introduction in 1979-80 but have been unchanged for the latest 17 years. Authorized officers may stop and noise test those vehicles that are suspected of not complying with the regulation. They are also empowered to require suspect noisy vehicles to be brought to a facility for noise testing. There is also a telephone "pollution line" to which anybody can report an excessively noisy vehicle[5], which may result in a warning letter being sent and possibly a requirement to bring the vehicle to a facility for noise testing.

The NSW penalties for using an excessively noisy vehicle are substantial: up to USD 8600 for individuals and USD 17000 for corporations in case of court cases, and USD 250 or 500 in on-the-spot fines [Labban, 2001].

However, according to Close [Close, 2001], the limits for at least some vehicles are far above current state-of-the-art, and it is even stated that "State enforcement agencies are unlikely to invest resources to enforce limits that are so high that subjectively judged noisy vehicles 'pass' the stationary test at current AVSR and ADR limits."

New Zealand has a regulation that prohibits the operation of any in-service vehicle that creates "excessive" noise. However, the excessive noise provisions are not particularly well enforced, and the trend of enforcement is declining [Hunt, 1993].

First in California and later (1975) under the authority of Bureau of Motor Carrier Safety, in-service noise limits of 88 dB(A) below and 92 dB(A) above 56 km/h (35 mph), measured at 15 m from the road lane center at highway speeds, were introduced for trucks and buses engaged in interstate commerce. California also had corresponding limits for cars (82 and 86 dB(A)). The regulation from 1975 is in force today under the responsibility of the Federal Motor Carrier Safety Administration (FMCSA). The regulation can be studied at the FMCSA web site[6]. The limits are given for various road-microphone distances, but converted to a 7.5 m distance and hard ground they would correspond to 91 dB(A) below 56 km/h and 95 dB(A) above 56 km/h. According to the FMCSA, there has not been any active enforcement of the regulation in recent years, but if a complaint is filed the Administration would act and do some measurements to follow-up the problem.

Sweden had a regulation introduced in the late 1980s somewhat similar to the one in New South Wales, but only for motorcycles. However, it has been subject to revision for some years and in the meantime no regulation is in effect.

In 1995, a new system for control of in-service vehicles was introduced in Norway. The noise level measured at a certain rpm in a stationary test (ISO 5130) is to be stated in the vehicle manual and when authorities check this by measurement at the regular vehicle inspections, the level must not be exceeded by more than 5 dB(A). The experience after a few years showed that less than 1% of the tested vehicles failed at the inspection. It was then decided that only those vehicles that are rated subjectively as having abnormally high sound levels are to be tested. Motorcycles are not part of this in-service inspection system, so at the moment the system has no effect on motorcycle-noise-related complaints.

A limit of 85 dB(A) based on a constant-speed test and a stationary test was already introduced in Japan in 1952 [Anon., 1993]. The former is still effective but the latter was replaced in the period 1986-89 by a new "Proximity Stationary Noise Test" suitable for road-side inspections, to cover all types of motor vehicles, with limits currently ranging from 94 dB(A) for the smaller motorcycles to 99 dB(A) for the heavy trucks (96 dB for cars).

Excessive in-service noise is a problem mainly for motorcycles. Many motorcycle drivers think that a motorcycle should emit a great deal of sound and therefore after purchase or legal testing of a motorcycle almost immediately exchange the legal exhaust silencer with another and much noisier one. A motorcycle industry study concluded that a high proportion of motorcycles in traffic in Europe have exhaust silencers that are illegal from the noise point of view [IMMA, 1996]. Of the European countries where surveys were conducted, the estimated proportions of all machines in use with illegal replacement exhaust silencer systems (RESS) ranged from 11% to 59%, the average being 32%. The impression is that this proportion is increasing, and it is argued that lowering of emission limits for new machines will only result in an increase in illegal RESS [van Assche, 2001].

---

[5] http://www.epa.nsw.gov.au/mao/pro/re/index.htm#noise

[6] http://www.fmcsa.dot.gov/rulesregs/fmcsr/regs/325menu.htm

Even though the number of motorcycles is relatively small, the sound output is extremely high and the way of demonstrating this by the drivers so obvious, that the contribution to L_{eq} and even more L_{max} may be substantial in traffic.

4. The Most Important Vehicle Noise Reduction Measures

In this report, a distinction is made between two major sources of vehicle noise: power unit noise and tire/road noise. Tire/road noise is the noise emitted from rolling tires during the tire/road interaction. Power unit noise is a term encompassing the various sources of the vehicle that take part in powering of the vehicle, such as the engine, air intake, exhaust and transmission (gearbox, etc).

Reductions of vehicle noise in order to meet the more stringent noise requirements have concentrated on power unit noise. Most of the efforts in the 1970s and the early 1980s were spent on improving exhaust systems. Over the last 20 years, considerable effort has also been made to optimize engine structures for low noise, while at the same time combustion systems have been developed with improved power and fuel consumption as well as meeting stringent new gaseous emission regulations [Anderton, 1992].

A list of examples of reduction measures follows in Table 1. Additional information is given in reports from Japan [Anon., 1992, Anon., 1999] and Germany [Drewitz & Stiglmaier, 1989]. Figures 2-4 illustrate the major reduction measures employed to satisfy the various steps in the tightening of noise emission limits. Note that this assumes that vehicles are driven according to ISO 362.

Regarding tires, especially after the latest EU and Japanese requirements were enforced, selection of tires is made in order to avoid such designs that make too much noise during extreme vehicle acceleration conditions, which occur when conducting measurements in accordance with ISO 362 or similar tests. Although the vast majority of vehicles are delivered with the same tires, such tires used during testing are not necessarily mounted on the vehicles in actual traffic. Tire manufacturers have made efforts to avoid tonal noise from tire tread patterns by randomizing the patterns (although this technique has been used more or less successfully for decades), but tread pattern design in general is probably the most important noise control measure with regard to tires.

Figs. 2-3 have kindly been provided by Porsche in Germany [Porsche, 2000]. Table 1 and Fig. 4 have been produced with the assistance of truck manufacturers Volvo and Scania.

5. Observed Changes in Public Annoyance

The “end product” of vehicle noise emission reductions should be a decrease in public annoyance from vehicle noise. However, it is not easy to know how much of such changes is attributable to vehicle noise emission changes and how much is due to other effects, such as changes in the built environment or traffic intensity.

There are not many investigations on this subject, but the Working Party has found a few studies of relevance. Two studies are summarized in Fig. 5 below. In a study in Germany [Infratest, 1993], repeated several years between 1977 and 1993, people have been asked to what extent they feel annoyed by noise from various vehicle categories. The percentages of people answering that they feel annoyed by noise of trucks, cars and motorcycles are shown in the top half of Fig. 5. The bottom half of Fig. 5 presents results of a study from the Netherlands; the percentages answering that they feel highly annoyed by cars, light trucks and heavy trucks are shown [TNO, 1994].

The results from these independent studies are rather consistent. There are no very significant changes in how people react to noise from cars or trucks. A rather optimistic interpretation of the trends might suggest that truck noise annoyance increased somewhat up to 1986-87 but decreased somewhat afterwards, while for cars there is a slight increase after 1986-87. From a strict statistical point of view, these results may not be significant, but since the observations seem to be similar in the two studies and since they can be logically “explained,” they are included.

Since the number of trucks and cars in traffic has increased steadily, it is natural that noise annoyance from them will increase somewhat with time. A counteracting trend may be that emission from single vehicles is reduced with time due to more stringent limits. This may be what happened after 1986-87 because rather large steps in limit reductions were made in the 1980s. For heavy trucks in Europe, there was an effective limit reduction of up to 11 dB(A) between 1981 and 1990, including the effect of changes in measuring method. The corresponding changes for cars were only 3 dB during the same time and limited in effect by tire/road noise. Some researchers also think that car tire/road noise has increased during the latest decade due to the much increased use of wider tires designed for higher speeds. The latter could possibly be an explanation for the observations in the figure during later years for cars.

The same data, but for all road traffic considered together, is the basis for a paper in which it is suggested that the major changes in annoyance are due to the implementation in the late 1980s and early 1990s of the Dutch Noise Control Act [de Jong et al., 1995]. However, this can hardly explain the differences seen between annoyance from cars, trucks and motorcycles, so the emission should also play a role.

Fig. 6 shows data, probably from the same Dutch study, but extended with newer data and also with mopeds and motorcycles listed. It suggests that the annoyance decrease for trucks has continued after 1993 but annoyance has also decreased for cars and motorcycles.

Another Dutch study of the annoyance in the Dutch population indicated that the percentage feeling annoyed by road traffic noise has decreased from about 34% in 1989 to about 30% in 1995 [Kruize et al., 1998]. As in the other studies mentioned, part of this result may be due to vehicle noise emission changes, and part of it may be due to physical planning, noise barrier, and sound insulation measures undertaken during this period.

A complicating factor is a possible change in dose-response relationship with time. In a study based on Japanese dose-response surveys, it was concluded that “the tolerance against noise tends apparently to decrease compared with ten years ago" [Kurra et al., 1995]. If this were a general, worldwide trend, the Dutch annoyance decreases 1987-1998 mentioned above would be even more remarkable.

For motorcycles, the German study (Fig. 5) also indicates a most significant decrease in annoyance, especially after 1985. It is unlikely that this is due only to changes in emission limits and there could also be other explanations; see the discussion on motorcycles in 7.9. The first limits were introduced in 1980 and it could be an effect of this that occured after 1983. The use of motorcycles as a whole has increased in Germany over the entire period, so there is no sudden drop in general motorcycle use which could explain the decreased annoyance, except perhaps that registrations of the lightest vehicles has been low since 1986.

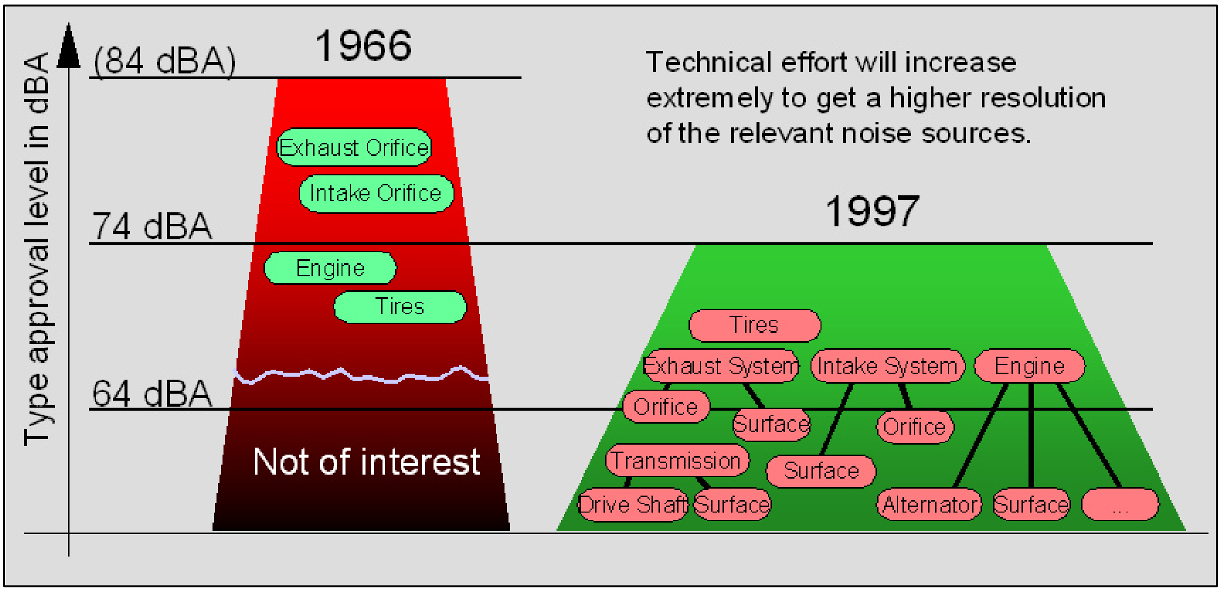


Fig. 2. Illustration of how noise reductions in the last 30 years forced by regulations has led to a totally different noise source distribution. Figure supplied by Porsche, valid for a common (but "noisy") car.

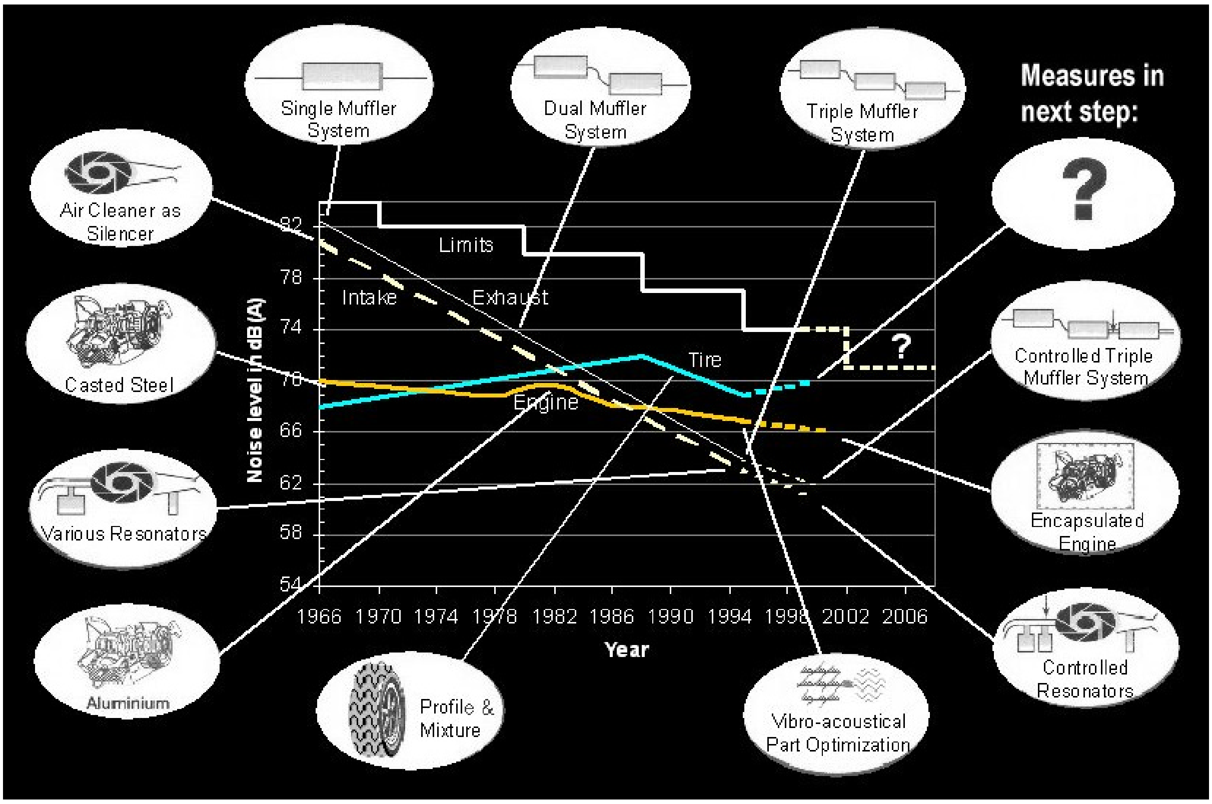


Fig. 3. The most important reduction measures employed in a common car in order to satisfy the various steps in tightened noise emission limits in Germany and the EU. Note the curves that indicate how the limits and the sources engine, intake, exhaust and tire have developed over time. Figure adapted by the author, based on published work [Porsche, 2000].

A study in Japan [Anon., 1992] showed that the percentage of people "troubled by roads or motor vehicle traffic" increased from 28% in 1977 and 24% in 1980 to 35% in 1986 and 46% in 1991. If only those who felt troubled by ***noise*** are sorted out, the figures were 17% in 1977, 13% in 1980, 19% in 1986 and 22% in 1991. This shows that the noise emission reductions have not been fully sufficient to compensate for the increase in traffic (from 1977 to 1991 the number of vehicles has almost doubled). However, since noise as the factor causing the trouble, among four other listed

Table 1. Examples of noise reduction measures. Note that some of the measures are not primarily due to the *noise* legislation, but should have affected noise in actual traffic.

Engine in general:
- Switchover to turbo-charged engines
- Optimization of the engine combustion process, e.g., by using electronics or by improving the shape of the combustion chamber
- Encapsulation or shielding of entire engines or especially noisy parts of them
- Use of hood blankets or laminated covers
- Sound absorptive material in the engine compartment
- Optimization of the stiffness of the cylinder block
- Use of structure-borne noise reducing material

Other vehicle components:
- Improvement of gearboxes, damped propeller shafts
- Improved rear axle transmission
- Shielding of transmission components
- Regulation of the fan by thermostat
- Decreased speed of fan by using a larger fan or optimization of fan shape
- Silencers for air compression outlet noise
- Improvements of brakes for reduction of brake squeal
- Improved aerodynamics
- Selection of suitable tires (low noise at acceleration)

Exhaust System:
- Minimization of outlet and mantle emission of exhaust silencers, e.g., by increased volume
- Introduction of more than one silencer
- Optimization of pipes to/from the silencer, e.g., by equal length pipes or air gap pipes
- Dual-mode mufflers
- Use of absorptive materials
- Active noise control

Induction System:
- 1/4-wave tuners or other resonators
- Thicker duct walls, and/or lined ducts
- Increased volume of air cleaner
- Intake covers or shields
- Active noise control

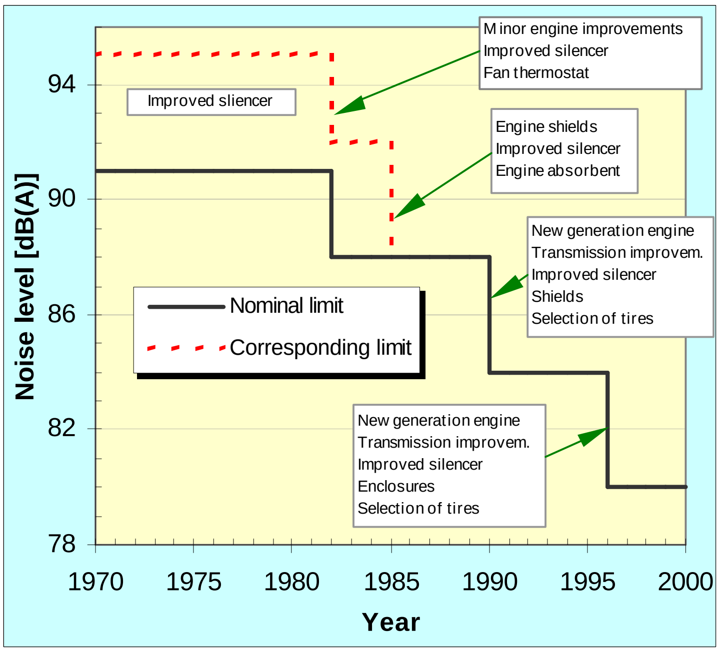


Fig. 4. The most important reduction measures employed in order to satisfy the tightened noise emission limits in the EU. Example for trucks >3.5 tons ("Corresponding limit" is the nominal limit compensated by the effect of measuring method changes 1985).

factors, has decreased from being mentioned by 61% in 1977 and 55% in 1980-86 to 48% in 1991, there are indications that the noise emission reductions have had a positive effect after all.

A similar study is available for Vienna, Austria [Pucher, 1993]. The question concerned the "degree of noise load" felt by the residents. Noise from road traffic was by far the most prominent cause of the noise (60% in 1991). The time trend shows a somewhat decreased annoyance from noise; after increasing somewhat during the period 1970-1976, the "annoyed" groups decreased from about 55% in 1976 to about 37% in 1991, see the figure by Pucher [Sandberg, 1995].

Regarding details in possible annoyance effects of road traffic noise, e.g., changes in frequency spectra, refer to Chapter 10.

With reservations concerning the sparse data available[7], it may be concluded that annoyance data suggest that annoyance due to road traffic has been reduced in the latest 10-15 years, despite increasing traffic. Part of this may, no doubt, be explained by general noise immission reduction measures being undertaken, but part of it may also be attributable to vehicle noise emission changes after the mid 1980s. In particular, the annoyance seems to have been reduced for the "noisier" vehicle types, such as heavy trucks and motorcycles, the categories for which measures seem to have been most effective—as described later in this report.

[7] It is suggested that annoyance scores for motorcycles may be significantly affected by the weather during the time of the study. The use of motorcycles may vary a great deal from time to time due to this; consider a year with a very rainy summer versus a year with a very dry summer.

6. Observed Changes in Community Noise Levels

Moving progressively away from the receiver (i.e., the affected person) toward the source, the next logical step after studying the subjective measure of “annoyance” would be to study the objectively measured traffic noise immission. When such possibilities are exhausted, it is time to turn to emission. This chapter concentrates on noise measurements made between the source and the receiver encompassing a stream of vehicles, mainly expressed as an equivalent (L_{eq}) or other average type of level. It means that these measures are influenced not only by the emission levels of individual vehicles but also by the number of vehicles, and the way they are driven. If immission is considered, changes in the physical environment between source and receiver may also occur, e.g., the introduction of noise screens. Even though the measurements are mostly made where road traffic is the major cause of noise, such measurements can be characterized as community noise measurements. A review of results collected from various sources follows.

First a look at typical increases in road traffic noise emission, independent of vehicle characteristics. Considering only the increase of traffic and changes in average speeds, it has been calculated that, for Germany, the noise levels were increased between 1975 and 1992 by 2.5 dB(A) on motorways and by 1.5 dB(A) on federal and state highways, as well as on county roads [Ullrich, 1994]. According to Steven [Steven, 2001-1], the increase on urban streets is even higher. It follows that for unchanged vehicle noise emissions, one can expect traffic noise increases of 2-4 dB(A) over the time period 1975-2000. If these large increases are not actually measured, it may indicate a favorable effect of the vehicle noise regulations. Of course, large variations may occur due to the traffic volume and speed changes on the particular road or street. As an extreme, it can be mentioned that between 1989 and 1994 in Ghangzhou, China, L_{eq} increased by 4 dB(A) due to a dramatic traffic increase [Wu, 1999], but as an overall rule of thumb it may be useful to consider the above values (2-4 dB over 25 years) as typical of most industrialized countries.

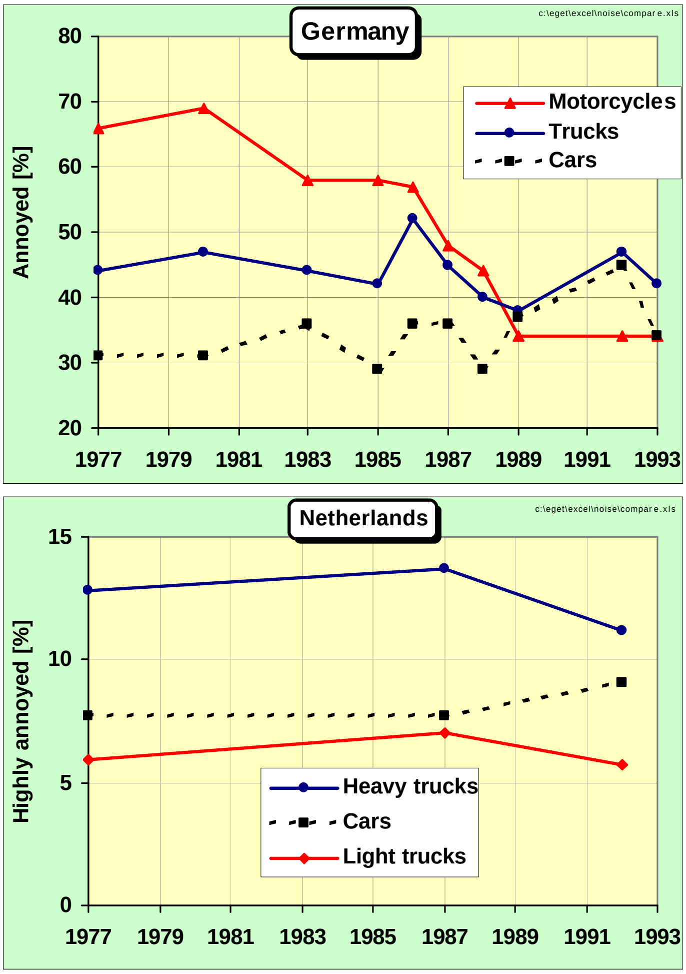


Fig. 5. Part of the population annoyed by noise from different road vehicles as a function of time. Top half from a German investigation, bottom half from a Dutch investigation.

In the USA, community noise levels have been studied since 1937. The first useful study was carried out in 1937 in four major cities by Bell Telephone Laboratories, covering a total of no less than 1700 sites. It has been possible to compare these early measurements to later measurements, according to Sutherland [Sutherland, 1986]. Utilizing over 40 community noise surveys in the USA and Europe from 1937 to 1978, Sutherland concluded that one clear trend is seen—the average noise levels in typical residential areas do not appear to have changed significantly over those 50 years. Since traffic has increased dramatically over this period, it would imply that individual emissions must have been reduced to compensate for this. Further, vehicle speeds have increased over this time period, and the latest major increase should have been the termination of the US national speed limit of 55 mph (89 km/h) in the early 1990s, raising maximum speed limits in most states to 65-75 mph (104-121 km/h).

A study reported by Vogiatzis and Psichas [Vogiatzis & Psichas, 1993] claims that in the city center of Athens, an increase of 3 dB(A) in L_{eq} has occurred between 1977 and 1987. This is based on 420 measuring points over an area of 12 km^2, but it is not clear how much traffic volume, speed and proportion of heavy vehicles may have changed over the same period. For example, a doubling of traffic volume should give a 3 dB(A) increase in L_{eq}, but it is unlikely that traffic has increased so much in Athens during the ten years.

Over the period 1983-1996, noise has been monitored in the Spanish town of Gandia at 50 sites in a network of 200x200 m [Romero et al., 1998]. The resulting mean L_{eq} varied between 68.5 and 70.6 dB(A), with the lower value at the first and last year and the highest in 1992. Unfortunately, Mr Romero has not been able to supply traffic volume data that would have been valuable in order to purge the data from the influence of traffic volume. However, it is likely that traffic volume, as in most European locations, would have increased greatly over the 13 years, so it is likely that vehicle noise emission reduction may explain why no noise increase was recorded from 1983 to 1996. In 1997, the mean level was 1.4 dB(A) lower than in 1996, but this was evidently attributable to the opening of a by-pass road.

A survey in Brisbane, Australia, made in 1974 and 1986 indicated no significant (L_{eq}) noise level change between these years [Renew, 1993].

The national Danish noise mapping in the beginning of the 1990s showed that, over the previous 10 years, the proportion of homes exposed to more than 55 dB(A) (L_{eq24h}) had decreased from 33% to 20% [Bendtsen, 1999]. The main part of this is believed to be due to planning and zoning, i.e. a large-scale separation of homes and high-volume traffic, although a minor part may be due to vehicle noise emission changes. Similar results have been recorded in Sweden for a longer time period (15 years).[8]

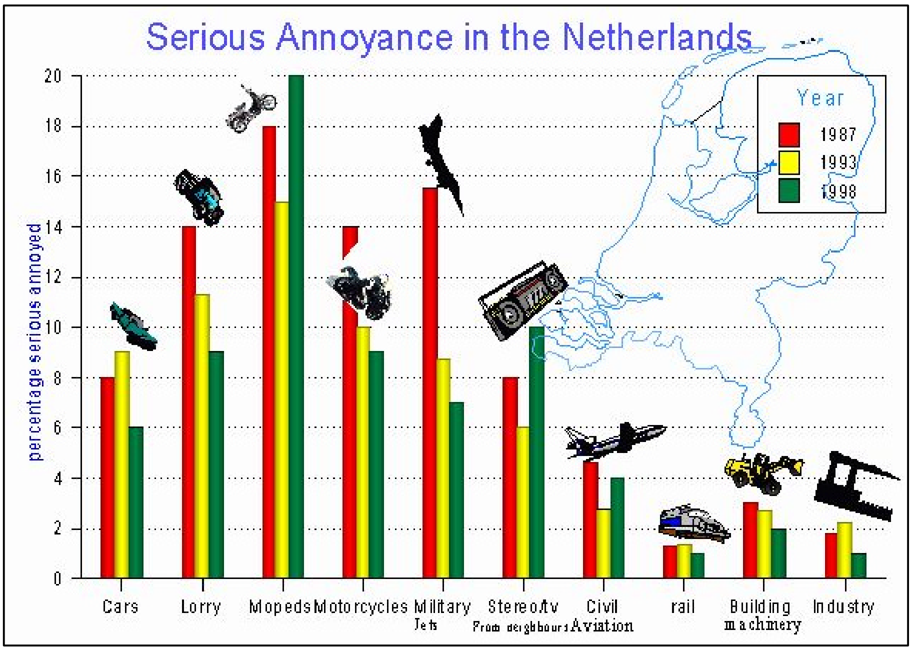
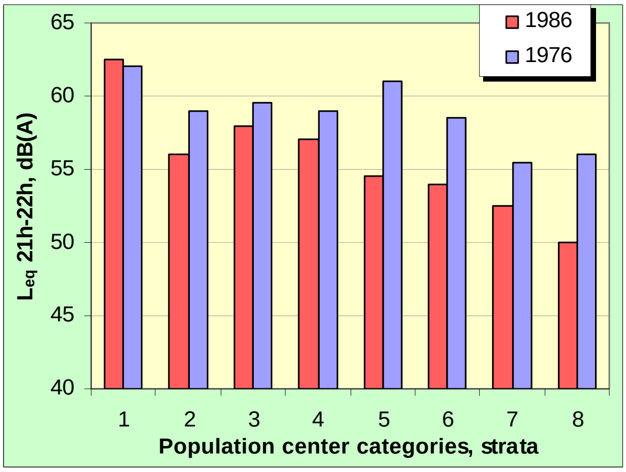


Fig. 6. Part of the population seriously annoyed by noise from different sources as a function of time. Data from [TNO, 2001] based on questions to 4000 Dutch adults.

The results of a survey presented by Sargent and Fothergill [Sargent & Fothergill, 1993] at 1000 sites in the United Kingdom arrived at an arithmetic mean for L_{10} (measured over 18h/day, 1 m from building facades) of 55.6 dB(A), which is compared by the authors with a similar survey presented by the Transport and Road Research Laboratory in 1972 that gave 57.0 dB(A). Road vehicles are dominating as noise sources. The years when data collection took place are not stated, but it seems as if a 20 year period resulted in a community noise reduction of approximately 1 dB(A). At the same time, the volume of traffic has approximately doubled and the length of public roads has increased by about a quarter. If a compensation of 3 dB(A) is made for the doubling of traffic, the result indicates that immissions for the same traffic volume would have been reduced by 4 dB(A). Emissions from the source would have been reduced by less, since it is likely that part of the reductions may be due to noise abatement schemes such as construction of noise barriers, etc.



Population categories - Legend
1. Paris city
2. Suburbs in the Paris area
3. Other conurbations, population > 1 000 000
4. Other conurb., popul. 200 000 to 1 000 000
5. Urban areas, population 50 000 to 200 000
6. Urban areas, population 20 000 to 50 000
7. Urban areas, population 5 000 to 20 000
8. Rural areas, <5000 inhabitants

Fig. 7. L_{eq} *levels measured in French urban areas of various types in 1976 and 1986, illustrating a change in general noise exposure in France. All measurements were made between 21 h and 22 h in the evenings.*

The most encouraging results of all come from France. Social and community noise surveys in 1986 and 1976 [Maurin, 1995] indicate that the French population was less exposed to traffic noise in 1986 than in 1976. Fig. 7 shows a compilation of measured L_{eq} levels in French urban areas. The levels had been reduced by 2-6 dB(A), except in the center of Paris where there was an increase of 1 dB(A). Part of this encouraging result is believed to be due to lower vehicle noise emission limits.

Noise levels at 3800-4600 sites in Japan were monitored between 1982 and 1991 [Anon., 1993] and compared with the "Environmental Quality Standards (EQS)" (i.e., a certain desired median level L_{50}) as well as "Required Limits" (i.e., an acceptable max. limit in L_{50}) at each site. The latter are 5-15 dB(A) higher than the former, depending on the type of area and road. Data for 1993-97 were taken from another Japanese report [Anon., 1999]. The proportion of sites where the EQS and the Required Limits are exceeded are shown in Fig. 8. It is clear that a certain impairment has taken place regarding the Required Limits. The EQS limits at the end of the 1990s still show a somewhat increasing trend.

---

[8] This author is skeptical of the extent of these dramatic improvements in the Nordic countries and thinks that it may be partly due to imperfect or not fully compatible mapping methods.

The data in Fig. 8 are influenced by traffic increases. Over the time period 1981-91, traffic volume increased by 37%, which corresponds to a noise level increase of approximately 1.4 dB. Such traffic changes could, at most, be responsible for the increase in the number of sites where Required Limits are exceeded, so this does not leave any room for significant noise emission reductions from individual vehicles.

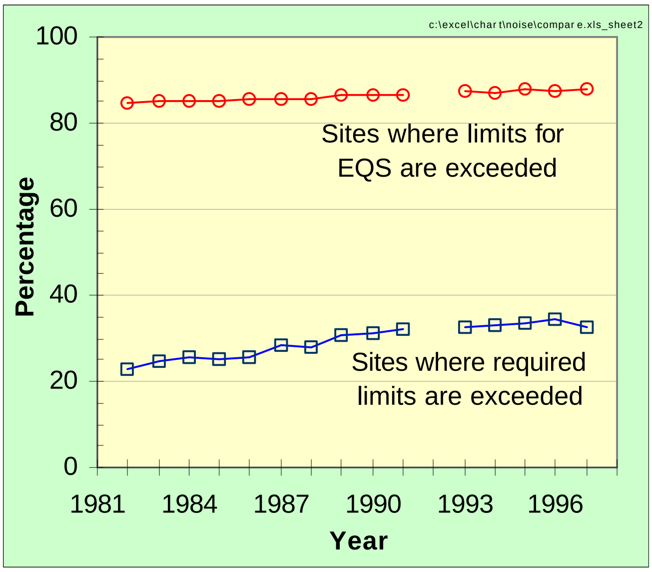


Fig. 8. How well noise immission standards were satisfied in Japan in previous years: Percentage of sites where limits were exceeded versus time.

With a lack of more meaningful data on immission changes with time, we will now have to study emission, i.e., measurements made at or very close to the roadside. Data, however, still refer to a mix of vehicles in actual traffic.

In Japan, Konishi [Konishi, 1981] concluded that between 1977 and 1980, noise emissions expressed as median level L_{50} at an elevated highway where traffic traveled at 50-70 km/h were reduced by 1-1.5 dB(A). These results have been normalized with respect to traffic volume. The theoretically calculated change as a result of limit tightening and exchange from old to new vehicles during the same period was 1.5 dB(A), so the measured effect was in accordance with that expected from the regulatory actions. This is not consistent with the results of the Japanese study mentioned above. However, when the same author measured the level changes at greater distances from the highway, the effect was diminishing with increased distance.

In the Japanese city of Nagano, measurement of noise levels in 1984 and 1990 showed that the average for the entire city (many sites) had been reduced by only 0.2 dB(A) [Takagi et al., 1997]. During the same time period, a certain increase in traffic volume had occurred. In Naha City, road traffic noise levels were essentially the same in 1992 as they were in 1984; however, with an uncertain tendency for a noise increase 1984-1988. The results for Nagano were further broken-down into classes of traffic volume, and from this it appeared that in the cases where traffic volume was essentially unchanged between 1984 and 1990, L_{eq} was reduced by 3.0 or 4.0 dB(A). This suggests that vehicle noise emission may have accounted for a noise reduction of over 3 dB(A).

A later article by the same main authors [Takagi et al., 2000][9], analyzed measurements of traffic noise in 38 Japanese cities. The results were then not so positive. It appeared that L_{50} was essentially unchanged from the time period 1980-83 to 1990-93, provided the traffic volume was about the same. A more detailed analysis indicated that noise level increases higher than motivated by increases in traffic volume occurred on 4-lane national roads (assumed by this author to be high-speed roads), whereas the contrary seemed to occur on 2-lane city and prefecture roads (assumed by this author to be low/medium-speed roads). Note that this is consistent with the findings later in this report, assuming that tire/road noise might have dominated in the first case while power unit noise might have dominated in the latter case.

Measurements at the roadside in Nanjing, China, at a site where noise levels were monitored in 1976, 1986 and 1993, showed that L_{eq} increased by 6 dB(A) between 1976 and 1993 [Liu, 1994]. After compensation for the increase in traffic volume by 3 dB per doubling of traffic, the results indicated a reduction from 1976 to 1993 of about 1 dB(A). This may be compared to a reduction of 2-6 dB(A) in emission limits, depending on type of vehicle, implemented in 1985 [Cheng, 1994]. Either the exchange from old to new vehicles was extremely slow or the efficiency of the limits must have been very low in China by that time.

In contrast to the above, another result from China, showed that between 1979 and 1985, equivalent levels at approximately 260 measuring points in the Beijing area had been reduced by 3 dB(A) despite a 150% increase in traffic volume [Wu, 1999]. Compensating for traffic volume, the noise decrease was about 7 dB(A). How could such a dramatic noise decrease be obtained after only 6 years? It appeared that the main cause was an excessive use of horns in 1979, something that was prevented by city regulations during the following years. Not only was the unnecessary use of horns forbidden, but drivers were also encouraged to replace their old horns with newer and less noisy ones. However, in 1979 the Chinese government also enacted regulations against vehicle noise emissions; with limits that were lowered in 1985. The former were similar to the first European limits and the latter were about 1-2 dB higher than those that were introduced in Europe 1979/80. It is probable that part of the 7 dB(A) noise reduction 1979-1985 may have been due to the vehicle noise regulations.

Very extensive measurements in 1976 in the German province of Bavaria have been compared with similar measurements in 1991 by Leuner [Leuner, 1991]. During each of these years, 300-400 sites distributed in urban areas of different population concentrations were utilized, of which 124 sites were identical in the two measurement series. Since a measuring point 1.5 m from the curbside of the road or street was always used, these measurements can be characterized as emission measurements.

---

[9] Since this and the previously referenced article were written in Japanese with English figure captions and abstract, this author is not entirely certain that the referenced results are absolutely correct relative to the article.

The results of one-half hour measurements in the period 22:00-06:00 are summarized in Table 2. In this table, the changes in traffic volume are also indicated, as determined from official German traffic statistics. Unfortunately, this is not for Bavaria but for the entire Germany (except the former GDR) and with no distinction between day and night. Finally, the table includes the original L_{eq} difference corrected by this author for the increase in traffic volume (L_{eqcorr}). The latter value is believed to be essentially independent of traffic changes and should better reflect the changes in individual noise emissions of vehicles.

Table 2. Noise emission measurements made in 1976 and 1991 in Bavaria, according to [Leuner, 1991]. The noise levels are the arithmetic averages of L_{eq} over all sites.

Measured parameter	Notes	Measurements in 1976	Measurements in 1991	Change from 1976 to 1991
L_{eq}	Bavaria Night	41.5 dB(A)	44.8 dB(A)	+3.3 dB(A)
Traffic volume	West Germany day + night	$292 \cdot 10^9$ km	$467 \cdot 10^9$ km	+60 %
L_{eqcorr}	Bavaria Night			+1.3 dB(A)

The change in L_{eq}, after correction for traffic volume, shows a slight increase. One should note here that the traffic data are for all (western) Germany while the noise data are for Bavaria only. If traffic increases in Bavaria would have been dramatically different from that in the rest of Germany, the noise level change would be different, although it is hard to believe that this could have been a significant factor. More likely is that the nighttime traffic may have increased more than the total traffic, which would mean that the noise increase is overestimated. It seems safe to conclude that a significant noise emission decrease (per vehicle) could not be documented in this study.

A compilation and summary of the studies mentioned in this chapter follows in Table 3 below. The table illustrates the rather wide range in results—from a significant noise reduction in France and the United Kingdom, to a small noise increase in Bavaria and Paris and, most probably, also in Greece. In the immission-type investigations, effects of noise reduction measures such as construction of noise screens and earth berms would influence the value obtained, while in the German investigation the measurements were made too close to the roads to be affected by such measures. Nevertheless, it is very difficult to understand why some investigations show such deviating results[10].

Although, variations between countries and locations are very large, on the average it seems that the vehicle noise decreases have approximately matched the effects of traffic volume increases, and thus kept community noise at a fairly constant level.

7. Changes in Individual Vehicle Noise Emission Levels

7.1 Introduction

As discussed in the previous section on community noise surveys, it was difficult to draw clear conclusions from such studies. To study noise emission levels from individual vehicles is probably a much more precise and consistent method, even though such studies are one step further away from the impact on human beings.

The Working Party has identified several studies that may give an input to the question of whether and how much vehicle noise emission for individual vehicles has changed over the past 30 years. Since several of these studies have not been internationally reported, some WP members have produced summary papers. In this limited space, it is impossible to present all studies and, therefore, a table summarizing the data in a systematic way are included at the end of this section. Nevertheless, a few of the major studies are mentioned and illustrated in the following.

There are certain problems with studies of these types. The most significant of them is the possible influence of different road surfaces used in the different studies. Although it has been the intent here to use data where the type of road surface is the same when comparing data from various years (generally a rather smooth dense-grade asphalt), surfaces within the type do give different noise levels. According to the author's judgement, such errors may normally amount to up to 2 dB(A) in this study; in some exceptional cases perhaps even a higher influence may have occurred. The road surface effects should, however, even out when considering such a wide range of investigations as are included in this report—although they may explain some of the otherwise strange variations in results. Other types of errors are the possibility of slight variations in measuring method from time to time as well as influence of acoustical reflections or absorption.

The driving conditions of the vehicles largely influence the result. Therefore, this section is divided into parts representing the major driving conditions.

[10] Perhaps it is due to influences of the methodology?

7.2 Vehicles at Standstill - Noise Changes for Engines and Exhaust Silencers

As is evident from Figs. 3-4, much of the effort in the 1970s and the early 1980s concentrated on improved exhaust systems. That this had some effect appears from the investigation by Friberg and Norberg [Friberg & Norberg, 1989] which is summarized at the top of Table 6a in the overview section. Friberg and Norberg measured a large number of in-service trucks at standstill. Comparing trucks produced in 1967-76 with trucks produced in 1983-86, one can see that, although the reduction from the early to the later models at a far-side position is very little or nil, the reduction in noise near the exhaust system is significant. Near the engine, the reduction is just marginal.

In a study by Wolschendorf [Wolschendorf et al., 1991] it is concluded that noise emission of series-production IDI Diesel engines (indirect injection Diesel engines, mainly used in cars) has been reduced by 5-8 dB(A) in the period 1975-90. However, this is in clear contrast to results of Anderton [Anderton, 1992] at ISVR in England who has recorded a reduction of only 1.5 dB(A) for the same type of engines, albeit with only 3 samples representing new engines, see Table 4. Anderton's study concerned all major types of car and truck engines and, as seen in Table 4, concluded that petrol engines and turbocharged DI Diesel engines have become noisier by 2 and 1 dB(A), respectively, while the normally aspirated DI Diesel has been reduced by 4 dB(A). The increased noise levels are blamed on mechanical noise "hiding" otherwise significant improvements in engine structure response, while the decreased noise is credited to the engine structure response improvements being fully efficient also on an overall basis. The quite remarkable result of increased petrol engine noise is due to some lightweight engines and engines with outputs higher than 45 kW/liter being much noisier than older types.

Table 3. Summary of changes in noise levels recorded in the community noise studies mentioned in the text.

Study	Studied period	Type of measure	Notes	Change in noise level with time
[Sutherland, 1986] USA + Europe	1937-78	$L_{average}$	Immissions. Big number of sites	none (dramatic incr. of traffic)
[Vogiatzis & Psichas, 1993] Athens, Greece	1977-87	L_{eq}	Immissions? 420 sites	+ 3 dB(A) (incl. traffic increase)
[Romero et al, 1998] Gandia, Spain	1983-96	L_{eq}	Immissions? 50 sites	none (incl. traffic increase)
[Renew, 1993] Brisbane, Australia	1974-86	L_{eq}	Immissions, several sites	none (traffic volume increase)
[Sargent & Fothergill, 1993] United Kingdom	1972-93	L_{10}	Immissions, 1000 sites	- 4 dB(A) (corr for traffic increase)
[Maurin, 1993] France	1976-86	L_{eq}	Immissions. Big number of sites	- 6 + 1 dB(A) (incl. traffic increase)
[Anon, 1992] Japan	1982-91	Sites mee-ting limits	Immissions, 3800-4600 sites	more sites exceed limits (incl traffic increase)
[Konishi, 1981] Hanshin, Japan	1977-80	L_{50}	Emission type, same single site	- (1-1.5) dB(A) (corr for traffic increase)
[Takagi et al, 1997] Nagano & Naha City, Japan	1984-90	L_{eq} L_{50}	Emission type, many sites	- (3-4) dB(A) (corr for traffic increase)
[Takagi et al, 2000] 38 cities, Japan	1983-93	L_{50}	Emission type, many sites	none (corr for traffic increase)
[Takagi et al, 2000] 38 cities, Japan	1986-93	L_{50}	Emission type, high-speed roads	increase (corr for traffic increase)
[Takagi et al, 2000] 38 cities, Japan	1986-93	L_{50}	Emission type, low-speed roads	decrease (corr for traffic increase)
[Liu, 1994] Nanjing, China	1976-93	L_{eq}	Emission type, same single site	- 1 dB(A) (corr for traffic increase)
[Wu, 1999] Beijing, China	1979-85	L_{eq}	Emission type, 260 sites	- 7 dB(A) (effect of horns) (corr for traffic increase)
[Leuner, 1991] Bavaria, Germany	1976-91	L_{eq}	Emission type, 300-400 sites	+ 1.3 dB(A) (corr for traffic increase)

A critical review of noise emission of diesel engines during the last 30 years has been presented by Spessert and Reddert [Spessert & Reddert, 1999]. These authors analyze the development in detail and conclude as examples that normally aspirated diesel engines from the beginning of the 1990s emitted 3.5 – 6 dB(A) lower noise than corresponding engines from 20 years earlier, while they had increased the power by 4-16% over the same time period; see Fig. 9. This is consistent with Anderton's article. For turbocharged engines, Spessert and Reddert indicated, as an example, that diesel engines from the beginning of the 1990s emitted 4 - 5 dB(A) lower noise level than corresponding engines from 20 years earlier, while they had increased the power by 58-94% over the same time period. This is not in line with Anderton's results for similar engines. The authors also conclude that the noise reduction has been achieved by a combination of combustion optimization and engine speed (rpm) reduction.

Spessert and Reddert also compared measurements on old direct-injection diesel engines (1975) with similar measurements in 1990 and concluded that, on the average, the noise levels had been reduced by 3 dB(A). Finally, they also compared measurements on diesel engines produced after 1992 and found that these were 8 dB(A) less noisy than their 1975 counterparts. All these results were averages for a large number of engines.

With regard to noise emission of idling vehicles, in particular with diesel engines, refer to section 16.4 on light trucks and sport utility vehicles.

Table 4. Difference between engine test bed overall noise levels measured in 1989-92 and noise predicted from formulas based on 1975 empirical data of ISVR and Ricardo. From Anderton [Anderton, 1992]. IDI = Indirect injection. A negative sign means a reduction in noise.

Engine type	Number of engines	Mean value of noise change from 1975 to 1989/92	Standard deviation
Petrol engines	17	+ 2 dB(A)	4 dB(A)
High speed IDI Diesel	3	- 1.5 dB(A)	1 dB(A)
Turbocharged DI Diesel	11	+ 1 dB(A)	2 dB(A)
Normally aspirated DI Diesel	7	- 4 dB(A)	2 dB(A)

7.3 Type Approval Testing Conditions

First, to give a historical perspective, one may note the data presented by Waters [Waters, 1974]. Waters presented measurements according to ISO R 362 (an early version of the present ISO 362) for heavy vehicles, encompassing year models 1913[11]-1970. The vehicles from the period 1935-1950 seemed to be the quietest ones and the models from 1965 to 1970 the noisiest ones. The latter ranged from 87 to 94 dB(A). Of course, the younger of those trucks would do much more efficient transportation work than the older ones. With regard to light vehicles, the only similar study that this author is aware of is the one presented by Sandberg [Sandberg, 1984], according to which power unit noise from cars seemed to be the same over the period 1920-1960, but with dramatic reductions in the 1960s and 1970s.

What these studies tell us is that before and a little after the modern vehicle noise limits were introduced in the 1970s, “pre-regulation” vehicles in traffic must have been much noisier (when it comes to power units) than the “post-regulation” vehicles.

However, there are always exceptions to the rule. The organization handling public transport within the greater Stockholm area, now called Stockholm Transport, had, many decades ago, strict purchase rules with respect to exterior as well as interior noise of city buses [Kaellberg, 1979]. Based on the early versions of ISO 362, the buses purchased 1960-65 emitted 83-90 dB(A); in 1967 the level was 83, in 1975 it was 80 and in 1978 it was 78 dB(A). It means that this organization and its bus suppliers—Volvo and Scania—were 15-20 years ahead of the coming EU regulations. This author tested in-service city buses at the end of the 1970s that emitted 76 dB(A) during ISO 362 driving, levels that today's buses match but hardly go below.

In a German study [de Veer & Ullrich, 1991], it was found that cars from the late 1960s, i.e., before modern noise regulations were introduced, were 4 dB(A) noisier than cars from 1987/88. Furthermore, trucks were 2 dB(A) more noisy from the earlier period than from 1985/87, although 3 dB(A) of reduction was obtained between 1977/81 and 1985/87, which means that the noise levels during the first decade increased somewhat before they decreased in the latter decade.

Another German document [Stenschke, 1993] shows a slight decrease (1 dB) between year models 1983 and 1991 when the median car is considered, but 2.5 dB for the 5th percentile car. See the section on maximum levels.

The results of de Veer and Ullrich are essentially confirmed by a Norwegian study [Berge, 1994], which is presented in Fig. 10. For cars, Berge recorded a little larger decrease of noise levels; for trucks he recorded first a slight increase and then a decrease. One can see that the trucks had a fairly good margin with respect to the limits the first decade (which seems somewhat contradictory to the data of Waters above), but since 1990 they really have had difficulties in meeting the requirements. Note, however, that the figure for trucks is partly misleading since a measurement method change has had the effect that around 1985/86 there is an additional improvement of up to 4 dB(A).

Other studies [Liedholm et al., 1980], [OECD, 1980], show that average cars during 4-7 years in the middle of the 1970s were about 1 dB(A) less noisy at the end of the period than at the beginning. In a study by de Graaff, [de Graaff, 2000] it is shown that the noise levels for cars between 1980 and 1990 approximately follow the same trend as in Norway, i.e., a big step is taken 1980-82 but later the change is very small. Most cars had a rather good margin with respect to the limit until 1996. See Fig. 11. For heavy vehicles, the noise trend follows the limit values well after 1982. Data were compiled in the Netherlands but collected for type approval at various places in Europe, comprising about 40000 cars and 39000 trucks. The report by de Graaff presents a wealth of detailed data from the period 1980-1999.

Both Fig. 10 and Fig. 11 indicate approximately a 4 dB(A) decrease in car levels in the years just after 1980. Most of this is probably due to the measuring method change that took place in 1980, in combination with the switchover from 4-speed to 5-speed gearboxes 1978-84—which implied that the majority of cars were no longer tested in the 2nd gear but in both 2nd and 3rd gears, with calculation of the average level.

Unfortunately, the Norwegian and Dutch data for trucks do not appear to be consistent in every way. This may be due to different vehicle fleets in the countries, but one should also note that the databases have their limitations. It is

[11] Yes, 1913 is correct. In fact, also vehicles from the years 1935, 1938, 1943, 1947, 1950, etc. were included

suggested that one should put more emphasis on the Dutch than on the Norwegian data since the latter is based on only a few vehicles.

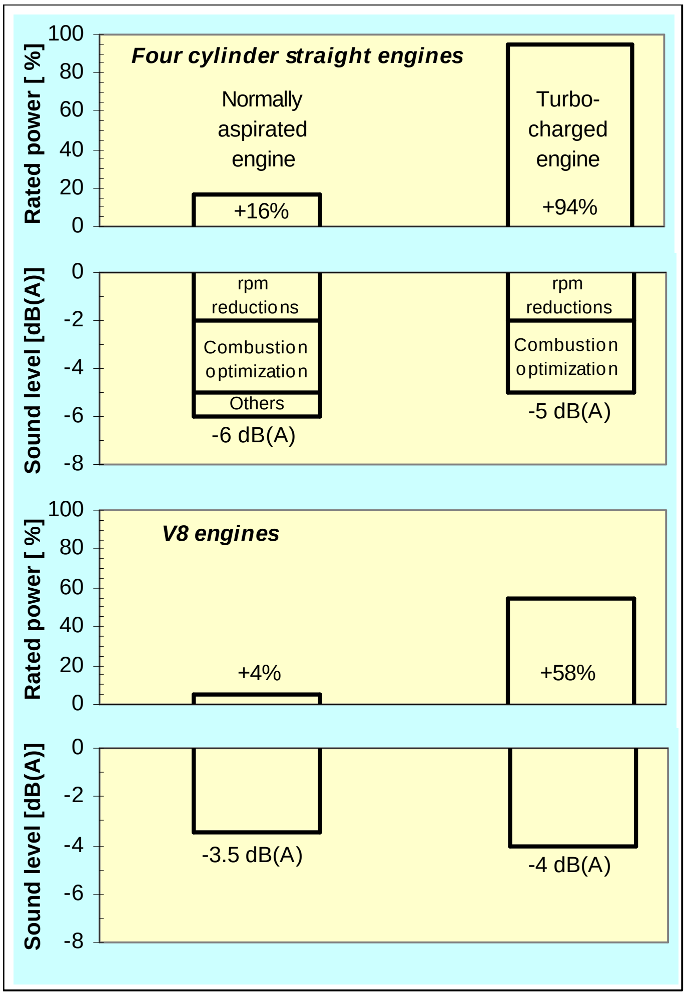


Fig. 9. Difference in rated power and noise between engines typical of 1971 and engines typical of 1988-90 (in the lower diagram the newer engine is from 1992). Negative sound levels mean a noise reduction with time. Diagram adapted from Spessert and Reddert [Spessert & Reddert, 1999].

In Fig. 11, the portion for trucks, it is remarkable that in the three years between 1989 and 1992 the median level decreased from 88 to 80 dB(A). What could be the reasons for such a dramatic reduction, and why is it greater than the actual limit change requires? de Graaff has proposed the following very plausible explanation. First, there was a limit change of 4 dB(A) in 1989-90. About the same time (1990), there was a special regulation in Austria, called Nachtfahrverbot (night travel prohibition). The authorities wanted to force any nighttime transit traffic, mainly between Germany and Italy over the Alps, to run much more quietly. To achieve this, Austria prohibited all commercial transit traffic during nighttime, unless the vehicles complied with a noise level 4 dB(A) lower than the EU limit coming into force about the same time. Austria was much criticized for this, including arguments that tire/road noise would not be affected and would limit the efficiency of the regulation. Two truck manufacturers offered such vehicles almost immediately. In 1989 one could find advertisements in journals and magazines for quiet 80 dB trucks marketed as e.g., “Flüsterer” (“Whisperer”).

This seems to have had a substantial and rapid effect on the entire European truck fleet, since most major manufacturers wanted to supply trucks that would not be limited in their operation by the Nachtfahrverbot. Thus, only a couple of years later, many, if not most, of the trucks met the 80 dB(A) limit. The solutions used to achieve this in such a short time had disadvantages the first time; for example, the use of enclosures was one of the major solutions. But it seems to have paved the way for the EU and ECE 80 dB(A) limits in 1996, for which the technical solutions are generally better than the ones used to meet the sudden Nachtfahrverbot. This illustrates the exceptional strength of market forces in promoting a noise reduction, if this is necessary for efficient transportation as in the Austrian case.

For motorcycles, there are two investigations available. First, a German study shows that type approval levels for motorcycles >175 cm^3 measured in 1994 versus 1990 have been reduced by 1 dB(A) when looking at median levels and 3 dB(A) when looking at maximum levels (5th percentile) [Stenschke, 1994]. In that period, a 2 dB lowering of limit values occurred. With regard to actual traffic, Stenschke concluded that “it was not possible during the period from 1978 to 1992 to demonstrate any successes in real traffic. Further measures have to be taken to reduce the noise emission of motorcycles”.

Secondly, a Norwegian study shows a reduction of motorcycle noise measured according to ISO 362 of about 3 dB(A) between 1970 and 2000 [Berge, 2001]; see Fig. 12. These measurements were made in 1995-99 on in-service motorcycles. Thus, they may not have had original components. Note that several of the motorcycles clearly exceed the limit values after 1987. It is neither possible to see any effect of the introduction of limits in 1980, nor the tightening of limits in 1988 and 1993. Thus, both Stenschke's and Berge's studies indicate very poor efficiencies for the regulations. More data is presented in Table 5.

7.4 Acceleration in Urban Conditions

A Japanese study showing the vehicle noise level measured at 20, 40, 60 and 100 m after a stoplight is illustrated in Fig. 13 [Yamashita & Tachibana, 1993]. From the start at the stoplight, vehicles accelerate gradually less and have a higher speed when driving towards the right part of each figure. The open circles denote cars/trucks meeting the noise standards of 1979 and the filled circles the standards of 1982 (cars) or 1985 (trucks). The nominal lowering of the limits was 3 dB for all three vehicle categories.

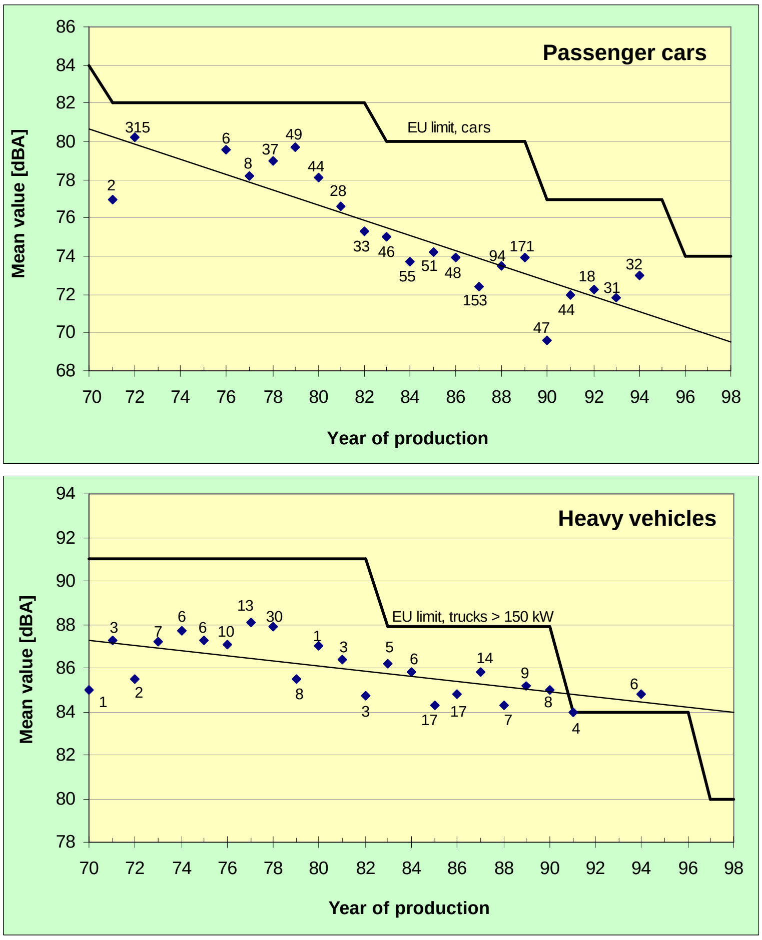


Fig. 10. Mean noise levels measured during type approval testing in Norway in different years. Values both from official type approval tests and research projects. The number of vehicles tested each year is indicated at each point. Note that for trucks, there is an additional reduction effect of changed measuring method around 1985/86 of up to 4 dB(A).

The resulting noise reduction between the two groups of vehicles is 3 dB for cars, 3 dB for light trucks and 1.5 dB for the heavy trucks—when the vehicles are close to the stoplights and still accelerating at rather low speeds. When the cars and light trucks are at 100 m they should already have reached a medium speed and have lower accelerations, and in that case the noise reduction is only 1 dB. The heavy truck noise reduction is 2 dB at 100 m, at which location the trucks are still in the full-throttle acceleration phase. Thus, it seems that the nominal limit reduction is also found in actual traffic, but only during rapid acceleration.

The results of a large German study are illustrated in Fig. 14. The figure is valid for acceleration of vehicles from a medium speed in urban conditions, but there is another figure available (not shown here) which shows approximately the same for vehicles accelerating from standstill. It is interesting to note that for the two heaviest vehicle groups there was first an increase in noise levels from 1978 to 1983 and then a decrease. This is consistent with some other results mentioned earlier and the reason may be that the measuring method change around 1985 was the first step in Europe that really forced truck manufacturers to make effective reductions. This "step" was (for trucks) approximately similar to the Japanese reduction from Phase I to Phase II that seemed to be quite effective, according to the previous paragraph.

The German noise reductions are insignificant for cars, vans and light trucks, but substantial for the buses and heavy trucks.

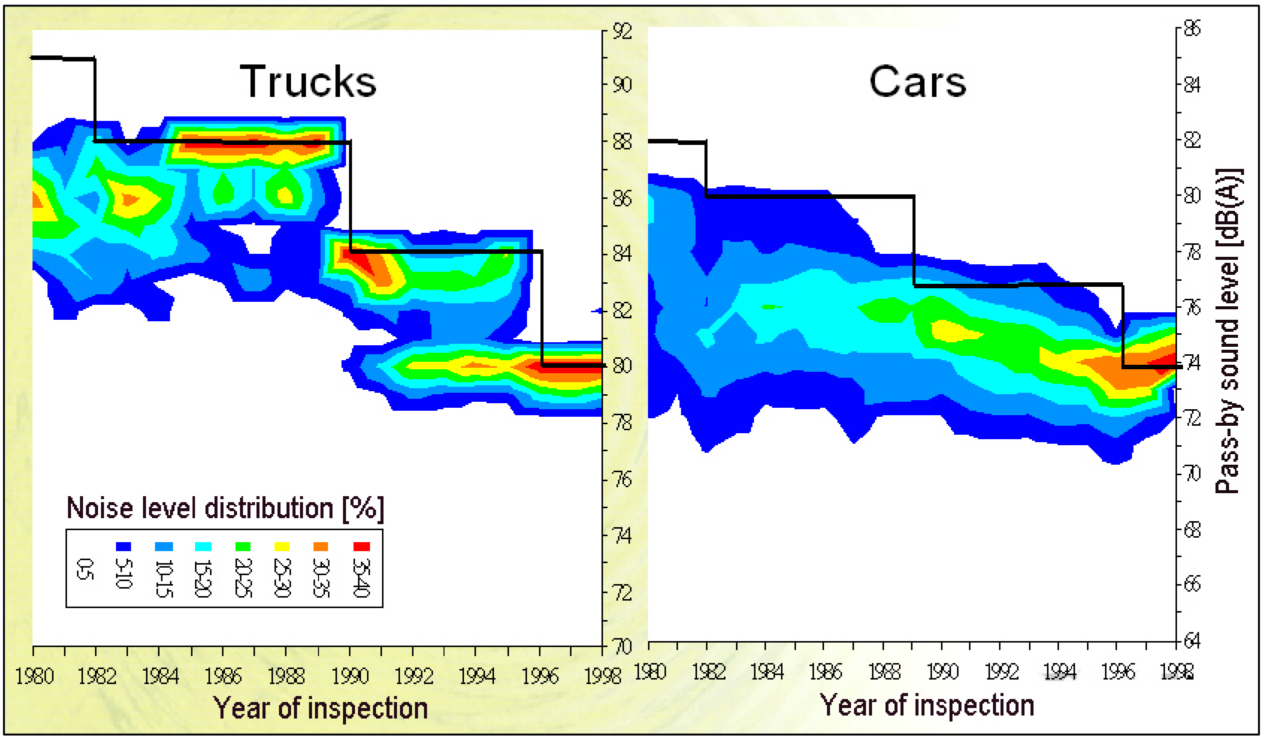


Fig. 11. Same as Fig. 10, but compiled in the Netherlands and for the period 1980-2000. Data processed from [de Graaff, 2000]. By "trucks" is meant the heaviest trucks.

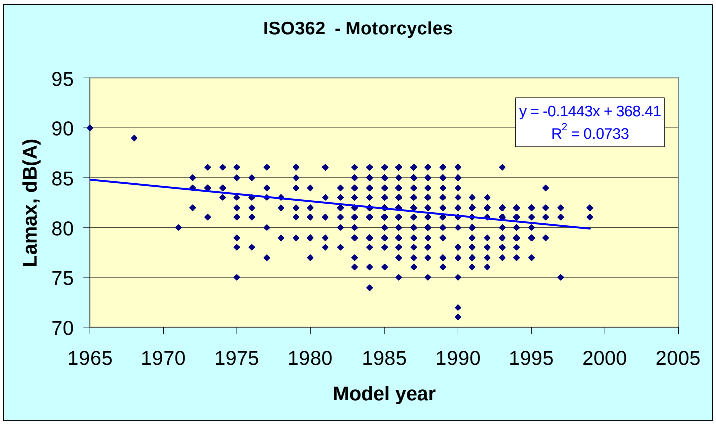


Fig. 12. In-service motorcycles tested in Norway, see text [Berge, 2001]

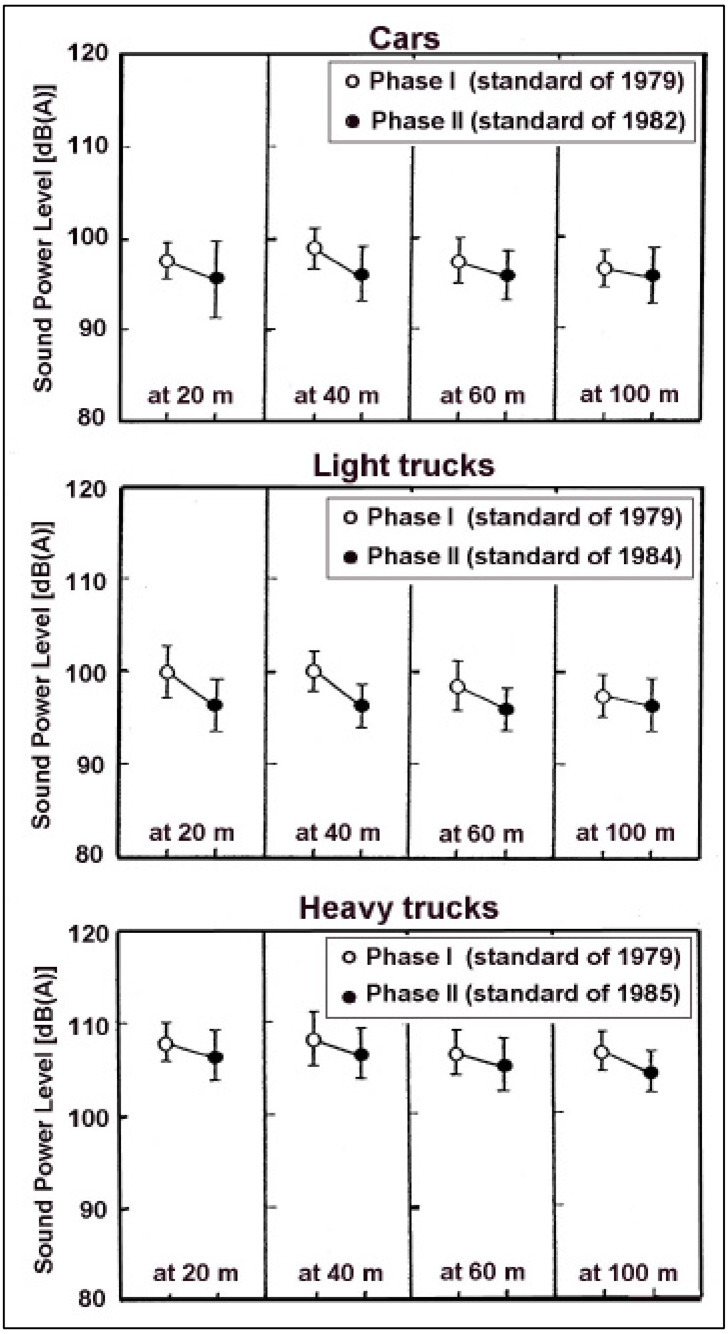


Fig. 13. Sound power level (maximum at pass-by 7.5 m from microphone) from accelerating vehicles as measured at different distances after a stoplight. Adapted from [Yamashita & Tachibana, 1993].

Note that, unlike the Japanese tests, the measured vehicles here include vehicles of all ages and meeting previous standards. The 1992 measurements may still include and perhaps are dominated by a lot of vehicles meeting the standards of the early 1980's. More data are presented in Table 5.

The studies reported in this section give reductions in noise levels of 0-3 dB(A), which is somewhat less than recorded reductions under type approval conditions for a corresponding time period.

7.5 Mixed and Constant Speed Driving in Urban Conditions

In a study of how power unit noise and tire/road noise for cars have developed over six decades, Sandberg [Sandberg, 1984] concluded that, while power unit noise had decreased by 10-15 dB(A) over the period 1920-1982, tires had not become any quieter over the same period. Although this does not tell anything about the efficiency of the limits introduced about in 1970, it gives an interesting long-term perspective.

Further data from the “pre-regulation” era is provided in a study by Kemper [Kemper, 1979]. Vehicle pass-by noise at a speed of 24-25 km/h had been measured in 1977-78 on thousands of cars. It is not stated whether the cars were driven at constant speed or whether they were accelerating, but it is reasonable to assume that power unit noise dominated. Since the model year was identified, the noise levels were plotted against model year of the vehicles (which is then also proportional to the age of the vehicles). The results showed that the car models of 1965-66 were 2.1 dB(A) more noisy than the models of 1977-78. The noise reduction was approximately 0.2 dB/year. Two effects should have contributed here: (1) cars of later models may be less noisy than cars of earlier models (in new condition), and (2) wear and tear of the cars may have created higher noise levels in the older cars than in the newer ones. Furthermore, Kemper points out that one major reason for the noise reduction may be the gradual phasing out of the VW Beatle cars during this period; the Beatle was known to be noisy, and the author estimated that the noise reduction “cleaned” of the *Beatle effect* would be about 0.1 dB/year.

Considering the Beatle effect, it is reasonable to assume that Kemper's data indicate that the car aging effect on noise seems to be less than 0.1 dB/year; i.e., it seems to be essentially negligible. Note that this was for cars from 25-35 years ago. Modern cars with more extensive and advanced noise reduction measures may be more sensitive to age-related impairment.

Cars passing-by at 20-30 km/h were 4 dB(A) less noisy in 1983 than in 1978, and a total of 5 dB(A) less noisy in 2001 than in 1978, according to Steven [Steven, 2001-3]. At speeds of 60-70 km/h (tire/road noise dominates) levels in 1992 were 2 dB(A) higher than in 1983, but in 2001 they were back to the same level again (may also have been a road surface effect).

The large German study is again illustrated in Fig. 15 [Steven, 1994]. The figure is valid for vehicles running at a constant medium speed in urban conditions. Note that the noise reductions have occurred mainly for the heaviest groups, i.e., for those that must have had the highest dominance of power unit noise. For motorcycles, the mean noise level increase of 1.5 dB(A) is in contrast to the reduction in type approval level and the dramatic decrease in annoyance scores(!). Fortunately, there is no increase, but rather status quo, for the peak levels within this group.

In Fig. 16, an Australian study is presented [Lawrence, 1993] which shows less positive results than the German study regarding group mean levels, but about the same for group peak levels—when similar time periods are compared.

When the Nordic Traffic Noise model published in 1978 was updated in 1996, the basic noise levels at speeds lower than 50 km/h had to be reduced by 3 dB(A) for the heavy vehicles and by 2 dB(A) for the light vehicles, reflecting emission reductions between the beginning of the 1970s and the beginning of the 1990s [Kragh, 2001].

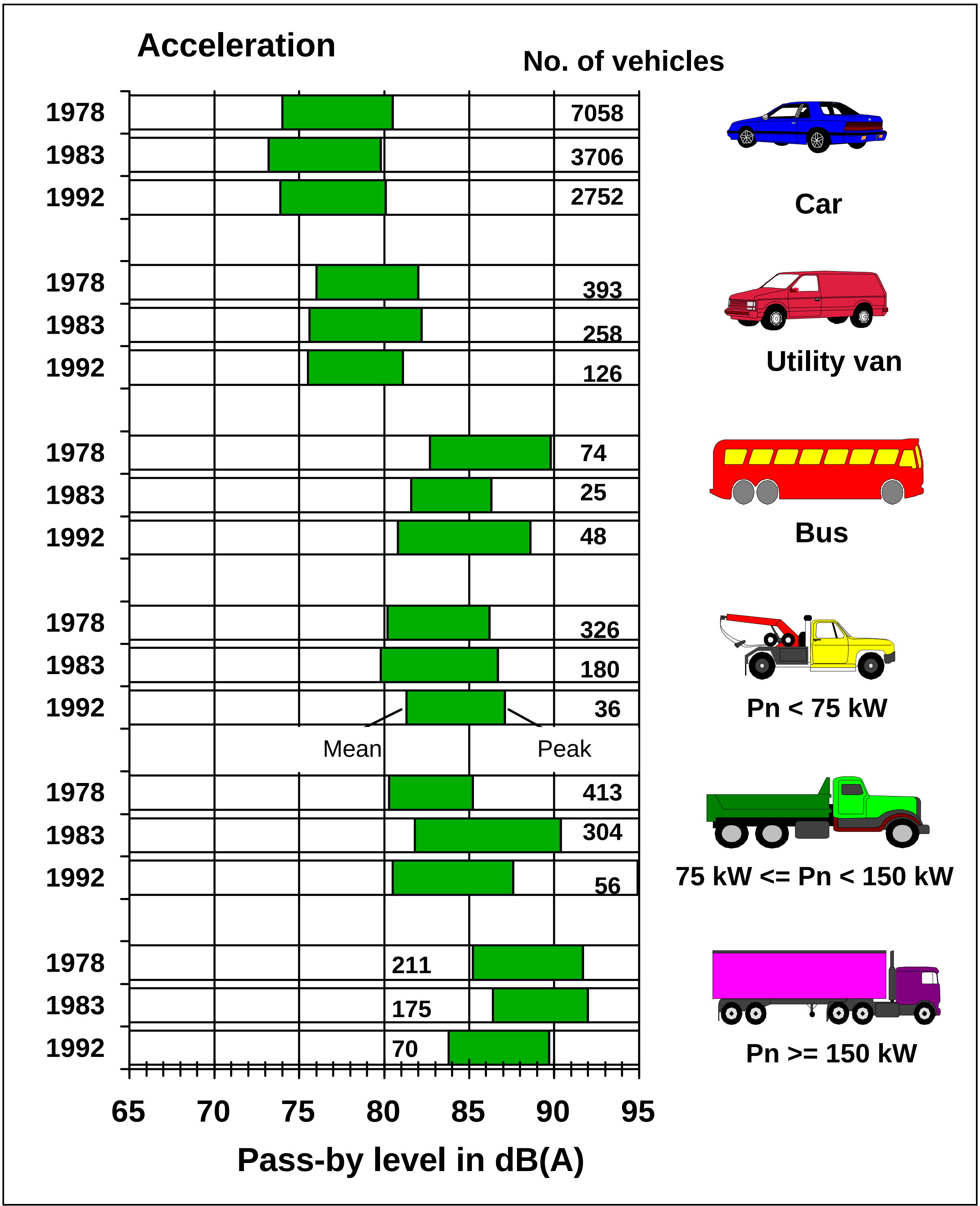


Fig. 14. Noise emission levels of motor vehicles in German urban traffic (7.5 m from street lane center) measured in three years. The numbers beside the bars indicate the number of measured vehicles. The left end of the shaded bar indicates the population mean noise level and the right end the "peak" level (exceeded by 5% of the population). Adapted from Steven [Steven, 1994].

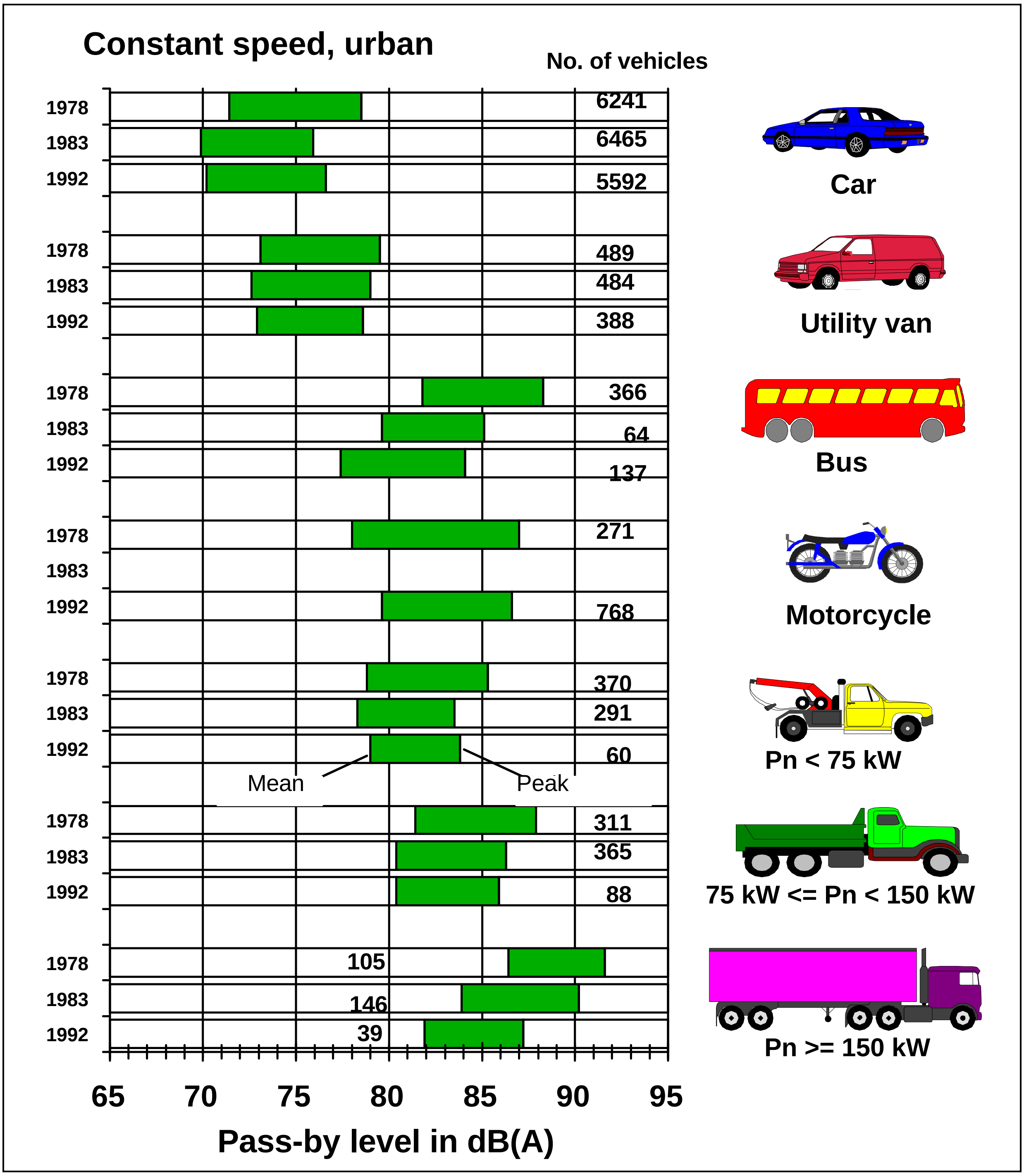


Fig. 15. Noise emission levels of motor vehicles in German constant-speed urban traffic measured in three years. See Fig. 14 for more information.

More data of relevance here are presented in Fig. 13 and Table 5. See also the Dutch and US data for low speeds in section 7.7.

Noise level changes in the investigations available here range from an increase of 1.5 dB(A) (motorcycles only) to a reduction as high as 5 dB(A).

7.6 Acceleration in Highway Conditions

There is only one investigation available [Steven, 1994], and this concerns trucks driving uphill on a motorway. This would mean that vehicle engine loads are the same as during acceleration. The result shows some resemblance to the case for acceleration in urban traffic, i.e., there was first an increase in noise levels and then a decrease. The net effect over the period 1978-1992 is, however, negligible.

7.7 Driving at Constant Speed in Highway Conditions

This is the driving condition for which most of the data apply. The reason is that road traffic noise prediction models have historically been first and most developed for constant speeds 50-150 km/h, and when these models have been updated it has created useful data for this report. There are too many investigations to be commented upon here (see Table 5d for more complete data). Two of the studies show “extreme” results, in contradictory directions, and they will be commented upon first.

Results processed by the author from Descornet [Descornet, 1992] indicate an increase in the period 1984-91 of as much as 4 dB(A) for light as well as for heavy vehicles. This was measured on a transversely grooved cement concrete, a type of surfacing generally considered to be one of the noisiest in common use. The large increase may be partly due to a difference in the status of wear of the surfaces (the two surfaces were both of the same type, having the same groove spacing, etc.) and/or it may be due to tires having become more noisy—particularly on such an extreme type of surfacing.

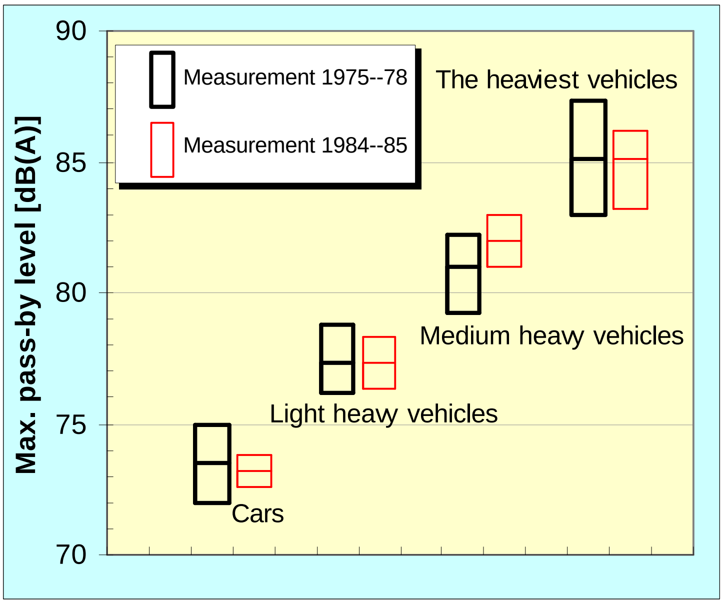


Fig. 16. Noise emission levels of motor vehicles in Australian urban traffic (7.5 m from street lane center) measured in two time periods. The bars indicate the population mean noise level and 95 % confidence limits, with the left and bold bars representing the early measurements and the right and thin bars the later measurements. Adapted from [Lawrence, 1993].

The other "extreme" result comes from a Japanese study, indicating a noise reduction of 1-2 dB(A) for cars and 4-5 dB(A) for trucks between 1978 and 1993 [Takahashi et al., 1994]. See Fig. 17. The 84 dB(A) (heavy) trucks should dominate the heavy fleet there in 1993 and perhaps a limit of 84 dB(A) was needed to get any significant effects, since Yamashita [Yamashita et al., 1993] obtained only a smaller effect in the period 1979-82. The changeover from diagonal to radial truck tires in this 15-year time period may contribute 1-2 dB(A) to the observations. Another important factor explaining the relatively large reduction of noise from trucks may be that the measuring method for type approval in Japan is closer to the actual operating conditions of the vehicles. Studies in Denmark and Sweden have been compiled, and are presented in Fig. 18 [Kragh, 2001]. This figure is based on "heavies" consisting of 30% two-axle trucks/buses and 70% multi-axle trucks. Two of the points for each vehicle class are from Sweden; the others are from Denmark. Note that the "low" points at 1990-91 are believed to be due to the test site having a new surface in 1990. The figure does not indicate any significant improvement either for heavy vehicles or for light vehicles.

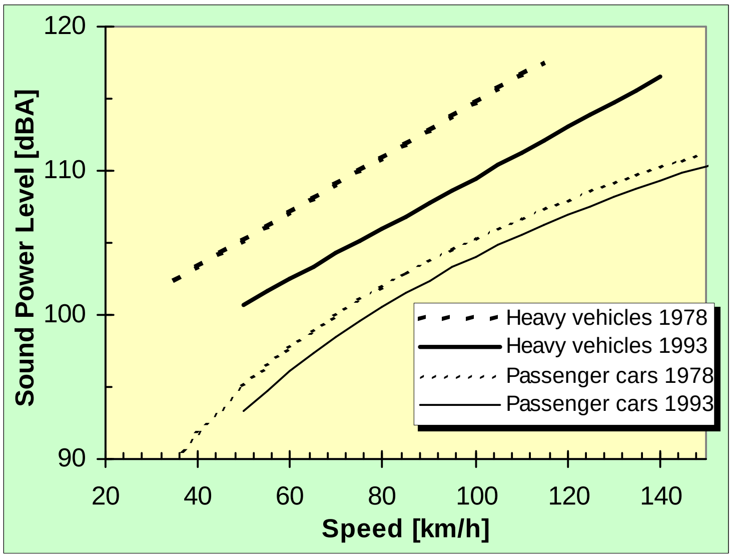


Fig. 17. Changes in sound power levels of Japanese vehicles 1978-93, as measured in a tunnel [Takahashi et al., 1994].

Two American studies, [Wayson & Ogle, 1992] and [Hendriks, 1985], compared measurements of noise emission data for U.S. vehicles in four states in 1974 with their own measurements in Florida (Wayson & Ogle) and California (Hendriks), made 8-18 years later. In the meantime, noise regulations for trucks had been introduced (1980) and tightened (1989) in the USA. The differences found can be explained either by:

a) Difference due to changes over time, i.e., what we are interested in,
b) differences due to vehicles being significantly different in different states, or
c) differences due to road surface

Point c) should not be so important here since it was a goal to make measurements only on asphalt concrete road surfaces of a rather uniform type and in good condition.

Differences in vehicles may exist between Florida and California and other parts of the USA due to more or less tourism, resulting in an overrepresentation of mobile homes and recreational vehicles in these states. However, the analyses have also been made with the Florida database stripped of such vehicles, and the results quoted in the following should not be influenced by such vehicle differences. It is believed that the main effect is the changes over time. With the assumption that the effect is due to time, the results indicate the following:

1. Cars had become approximately 1-2 dB(A) noisier in the later period.
2. Medium trucks had become approximately 2-3 dB(A) less noisy at 80 km/h, over the same time period, but approximately 0-1 dB(A) more noisy at 50 km/h.
3. Heavy trucks had become approximately 3 dB(A) less noisy, over the same time period, at 80 km/h, but there was little or no change at 50 km/h.

The results for trucks may be explained by a change in noise regulation levels between the two time periods and/or a changeover from bias to radial tires. It is difficult to explain why the former would not have had any effect at low speeds, however. The latter generally is assumed to reduce tire/road noise by some 2 dB and should be effective at the higher speeds where tire/road noise dominates.

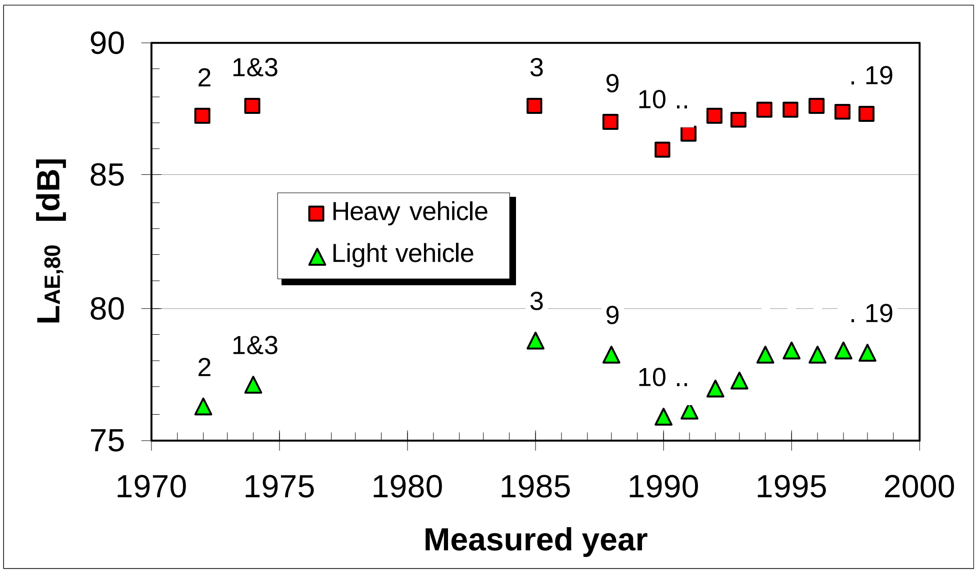


Fig. 18. Vehicle population mean noise levels for light and heavy vehicles, as measured in different years. Data collected in Denmark and in Sweden. The noise levels have been re-calculated to single-event equivalent levels normalized to 1 s (at 80 km/h). The number over each point identifies the measurement series.

The results for cars may be explained by the lack of any federal regulations, change from rather narrow rib-patterned tires in the mid-1970s, to tires with much wider, more block-like patterns in the late 1980s. However, the change must also accommodate the effect of changeover from a large proportion of bias tires to a dominance of radial tires. It may also be that the old American cars, which had very low power unit noise, to a large extent had been exchanged with more compact European and Japanese cars with possibly higher power unit noise.

A different type of approach to the problem has been presented by Sharp [Sharp, 1974]. In this study, measurements of truck noise were made in 1973 in a number of states in the USA. Beginning in 1998 in California, trucks had, beginning in 1968, to meet a certain limit for new as well as for used vehicles, while this was not the case in the other states used in the comparison. The measured effects of regulations (i.e., California versus the other states) was a reduction of 2-3 dB(A). It was also possible to check this result by comparing the Californian post-regulation levels with Californian pre-regulation levels, the latter measured in 1965, in which case the conclusion was the same as mentioned above. One should note that the US truck noise levels from which the regulation started were exceptionally high by European and Japanese standards, namely a 10-percentile level of 96 dB(A) for speeds below 56 km/h and 98 dB(A) for speeds above 56 km/h (both levels corrected by +6 dB(A) for the difference in measuring distance: 7.5 m versus 15 m).

One reason for the indisputable success of the Californian regulations, judged from Sharp [Sharp, 1974], could be that they included new as well as in-service vehicles, and testing below as well as above 56 km/h. The latter would have affected not only power unit noise but also tire/road noise.

Newer US data, obtained from Fleming [Fleming, 1996] are presented in Fig. 19. In this figure, the basic noise levels on which the early US prediction model STAMINA (1978) was based are compared with the same type of data for the latest model FHWA TNM of 1998. The measurements for these were conducted in 1975 (STAMINA) and in 1994-95 (TNM 1998); thus it is 20 years between them. The figure also includes measurements made in 1982-85 in California by CALTRANS. For cars at high speeds, there is an increase of approximately 2 dB(A) with time; at low speeds there is an increase of approximately 1 dB(A). Note that there are no federal noise regulations for cars in the USA. It is speculated that the increases may be due to the following. As noted later in this report, more and more light trucks and vans (LTV) and sport utility vehicles (SUV) are now being sold in the US. These may have somewhat increased the power unit noise at low speeds, but more importantly, probably increased tire/road noise. Several factors have been at work to increase the contribution of tires. The LTV/SUVs are often equipped with “off-road” tires which are quiet enough to meet the pass-by limit, but typically will produce more noise at highway speeds. Further, there are many replacement off-road tires which are available and are noisier than the original tires.

For the heavy trucks at high speeds, there was first a reduction of 3 dB(A), then an increase of 1 dB(A). The former could be due to a combination of power unit reductions caused by the legislation in 1980 (preceded by California regulations a decade earlier) and the changeover from bias ply to radial truck tires in the first half of the 1980s[12]. At the

[12] According to the Rubber Manufacturers Association, in 1983 approximately one-half of the truck tires sold were radials

low speeds, there has been a steady decrease of noise, by 3 dB(A). This is probably entirely due to power unit noise being affected by the noise legislation. For the medium trucks the situation seems to have developed much the same as for the heavy trucks.

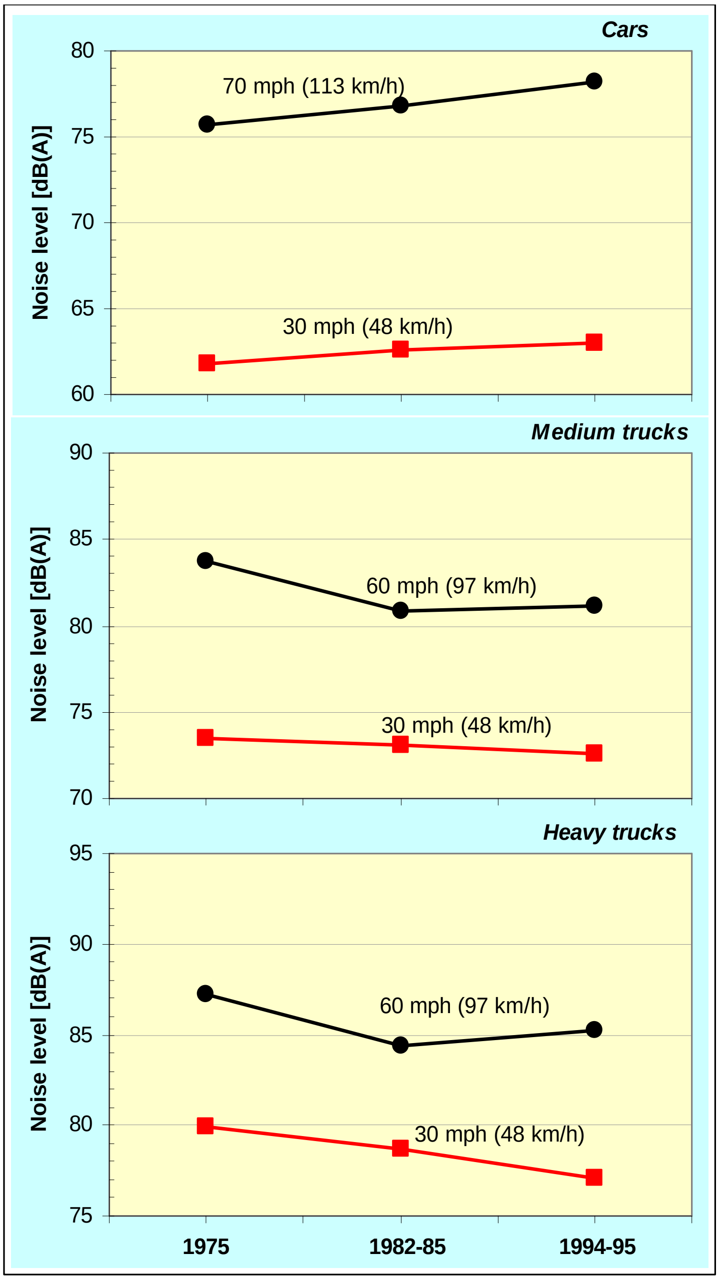


Fig. 19. Comparison of vehicle noise emission data for three time periods in the USA. Figure by the author based on Fleming [Fleming, 1996].

Finally, an extensive study of the effect of vehicle noise regulations in the Netherlands is summarized [de Graaff, 2000], [Hooghwerff, 2000]. Fig. 20 shows vehicle noise as a function of speed for vehicles tested in 1974 compared with 1999. The data from 1974 were the basis for the Dutch traffic noise prediction method RMV 1981, and the data from 1999 are the basis for the updated RMV 2000.

It appears that at speeds of about 30 km/h (power unit noise presumably plays a major role), cars have unchanged noise emission, while light trucks are 5 dB(A) quieter and heavy trucks 7 dB(A) quieter. At highway speeds (around 80 km/h, at which tire/road noise presumably plays the largest role), cars are 1 dB(A) noisier, while light trucks are 1 dB(A) quieter and heavy trucks are 1.5 dB(A) quieter.

Essentially, the picture is rather consistent. Car noise has changed +4 to -2 dB(A) and bus and truck noise +1 to -4 dB(A) over approximately 25 years. The noise increases are typical of high speeds and cars; the noise decreases are typical of low speeds, in particular for heavy vehicles. The variations between the investigations may be caused by differences in noise control policy between countries, by the time period considered, and by the uncontrolled influence of road surfaces in some or even most of the experiments.

7.8 Vehicle Age Effect

In section 7.5, it was reported that the effect of the age of a vehicle seemed to be small for vehicles in the 1960s and 1970s [Kemper, 1979], probably a maximum of 0.1 dB(A) per year. This is confirmed by data collected in the U.K. in 1998 [Phillips, 1999]. Phillips plotted pass-by noise level (SPB method) at 110 km/h as a function of year of registration, and found that the age influence was negligible for light vehicles 0-10 years old (0.01-0.04 dB per year). The only remarkable effect seemed to be a 1 dB lower level for the very newest vehicles, which may be due to, for example, these vehicles having newer tires than the average age vehicles. Since in this driving condition tire/road noise dominates, this does not say anything about whether power unit noise may change with a vehicle's age. Things may also be different for heavy vehicles.

A special study of three vehicle types, VW Beatle 25 kW, VW Rabbit 37 kW and VW Rabbit 40 kW, passing-by in actual urban traffic (registration year obtained by study of license plates) showed that the differences over an age range of 6-12 years was negligible for two of the car types [Steven, 2001-3]. For the Rabbit 40 kW, the 6-8 year old cars were approximately 1.5 dB(A) noisier than the 1-5 year old ones; but only at acceleration around 30 km/h, not at 50 km/h. This may be just by chance, but it may also be interpreted as an age-related increase of power unit noise for one of the three vehicles. It is likely that such effects may be very different between vehicle types; for example, one type may depend somewhat on a noise abatement material mounted underneath the hood that may tend to fall-off after some years, while others may have more durable installations.

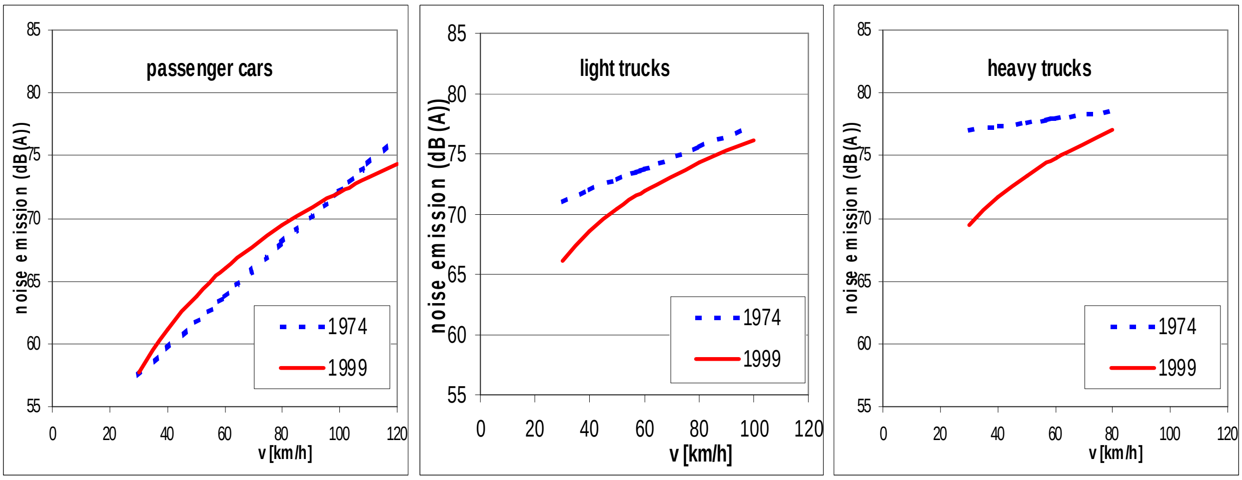


Fig. 20. Comparison of results of noise emission measurements from 1974 and 1999; based on many hundreds of measurements on individual vehicles driving in normal traffic. Diagram from de Graaff [de Graaff, 2000].

7.9 Overview and Conclusions

The remaining part of this section is an attempt to make a synthesis of the results. The overview is presented in Tables 5a, 5b, 5c and 5d and commented upon as follows:

Individual vehicle components (except tires): As a result of the first steps in the regulations (introduction and tightening in 1981), truck exhaust noise seems to have been reduced by approximately as much as the lowering of limits in 1981. This is natural, since it was the major noise reduction measure that was undertaken. No data are available for the exhaust noise development after the mid 1980's, but the trend has continued according to vehicle manufacturers' statements.

Over the 20 year period 1970-90, most diesel engines became less noisy; the reductions range from 1 to 8 dB(A)[13], while petrol engines remained at the same level or even became noisier. However, in the 1990s, following the lowering of EU limits in 1990 and 1996, it seems that even more substantial noise reductions have been achieved for diesel engines (some 5 dB, no data for petrol engines available), and the total noise reduction over the period 1975-2000 may amount to some 8 dB(A) on the average.

The results are supported by Figs. 2-4, in which it appears that it was mainly from 1990 when engines really had to be exchanged for more quiet ones and that measures before 1990 were focused on exhaust silencers.

Acceleration according to type testing, for cars: The introduction of a noise limit in Europe seems to have reduced mean type approval levels by approximately 1 dB(A), and another 3 dB(A) occurred in the step in 1981. After this, overall measured changes have not matched the nominal tightening of limits. Twenty years ago, a large proportion of the cars already met the limit of today (Fig. 11). From about 1981 until the present time, the median type approval levels have been reduced by only 1-2 dB. The fairly good margin between limit and actual type approval level for the population mean in the 1980s has gradually diminished during the end of the time period studied. However, one must also bear in mind that measuring method changes have somewhat counteracted these reductions in real traffic.

Acceleration according to type testing, for heavy vehicles: The time trend before 1970 was not very favorable from the acoustical point of view. The first European limit seems to have eliminated some trucks emitting excessive noise, an effect easily obtained by fitting better exhaust silencers. But, apart from this, the limit was still too liberal to produce any measured change during the 1970s. Most trucks complied with the limit with a fairly good margin. The first tightening (3 dB) seemed to be quite inefficient; possibly a reduction of 0-2 dB occurred. The tightening due to a change in measurement method in 1985 seems to have been consumed by most of the trucks coming closer to the limit value and the net effect seems to have been small. However, the latest steps seem to have been quite difficult for the truck manufacturers—judging from the minimal margin between limit and actually measured type approval level. Manufacturers can no longer rely on changes to just a few components; practically all noise-producing components must be acoustically optimized, and often the measures required may be very difficult to do without negatively affecting characteristics other than noise. Fig. 2 is an excellent illustration of this need to consider all system components after the recently applied limits. The tightening of limits in 1990 and 1996 therefore seems to have reduced the measured population mean levels by close to 100% of the nominal changes (8 dB). In summary, a very small effect during the period 1970-1990, but substantial effects after that.

Acceleration in actual urban traffic for cars: Between 1965 and 1978, a 2 dB noise reduction seems to have occurred, but it is doubtful whether this was a result of the legislation or perhaps was "natural", i.e., it may have happened even without noise legislation. Then, over the period 1975-90, it seems that reductions amounted to 0-5 dB in Europe. In Japan a rather large effect was noted between vehicles of 1977 and 1992 (2-3 dB).

---

[13] The author suspects that most of the higher values may be for engines that were to be introduced on the market a few years after they were tested in the laboratories.

Acceleration in actual urban traffic for heavy vehicles: Between 1975 and 1992, noise reductions seem to have amounted to only 0-2 dB; in special cases even a small increase has been reported. However, 50-75% of the European lowering of limits in 1996 for heavy trucks could be observed. In Japan, when the limits were reduced from 89 to 86 dB(A), this was reasonably efficient. In Europe, on the other hand, the effect has been much lower than the changes in requirements. For example, between 1970 and 1992 the change in requirements, including effect of change in measurement method, has been 11 dB(A) whereas the best recorded effect has been only 2 dB(A), albeit not covering the earliest years. See further below the case of constant low speeds for heavy vehicles.

Constant low speeds in urban traffic for cars: The results here range from an increase of 1 dB to a reduction of 5 dB over the time period studied. The large variation is probably due to different speeds, and whether or not some minor accelerations occurred. The effect was most notable at very low speeds. In any case, the effect seems to be less than the change in type approval levels. According to modeling of noise emission from an urban drive cycle, cars that met the 77 dB(A) standard are not significantly quieter than cars that met the 82 dB(A) standard, see Fig. 28. In the USA, having no federal noise limits for cars and with state limits insignificant, car noise seems to have increased between 1975 and 1995. This is probably not caused by the absence of more stringent limits; instead, as written in section 7.7, this may be explained by the increased proportion of light trucks and SUVs.

Constant low speeds in urban traffic for heavy vehicles: The first limits, state as well as federal, had a substantial effect in the USA, where trucks were noisier in relation to the limit than trucks were in Europe. Also, the tightening in 1989 seems to have had a certain effect. All this applies more to the heavy trucks than to medium trucks. The latter group was only marginally less noisy in 1995 than in 1975. A few noisy vehicles were also eliminated in Europe by the introduction of limits (by just replacing the exhaust silencer). In the period 1975-1999, truck noise in Europe at low speeds has been reduced by up to 7 dB, most of this effect occurring in the 1990s. Aside from noise regulations, the use of lower engine speeds (rpm) due to energy saving demands have been beneficial.

The effects at constant speed seem to be larger than for acceleration (see above). This is not logical; the effects at acceleration should not be lower than at constant speed, and should possibly be higher. The difference in driving conditions between that of the measurement method and that of actual traffic makes it difficult to say what the effects in actual driving would be. However, the measuring method requires testing at full-throttle acceleration between maximum rated speed and high idling (often 2000-2400 rpm), while in actual constant-speed traffic the “green area” for optimum fuel consumption nowadays is 1000-1500 rpm (it used to be higher). The author thinks that the apparently illogical effect mentioned above may be due to a lack of data in the acceleration case; in particular, data that cover the latest years when most of the effects have occurred.

Table 5. Summary of experimental data related to the influence of time and regulations on vehicle noise emissions. The noise change is the difference in vehicle noise between the beginning and the end of the time period (negative values represent noise reductions). Regarding the origin of the study, see the reference list. By "heavies" is meant all heavy vehicles. S = small, M = medium, H = heavy. The table is divided into four parts.

5a. Testing of stationary vehicle components

Origin of study (author, country and year of publ.)	Type of driving (const speed, accel. or mixed)	Time period studied	Type of vehicle	Noise change with time in dB(A)	Data base extent	Notes
Friberg et al (S) 1989	Measur. near exhaust pipe	1967/76-1983/86 yr model	Trucks (S) Trucks (M) Trucks (H)	- (3-4) - 1 - 4	Large Large Large	Trucks in service measured at standstill
Friberg et al (S) 1989	Measur. near the engine	1967/76-1983/86 yr model	Trucks (S) Trucks (M) Trucks (H)	- (2-3) - 1 - 1	Large Large Large	Trucks in service measured at standstill
Friberg et al (S) 1989	Measur. 7 m to the side of the truck	1967/76-1983/86 yr model	Trucks (S) Trucks (M) Trucks (H)	- (1-2) ± 0 ± 0	Large Large Large	Trucks in service measured at standstill
Wolschendorf et al (D) 1991	Meas. in engine test beds	1975-90	Cars (IDI Diesels)	- (5-8)	?	Tests on new series-production engines
Spessert & Reddert (D) 1999	Meas. in engine test beds	1971-90	NA Diesel Turbochar.	- (3.5-6) - (4-5)	? ?	Tests on diesel engines
Spessert & Reddert (D) 1999	Meas. in engine test beds	1975-90 1975-98 ?	DI Diesel DI Diesel	- 3 - 8	Med. Med.	Tests on truck diesel engines
Anderton (UK) 1992	Meas. in engine test beds	1975-1989/92	Petrol eng IDI Diesel Turboch D NA. Diesel	+ 2 - 1.5 + 1 - 4	Med. Small Med. Small	Petrol engines IDI Diesel engines Turbochargar. Diesels Norm. Aspir. Diesels

5b. Type testing conditions:

Origin of study (author, country and year of publ.)	Type of driving (const speed, accel. or mixed)	Time period studied	Type of vehicle	Noise change with time in dB(A)	Data base extent	Notes
Waters (GB) 1973	Type testing ISO 362	1913-70	Buses and trucks	+ (3-7)	Small	Note the very early time period
Kaellberg (SE) 1979	Type testing ISO 362	1960-78	City buses	- (5-12)	Med.	Buses purchased by transp. company. Special req:s. Note the early time period.
deVeer/Ullrich (D) 1991	Type testing ISO 362	1965/69- -1987/88	Cars	- 4	Large	
deVeer/Ullrich (D) 1991	Type testing ISO 362	1965/69- -1985/87	Trucks	- 2	Large	But - 3 dB from 1977/81 to 1985/87
Stenschke (D) 1993	Type testing ISO 362	1983-91 yr model	Cars Cars	-1 -2.5	Large Large	Median car (50 perctl) Noise at 5th percentile
Berge (N) 1994	Type testing ISO 362	1972-94 1971-94	Cars Trucks (H)	- 8 - 3 (-7*)	Large Large	*see note underneath the table frame
de Graaff (NL) 2000	Type testing ISO 362	1980-98 1980-98	Cars Trucks (H)	- 4 - 8*	Large Large	But only –2 1982-98. Occurring after 1989.
Liedholm et al (S) 1980	Type testing ISO 362	1971/74- 1978/79	Cars	- 1	Large	Compares before/after Swedish noise limits
OECD (NL) 1980	Type testing ISO 362	1971/73- 1976/77	Cars	- 1	Large	Compares before/after Dutch noise limits
Anon. (NL) 1994	Type testing ISO 362	1980-90 1980-90	Cars Trucks (H)	- 2 - 6 (-8*)	Large Large	Effect occurred 1980-1982, then nothing Effects occurred 1980-1981 and around 1985
Stenschke (D) 1994	Type testing ISO 362	1990-94	Motor-cycles	- 1 - 3	Large	For median (50%) MC For 5th percentile MC
Kragh (DK) 1994	Urban, accel. (ISO 362)	1978-91	Trucks (H)	- 2	Large	Heavy trucks taken from actual traffic

* Includes assumed effect of change in the measurement method

Please note that the figure caption for tables 5a-5d appears on page 31

5c. Urban driving conditions (0-50 km/h):

Origin of study (author, country and year of publ.)	Type of driving (const speed, accel. Or mixed)	Time period studied	Type of vehicle	Noise change with time in dB(A)	Data base extent	Notes
Kemper (D) 1979	24-25 km/h	1965-78	Cars	- 2	Large	Note the early time period
Kragh (DK) 1994	Urban, accel. (ISO 362)	1978-91	Trucks (H)	- 2	Large	Heavy trucks taken from actual traffic
deVeer/Ullrich (D) 1991	Urban, accel. Loaded engine	1975-90	Cars Trucks	- 2 - 1	Large Large	Driving uphill at 25-70 km/h
FIGE (D) 1994	Urban, accel. From med. spd & frm standstill	1978-92	Cars Buses Trucks	± 0 - 2 - 2 /+2	Large Large Large	Depends on size
Yamashita et al (JPN) 1993	Urban, accel.	77/79-82 79-84/85	Cars Trucks	- (2-3) - (2-3)	Large Large	For vehicles meeting standards of resp year
Sandberg (S) 1992	Urban, accel.	1991-96	Trucks	- (2-3)	Small	Compares before/after new Direct 92/97/EEC
Steven (D) 2001-3	Mixed, urban 20 km/h	1978-83--92-2001	Cars	- 5	Large	Most of the effect occurred 1978 - 1983
de Graaff (NL) 2000	30 km/h	1974-99	Cars Trucks (M) Trucks (H)	± 0 - 5 - 7	Large Large Large	
Kragh (DK) 2001	Urban mixed, 30-50 km/h	1972-92 (ca)	Cars Heavies	- 2 - 3	Large Large	Basic levels for Nordic Trfc Models '78 vs '96
Sandberg (S) 2000	50 km/h const speed	1982-96	Cars Trucks	+ 1.1 - 2.0	Med-ium	
Maurin (F) 1995	Mixed, urban	1976/79--1987	Cars	-(0-1)	Large	
FIGE (D) 1986	Mixed, urban	1965-80 1970-80	Cars Cars	- 3 - 2	Large Large	Noise as function of car registr. year
Lawrence (AU) 1993	Mixed, urban, mainly const.	1975/78--1984/85	Cars Heavies	- 0.3 ± 0 + 1	Med. Med.	Depends on size
FIGE (D) 1994	Urban, constant spd.	1978-92	Cars Buses Trucks	- 1.5 - 4 - (1-5)	Large Large Large	Depends on size
Stenschke (D) 1994	Urban, constant spd.	1978-92	Motor-cycles	+ 1.5	Large	
Sandberg (S) 1984	Urban, constant spd.	1920-82	Cars Car tires	- (10-15) ± 0	Small Small	Only power unit noise Only tire/road noise
Fleming (USA) 1996	Mainly constant spd.	1975-95	Cars Trucks (M) Trucks (H)	+ 1 - 1 - 3	Large Large Large	
Sharp (USA) 1974	Urban, constant spd.	1973-73	Trucks	-(2-5)	Large	Comparing states with & without regulations

5d. Highway driving conditions:

Origin of study (author, country and year of publ.)	Type of driving (const speed, accel. Or mixed)	Time period studied	Type of vehicle	Noise change with time in dB(A)	Data base extent	Notes
FIGE (D) 1994	Highway, accel. (uphill)	1978-92	Trucks	± 0	Large	+ 1 dB 1978-83, but - 1 dB 1983-92
FIGE (D) 1994	Highway, constant spd.	1986-92	Cars Buses Trucks	+ 0.5 ± 0 - 1	Large Large Large	
Steven (D) 2001-3	60-70 km/h, const. speed	1978-83 1983-92 1978-01	Cars Cars Cars	-1 +1 - 2	Large Large Large	
deVeer/Ullrich (D) 1991	Highway constant spd.	1972-88	Cars	± 0	Large	120 km/h
Kragh (DK) 2001	Highway Constant spd.	1972-98	Cars Heavies	+ 1 ± 0	Large Large	
Kragh (DK) 2001	Highway Constant spd.	1972-92 (ca)	Cars Heavies	- 1 - 1	Large Large	Basic levels for Nordic Trfc Models '78 vs '96
Astrup (DK) 1993	Highway Constant spd.	1985-93	Mixed traffic	+ 1	Large	Leq corr'd for traffic incr. 6 meas. 1985-1993
Sandberg (S) 1989	Highway, constant spd.	1974- -1982/88	Cars Heavies	+ (1-2) ± 0	Large Med.	
Sandberg (S) 2000	80-100 km/h const speed	1982-96	Cars Trucks	+ 2.6 - 0.7	Med-ium	
Maurin (F) 1995	Highway, constant spd.	1976/79- -1987	Cars	- 2	Large	
Descornet (B) 1992	Highway, constant spd.	1984-91	Lights Heavies	+ 4 + 4	Large Large	Leq corr'd for traffic incr. Extra noisy surface. Road surface change?
de Graaff (NL) 2000	80 km/h	1974-99	Cars Trucks (M) Trucks (H)	+ 1 - 1 - 1.5	Large Large Large	
Yamashita et al (JPN) 1993	Highway constant spd.	1979-85 1979-82	Cars Trucks (H)	± 0 - (1-2)	Large Large	For vehicles meeting standards of resp year
Takahashi et al (JPN) 1994	Highway constant spd.	1978-93	Cars Heavies	- (1-2) - (4-5)	Large Large	Sound power meas. in tunnel (diff. -78 & -93)
Wayson & Ogle (USA) 1992	Highway Constant spd.	1974- 1985/92	Cars Trucks (M) Trucks (H)	+ 2 -2 + 1 - (0-3)	Large Large Large	Effect might also be due (?) to different vehicles in diff. states
Hendriks (USA) 1987	Highway Constant spd.	1974- 1982/85	Cars Trucks (M) Trucks (H)	+ 1 - (0-3) - (1-3)	Large Large Large	Effect might also be due (?) to different vehicles in diff. states
Fleming (USA) 1996	Highway Constant spd.	1975-95	Cars Trucks (M) Trucks (H)	+ 2 - 2 - 2	Large Large Large	
Sasor (USA) 1997	Highway constant spd.	1977-93	Trucks & buses	- 3	Large	
Sharp (USA) 1974	Highway constant spd.	1973-73	Trucks	-(2-3)	Large	Comparing states with & without regulations
Sandberg (S) 1992	Highway, constant spd.	1991-96	Trucks	- (0-1)	Small	Compares before/after new Direct. 92/97/EEC
Stehno (A) 1992	Highway constant spd.	1992-92	Trucks (H)	- 2	Small	Compar. trucks meeting 80 vs 84/88 dBA limits

Constant (medium or high) speeds in highway conditions for cars: This case would imply a total dominance of tire/road noise. The effects or changes with time range from +4 to –2 dB(A). This large range may be due to difficulty to "control" the road surface effect even though surface types are the same. Overall, there seems to have been no benefit from the lower limits in this case.

Constant (medium or high) speeds in highway conditions for heavy vehicles: The effects range from +1 to –3 dB(A), with exceptional cases of +4 as well as –5 dB(A). This large range may be for the same reasons mentioned for cars. Overall and as an average, there seems to have been just a slight improvement of about 1-2 dB(A). The most notable exception is the Japanese study reporting –4 to –5 dB(A) between 1978 and 1993. Also in this case, tire/road noise plays a major role on at least the newest vehicles. The changeover from diagonal to radial tires in this time period may contribute 1-2 dB(A) to the observations.

Tires: The situation with respect to tire/road noise is essentially the same as the constant-speed cases (highway condition) above, although for the heavy vehicles up to around 1990, power unit noise also contributed significantly. Possibly with the exception of Japan, therefore, tire/road noise seems to have been either constant over time or have increased slightly; a clear majority of studies indicate an increase with time (for cars). During the time period studied, tire widths have increased substantially and this is known to increase tire/road noise [Sandberg, 2001-2]. According to de Graaff [de Graaff, 2001], the most common car tire width was 165 mm on car models registered in 1980, which has changed to 195 mm now. Another change is that higher top speeds of vehicles have led to an increase in the speed class of the tires, something that normally makes optimization with respect to noise more difficult.

For heavy vehicles, during the period studied, bias ply tires were replaced with radial tires. This occurred in the very beginning of the period in Europe and Japan, but in the middle of the period in the USA. It is generally assumed that this change from bias to radial tires meant a noise reduction of 1-2 dB(A). The observed changes in truck noise at high speeds generally suggest that tire/road noise has been unchanged with time after the changeover to radials. The small noise reductions recorded over the 30-year period are more likely due to power unit noise reductions having a small effect at high speeds.

The special case of motorcycles: The investigations for motorcycles are insufficient to make general conclusions. The experimental studies indicate that type approval levels have been reduced, but that mean levels in traffic have increased somewhat. The maximum levels do not seem to have increased, however. Nevertheless, there is an inconsistency with the decrease in annoyance (see Figs. 5-6). How can this be explained?

The measurements referenced in this report come from Germany. The positive annoyance scores come from Germany as well as from the Netherlands. At least in Germany, it is likely that the reason for the decreased annoyance has to do with the introduction of an "anti-tampering catalogue" which has been in effect since 1986. Furthermore, since that year the registration of very light motorcycles (such as mopeds) has been low and these vehicles are no longer a conspicuous source of noise. This is what the annoyance investigation may have picked-up. However, the main problem with motorcycles is still the use of non-approved replacement silencers and the excessively noisy driving behavior of some drivers.

Special Japanese experience: There are indications that the Japanese experience is more positive than the others. There are at least four things that might be responsible for this. Firstly, in Japan, type approval has been based on a measuring method which is modified from ISO 362, but is more representative of actual traffic than in Europe and Australia. For example, heavy vehicles are tested loaded in Japan in contrast to unloaded in Europe and, of course, few heavy vehicles are run unloaded in actual traffic. In fact, it has been a general observation in this study that noise emission during type approval based on ISO 362 correlates poorly with noise emission in actual traffic, see section 16.6. Secondly, in Japan there is a long tradition of control of in-service vehicles. Thirdly, the tolerances between actually measured noise levels and limits are very different in Japan in relation to Europe; see section 16.8. Finally, Japan has had a separate limit for vehicles driven at constant high speeds. It is possible that this could have encouraged a certain tire selection.

8. The Inertia Effect

As far as this Working Party is aware, no further lowering of vehicle noise emission limits is planned. However, it may be interesting to study how the latest limits are expected to affect traffic noise levels. The reason is that traffic noise overall values, such as the conventional equivalent level L_{eq}, the L_{dn} used in the USA, or the new community noise measure decided upon in the EU, L_{den}, are all affected by the composite sound from all vehicles traveling on the roads or streets. Due to the logarithmic sound scale, the vehicles with the highest noise levels have a disproportionally large effect on the overall level. It follows that older, and presumably noisier, vehicles will continue to affect the overall levels for many years after stricter noise emission limits have been introduced.

For example, if we have a vehicle fleet with 50% new vehicles having a noise emission of 80 dB(A) and 50% older vehicles having a noise emission of 84 dB(A), all vehicles driving the same distance, the group of older vehicles will create more than 70% of the total sound energy. The contributions from the groups will be equal when the proportion of the older vehicles has dropped to less than 30%.

The above implies that there is a substantial inertia in traffic noise abatement by emission limitations, since older vehicles are slowly exchanged for newer ones. Fig. 21, obtained from WP member J. Kragh, illustrates this inertia. It is based on a status-quo scenario with regard to the current limits in the EU, but with certain assumptions regarding the exchange rate of new to old vehicles. The figure was intended to explain what one could expect of the latest lowering of limits that took place in the EU (1996). The base year is 1993, and it is assumed that the average vehicle lifetime is 10 or 20 years. It means that one can follow the development in noise level (energy-averaged population mean) provided that vehicles are exchanged at an equal rate spread out over 10 and 20 years, respectively. In order to avoid a case with the achievable noise reduction almost totally limited by unchanged tire/road noise, the case chosen is for heavy vehicles, low speeds and interrupted flow. It is assumed that for the newest vehicles, tire/road noise constitutes approximately 50% of the sound energy.

The results show that moderate effects are expected, but that these effects will not be fully noticed for several years. When considering all effects reported in section 7 and comparing them with the change of limits, one should remember the effect of such inertia.

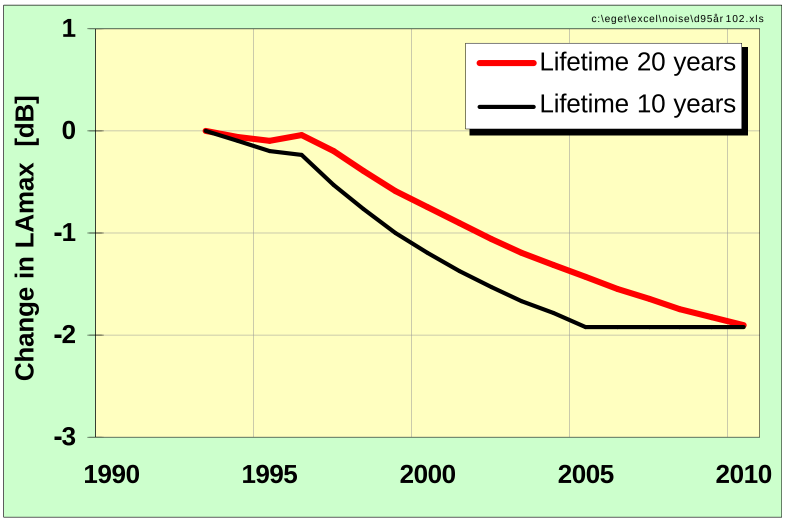


Fig. 21. The expected inertia in noise level changes resulting from the latest lowering of vehicle noise limits in the EU. Noise levels are population means (energetically averaged). Calculations and figure produced by J. Kragh [Kragh, 2001].

Kragh's figure also gives us an estimate of the further noise reductions that we can expect in future traffic, resulting from the existing regulations. For example, assuming an average heavy vehicle lifetime of 10 years, we can expect to enjoy another 1 dB of heavy vehicle noise reduction (at low speeds) after 5-10 years, compared with the situation in the year 2000.

It can be mentioned that in 1994 a Nordic group of vehicle noise experts estimated the effect of the 1996 tightening of limits, see Kragh and Sandberg [Kragh & Sandberg, 1994]. It was concluded that, noise levels will be reduced by the year 2010 by approximately 1 dB(A) for light and 2-3 dB(A) for heavy vehicles as compared to the "base year" of 1990. This was for interrupted-flow traffic. For high-speed traffic, noise levels were predicted to remain the same as in 1990 by the year 2010.

The Nordic group then (in that particular scenario) assumed that no progress would be made in tire/road noise reduction. But what is the current situation with regard to tire/road noise?

9. Tire Noise Emission Limits

In early 2001, the European Council and the European Parliament reached an agreement on tire noise emission limits for new tires (type approval), to be printed later in 2001 as an amendment to the existing tire Directive (Directive 92/23/EEC)[14]. The limits are presented in Table 6. They have not yet been published and will not be valid until after publication, but the author believes that there will not be any change at this stage. It is likely that the United Nations Economic Commission (ECE) will follow the EU, and thus the limits may be accepted by several countries outside the EU. In Australia, there is an interest in adopting a tire noise regulation [Close, 2001].

The time of enforcement depends on when the amendment will be published, but it is likely to be at the beginning of 2003. A possible lowering of some of the limits in 2007, 2008, or 2009 is indicated. The rightmost column even indicates a possible second tightening for some tires. However, even though values are indicated, these will be decided after special studies have been made, and thus the indicated values (columns 3 and 4 in the table) have no legal status.

With regard to the nominal values in the table, it should be noted that the measured levels shall be truncated and then a deduction of 1 dB shall be made. It means that the limits, in comparison to actually measured levels, are up to 1.9 dB higher in practice.

The limits allow higher noise levels for wider (car) tires. The reason is that relationship between noise emission and width of tires has been well documented, see for example Sandberg [Sandberg, 2001-2] and Phillips [Phillips, 2001]. It has been proposed that the differentiation should not be made with regard to width but rather with regard to load index. A relaxed requirement for a wider tire in comparison to a narrower tire could encourage the use of a wider tire than necessary—which could result in higher noise emission.

Tests are made at a range of speeds 70-90 km/h for car tires and 60-80 km/h for truck tires, and there have been some suggestions that lower speeds be added, for example, speeds typical of vehicle noise tests, in order to avoid suboptimization. The test surface is the same as for vehicle noise testing (ISO 10844), which has been another concern, since the ISO measurement surface was not developed for this purpose. Work is therefore under way in a subgroup of ISO/TC 43/SC 1/WG 42 to improve ISO 10844. The use of this single test surface may also imply a suboptimization. However, suboptimization is inherent in many regulations, including those for vehicle noise, and may have to be accepted for a limited time.

Retreaded tires are not covered by the Directive, despite the fact that in some countries they constitute up to 25% of the car tire market and 50% of the truck tire market.

A discussion of the expected effects of the amended Directive, i.e., the tire noise limits, can be found in Sandberg [Sandberg, 2001-2]. It was concluded, after comparison with measured values, that the limits will be ineffective. They will, at most, eliminate a very small proportion of all tires, so the effect on overall traffic noise levels may be counted in hundredths, or at most a few tenths of a decibel. Similar conclusions, based on recent measurements, are drawn by Stenschke and Vietzke [Stenschke & Vietzke, 2000, Stenschke & Vietzke, 2001]. Even with the indicated and future tightened limits, the effects on traffic noise will be too small to be significant. Thus, it is concluded that one cannot expect any substantial tire noise reductions due to the EU tire Directive within this decade.

[14] Published after this article was written as Directive 2001/43/EC amending "Council Directive 92/23/EEC relating to tyres for motor vehicles and their trailers and to their fitting", published in the Official Journal 4 August 2001

Indirectly, tire noise has been limited by regulations for some years, namely by vehicle noise regulations (Fig. 1). In order to meet the required limits with some practical margin, the vehicle manufacturers demand tires from the tire manufacturers that will meet certain exterior noise criteria. In some cases, this could mean that vehicle manufacturers could demand tires that have up to perhaps 5 dB lower noise emission than "normal" tires have today. In this way, one can say that, for a few years, the tire manufacturers have been pressed to produce tires with lower exterior noise.

Table 6. Noise emission limits for new tires in the EU. Note that the values in the third and fourth columns are only indicative. Final values will be decided after further studies have been made by the Commission.

Type of tire, Section width [mm]	Limit value [dB(A)]	Limits after 1st tightening	Limits after 2nd tightening
For cars (C1)**:**			
≤145	72*	71*	70
>145 ≤165	73*	72*	71
>165 ≤185	74*	73*	72
>185 ≤215	75**	74**	74
> 215	76***	75***	75
Light truck (C2):			
Normal	75		
Snow	77		
Special	78		
Heavy truck (C3):			
Normal	76		
Snow	78		
Special	79		

* Limit values in column 2 shall apply until 30 June 2007; Limit values in column 3 shall apply as from 1 July 2007
** Limit values in column 2 shall apply until 30 June 2008; Limit values in column 3 shall apply as from 1 July 2008
*** Limit values in column 2 shall apply until 30 June 2009; Limit values in column 3 shall apply as from 1 July 2009
**** Reinforced car tires have 1 dB higher limits
**** "Special" car tires have 2 dB higher limits

The first problem is that these tires, at least in the EU and in countries honoring the ECE Regulations, do not have to be used on the vehicles in actual traffic, not even when the vehicle is sold. They must be available on the market and they must have a minimum tread depth of 1.6 mm. It means that the vehicles of some companies are tested with worn-out tire treads. It is common that on trucks, tires typical of the steering axle are fitted on all axles during testing, whereas when the truck is sold, it is equipped with traction tires on the drive axle(s). The second problem is that the tires are optimized for the special vehicle noise testing condition (high torque on the tires) and this optimization may not at all work in the same way during normal driving of the vehicle. However, despite these problems, the vehicle noise regulations, in contrast to the tire Directive, may, in fact, push the tire market a little towards lower noise.

Further evidence of the latter is presented in Fig. 28, in which a hypothetical lowering of vehicle noise emission limits for cars to 71 and then to 68 dB(A) are modeled. Since this would force tire/road noise to be reduced at least as much as power unit noise, the effect on urban driving, as well as highway driving, will be substantial.

10. Spectral Changes

Few studies in which it is possible to compare time trends have reported spectral characteristics. The only one, although a very important one, seems to be a Dutch study [Hooghwerff, 2000]. A spectral comparison of the 1974 and 1999 measurement series is presented in Fig. 22.

The following observations can be made:

- For light vehicles, at 50 as well as at 110 km/h, the low frequency content (125-250 Hz octave bands) was lower in 1999 than in 1974. This suggests a decrease of power unit noise.
- For all vehicles, especially for light vehicles, in 1999 the spectral shape has become more "peaky" around 1 kHz. This is typical of noise from modern tires, see Sandberg and Ejsmont [Sandberg & Ejsmont, 2002].
- For all vehicles, the high frequency content (4–8 kHz octave bands) has been reduced. This is typical of lower power unit noise. Alternatively, it may be an effect of better aerodynamics of vehicles, eliminating most of the air turbulence noise on the modern vehicles.
- For all cases, except cars at 110 km/h, there is an increase from 1974 to 1999 in the 63 Hz octave band. This may be related to vehicle changes, see below, but it may also be a measurement error.

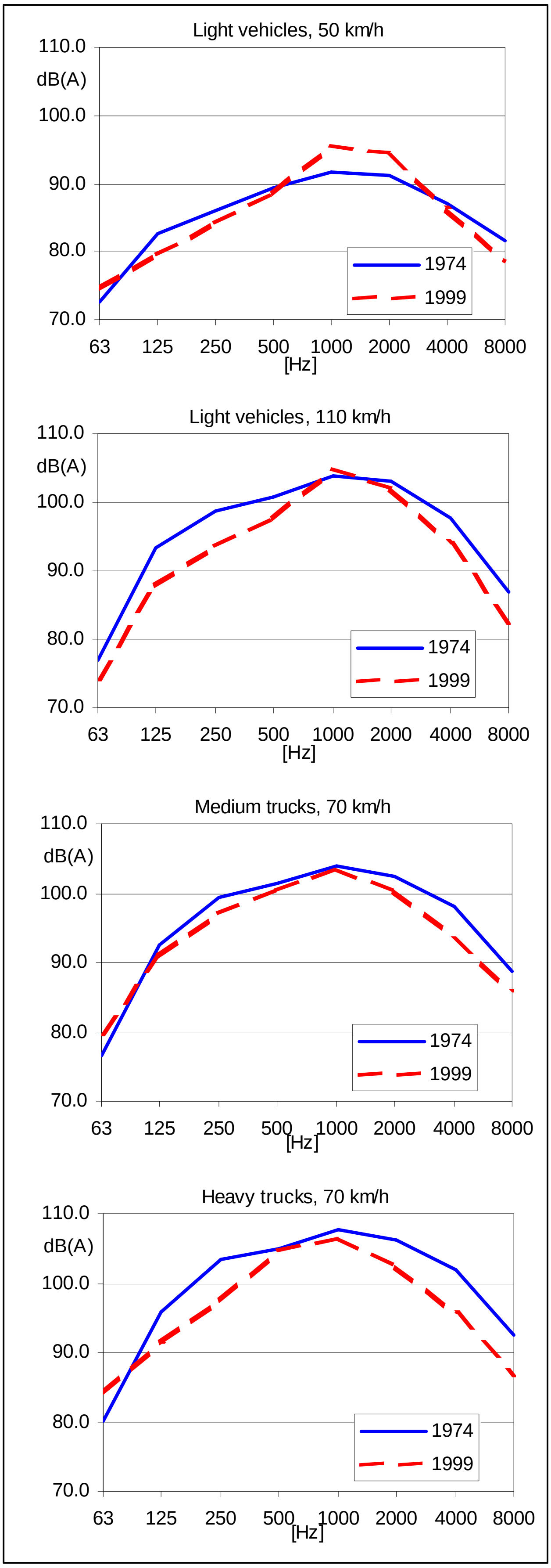


Fig. 22. Comparison of frequency spectra of vehicle pass-by measurements made in 1974 and 1999. Data adapted from [Hoogwerff, 2000].

11. Indoor Noise Levels - Propagation, Transmission, and Source Height

Changes in indoor noise levels will differ from the outdoor levels close to the road, as a result of three major mechanisms:

1. Sound transmission through facades/windows will alter the frequency spectrum so that indoor noise will be more dominated by noise at low frequencies
2. Sound propagation from source to buildings may somewhat affect the vehicle noise frequency spectrum; in principle towards more weight on noise at low frequencies
3. If source heights or the height of the combined sources have changed with time or regulations, noise screens and/or ground attenuation may have become more or less efficient

Tire/road noise has relatively small contributions at low frequencies, and, when low frequencies are emphasized, it is likely that power unit noise reductions will have an increased effect. It follows that mechanism No. 1 above should have made the regulations more effective indoors than outdoors. Unfortunately, there is an effect acting in the other direction, which is due to noise at the low frequencies from exhaust systems. Some limited data [Steven, 1994] have suggested that although exhaust systems as a whole have become much more effective, this improvement has primarily been made at medium and high frequencies, which influence A-weighted values. If low-frequency noise is emphasized, as is the case indoors, the effect indoors may have become more limited. A study of Fig. 22 may give support for such an effect, but only in the 63 Hz octave band. Windows have rather poor sound insulation at 63 Hz. However, exhaust systems are not likely to be the cause of the 63 Hz increase, since this would produce undesirable in-cab effects that manufacturers would not accept. Another possibility is that the reason for the 63 Hz effect is the change in engine speed. Before the "oil crisis," trucks were often driven at engine speeds of around 1800 rpm, but now 1200 is more typical, and the latter could possibly lower firing frequency components down into the 63 Hz octave. The firing frequency for a 4-cylinder car was typically in the lower part of the 125 Hz octave in 1974 but in the higher part of the 63 Hz octave in 1999. Note also the possibility that the effect observed at 63 Hz may be due to some measurement error—for example, wind noise in the microphone.

Mechanism No. 2 above acts in the same direction as No. 1. Regarding mechanism No. 3, it is likely that the active sources have been lowered just a few centimeters over the last 30 years. However, the height of the combined sound from the vehicles has been lowered substantially, since exhaust noise and other power unit noise, usually located between 0.3 and 1.3 m above road level, have become less important and tire/road noise with an average source height of less than 0.1 m more important. The latter will absolutely benefit noise reduction. The Working Party has not been able to find any comparable experiments conducted at sufficiently separated times to quantify this.

Most noise prediction models that have been updated in recent years have been designed with lower source heights to reflect such general assumptions. For example, based on sound intensity measurements summarized by Tachibana and Oshino [Tachibana & Oshino, 1992], the new Japanese model has zero source height, whereas the old one had 0.3 m.

Some trucks have exhaust outlets above and behind the cabin. Such high exhaust outlets are not very common in Europe but, for example, they were required for diesel trucks in Australia to enable easier detection of air pollution. In Europe, they may be used, for example, on garbage trucks, in order to avoid dust from being blown up from the ground. It is not known whether these high exhaust outlets have become more uncommon in recent years. It is of interest to consider this development, since high exhaust outlets may make noise barriers less effective.

12. Interior Noise Levels

By *interior noise* is meant the noise inside a vehicle. It has never been a task of this group to study how this type of acoustical environment has changed with time. Nevertheless, Fig. 23 from Takagi [Takagi et al., 1987] presents an interesting example of how development has progressed in this field. The figure concerns cars with small-to-moderate-sized engines measured in Japan while traveling at 100 km/h. It appears that over the decade 1976-1985 there has been a trend of decreased interior noise of around 8 dB(A). This can be compared to the trend of exterior noise which shows no significant change at similar speeds, according to section 7. It is interesting to note that the interior noise at 100 km/h should be dominated by tire/road noise. The data in Fig. 23 is, of course, not valid for a general case, but it fits rather well the general impression of the Working Party members regarding interior noise changes.

The same trend has occurred for heavy vehicle cabins. It has been reported by Waters [Waters, 1995] that between 1962 and 1978, the maximum interior levels in truck cabins have decreased from an average of 93 to 85 dB(A). Waters identifies market forces as the reason. The noise reduction per time unit is a little lower than for cars (0.5 versus 1 dB/year), but the market forces may be stronger for cars than for trucks. In 1984, the author measured interior noise in seven heavy trucks, 1982-84 models, and obtained maximum levels in the range 75-79 dB(A). With regard to today's new heavy trucks, corresponding levels seem to be 65-70 dB(A). This is about 20 dB of noise reduction in 30-40 years, again about 0.5 dB/year.

The reason for the success in reducing *interior* noise, without severe legal requirements forcing it, but failure of severe legal requirements for *exterior* noise reduction, is that low interior noise is a very important selling point (health and comfort of the driver and the passengers), while exterior noise is of little commercial importance after complying with the requirements of authorities. Low *exterior* noise may be a minor but not negligible selling point, if only to give the prospective buyer a good acoustical impression at standstill and possibly at low speeds when the sound of his car may be heard by neighbors and others.

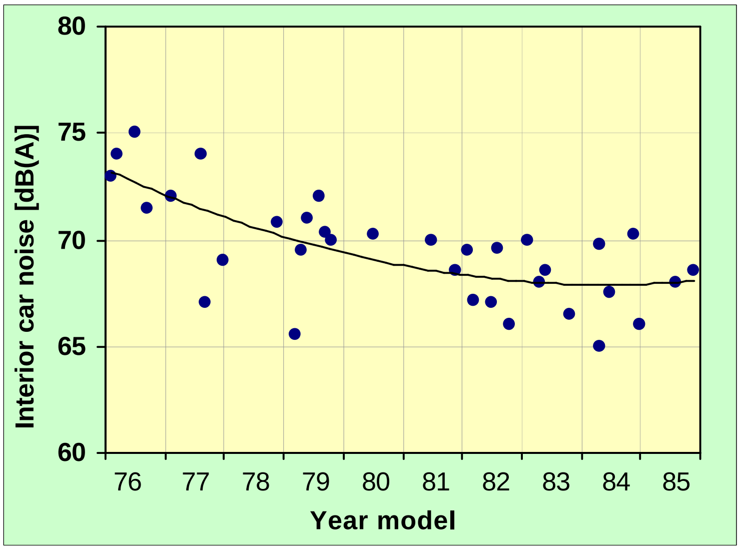


Fig. 23. The development of interior vehicle noise with time, as processed from Takagi [Takagi et al.,1994]. Cars with 1.5-1.8 l engines measured in Japan, travelling at 100 km/h.

13. Maximum Noise Levels

“Maximum noise level” may mean different things in different studies. In this report, maximum noise levels are single noise events when levels are reached that far exceed the average level in traffic. Such maximum noise levels may cause awakening during nighttime. Typical noise events that create “maximum levels” are pass-bys of heavy truck, pass-bys of a car traveling at high speed and pass-bys of a car or motorcycle with a poor exhaust silencer.

The maximum levels are determined by the noisiest and the fastest traveling light vehicles, which is a relatively small proportion of all light vehicles, as well as by a majority of the heavy vehicles. For this purpose, therefore, we shall study the few “worst cases” of noisy cars (say the 5% noisiest), the noisier part of the motorcycles and all of the heaviest vehicles.

It is apparent from the data collected that such levels have been reduced more than the population means treated above. For example, in Fig. 24 reproduced below [Stenschke, 1993], it appears that the noise levels of the 5% noisiest vehicles have been reduced by at least twice as many decibels as the median vehicle. The limits will remove the worst cases and make the noise level distributions more narrow, mostly compressing the “high side.” The data here are from type approval tests.

Similar data are shown in Fig. 11. It appears there that the difference between the peak and the mean level for cars has been reduced from about 4 dB in 1982 to about 2 dB in 1998. For heavy trucks, the reduction is from about 3 dB in 1982 to 1.5 dB in 1998.

The Japanese proximity stationary test for in-service vehicles is aimed at removing the noisiest vehicles from traffic. The number of violations recorded by roadside police inspection increased during its introduction period 1986-89 to peak at almost 12000 in 1989 but declined to about 8000 in 1991. This indicates that an improvement has been made.

Figure 25 shows data collected in roadside measurements by this author. It shows the mean level and standard deviation[15] changes between vehicle data measured in 1974 and the same type of data measured 1982-88 and 1996, i.e., roughly once per decade. It is apparent that the most conspicuous change is a narrowing of the range. The difference between cars and heavy trucks has decreased markedly. The difference between the noisiest heavy truck (mean plus one standard deviation) and the quietest car (mean minus one standard deviation) in 1974 was about 17 dB, in 1982-88 it was 14 dB and in 1996 it was only 10 dB. This means that vehicles have become more uniform in their noise characteristics not only within their respective categories but also between the categories. This trend should logically have continued after 1996.

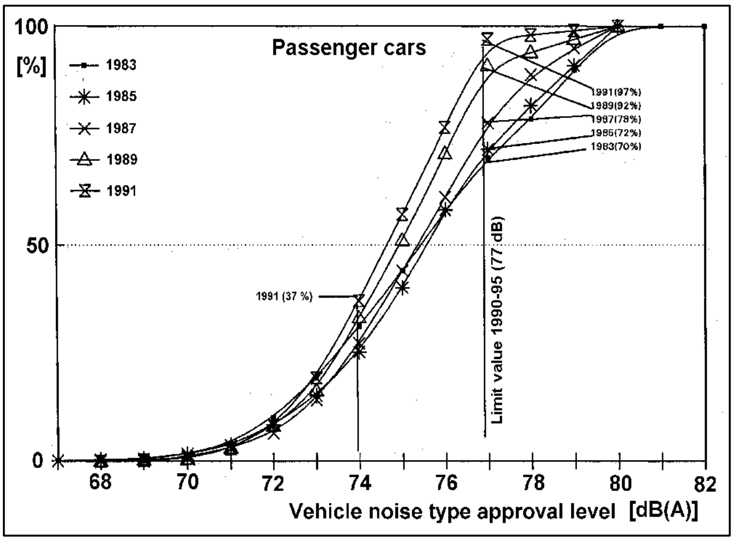


Fig. 24. The development of type approval values (cumulative distribution) for cars in Germany over 8 years [Stenschke, 1993]. The years and percentages indicated at the line of 77 dB(A) show what fraction that met this limit.

Unfortunately, the most important reason for this narrowing of range is that the cars, in reality car tires, seem to have become noisier.

Other investigations showing the same trend are (see also Table 5):

- 2-3 times higher influence on 2nd and 5th percentiles were recorded by Sharp [Sharp, 1974] than on median levels
- In the study by Stehno [Stehno, 1992], the maximum levels were reduced almost twice as much as the mean levels when comparing low-noise trucks with “normal” trucks
- As seen in Fig. 16 the variation in noise levels has been considerably reduced between 1975/78 and 1984/85, even though mean levels are relatively unaffected [Lawrence, 1993]
- For a majority of the cases presented in Figs. 14-15 [Steven, 1994], the peak levels are closer to the mean levels in the latest year tested than in the first year of test. However, it is not a dramatic change
- At 50 km/h, standard deviation of vehicle cruise-by noise has decreased from 3.0 dB(A) in 1978 to 1.5 in 2001 [Steven, 2001-3]. The effect is more pronounced at speeds lower than 50 km/h and less pronounced at speeds higher than 50 km/h, suggesting that it is mainly power unit noise that has been affected
- From a further analysis by this author of the investigation by Descornet [Descornet, 1992], it was found that although mean levels of the vehicle groups increased by 4 dB(A) 1984-1991, the variation within the groups (the 5th minus the 95th vehicle percentiles) decreased by 40% for the light and 30% for the heavy vehicles. The noise emission thus developed towards more uniform levels.

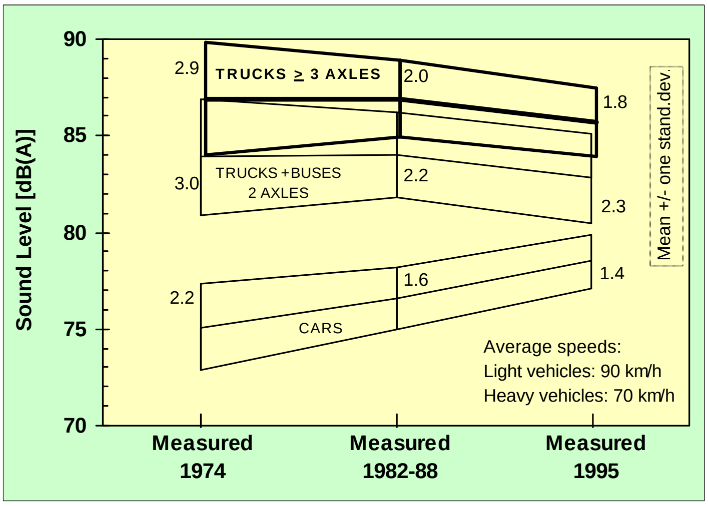


Fig. 25. The development between 1974 and 1996 of mean vehicle noise levels, ±one standard deviation, measured at the roadside (SPB measurements). Highway conditions, dense asphalt surfaces. Indicated values are standard deviations.

No investigation showing a contrary trend has been found. It can be concluded that measured data consistently show the range in vehicle noise levels between the noisiest and the median vehicles has been reduced over the period studied, and maximum vehicle noise levels therefore show a more positive trend with time than median or average levels. In this context, it is also positive that the heavy vehicles have been exposed to more stringent requirements than light vehicles, and that this appears to some extent also in actual traffic. All of these changes mean that a major and very substantial effect of the regulations has been to remove the noisiest vehicles from traffic and to reduce differences between the noisiest and the quietest vehicles.

[15] Residual standard deviation around the regression line of noise on speed

14. Potential Changes in Annoyance due to Spectral or Temporal Changes (Engine Brakes, etc.)

Although A-weighted noise levels may be similar, annoyance may be very different, depending on the temporal or spectral characteristics of the noise. The Working Party has considered possible changes with time in annoyance due to such potential effects.

First, regarding temporal noise characteristics, it should be noted that in the 1970s the oil crisis meant better public awareness of energy consumption for operation of vehicles. This led to a change in driving behavior among certain groups—toward softer and quieter driving with fewer sudden accelerations. It is not known if this improved behavior is still significant.

An increased use of automatic transmissions would have a similar effect on temporal noise characteristics. However, there have been only small changes in the preferences for automatic or manual gearboxes; i.e., Americans still prefer automatic and Europeans still prefer manual transmissions (for light vehicles). Although an increasing number prefer automatic transmissions, Australians and Japanese have not changed in preferences to such an extent that it could have had a significant influence on noise.

Certain vehicles, notably trucks and buses, have auxiliary braking mechanisms, commonly known as retarders, which augment the wheel brakes. One such retarder type is the engine compression brake; another is the exhaust brake. Regarding the first: when activated, the fuel supply to the cylinders is shut off and the engine acts as a compressor effectively driven by the wheels. The use of engine brakes has often been identified by the community as one of the most intrusive road vehicle noises. A frequently used type called "Jake brakes" (Jacobs engine brake) is often perceived as very noisy and when this type of brake is applied, a sudden and extremely loud staccato sound with a very special temporal pattern may occur. The Jacobs company blames the loud noise on the use of engine brakes in vehicles with poorly muffled or unmuffled exhaust systems, exhaust systems that have been illegally modified or are poorly maintained, and/or truckers who simply enjoy making noise.

Engine brake noise has been and still is a problem in USA, Australia and New Zealand, among other countries, and regulations have been considered in Australia against such noise. Local regulations exist in the USA and one frequently sees signs in residential areas adjacent to a highway saying "No Jake brakes"[16]. In recent years, in New Zealand, the use of such brakes in urban areas is prohibited—see Fig. 26. In Australia, the Motor Vehicle Environment Committee is currently examining this issue. In New South Wales, for example, noise from exhaust brakes is the responsibility of the Roads & Traffic Authority (RTA). The Authority provides signs in areas where complaints have been received outside urban areas requesting truck drivers not to use exhaust brakes. The RTA also has an education program with commercial vehicle operators to minimize the use of exhaust brakes [Labban & Ryan, 2001]. More about engine brakes can be found in a study by Close [Close, 2001].

Fig. 26. Prohibition to use engine brakes in built-up areas in New Zealand. Photo: The author

In Europe, this does not seem to be a problem any longer. From about 1990, heavy vehicles in Austria are not allowed to emit more than 80 dB(A) when using any engine compression brake. Since vehicle manufacturers want to avoid too many variants of vehicles, most truck manufacturers in Europe meet the Austrian requirement for vehicles sold in other countries. Furthermore, and not least, air pollution requirements have required manufacturers to develop improved solutions, producing fewer noisy engine compression brakes. In recent years, many heavy trucks in Europe have retarders that work on the transmission or drive-shaft—for example, by electromagnetic means. Such retarders are said to be less noisy than engine compression brakes.

A somewhat related problem is that of compressed air outlet noise from pneumatic components of brakes. Such noise used to be very pronounced earlier but is significantly reduced on most modern vehicles. In the EU and ECE regulations, there is a limit on compressed air noise of 72 dB(A) that has been introduced during the period studied.

All the improvements mentioned in the previous paragraphs—together with the local or national regulations against the use of such brakes in urban areas, where such exist and are observed, must have improved the noise situation. These effects would not normally be detected by the measurements presented in Table 5, for example.

Second, regarding tonality or spectral characteristics, it is well known that frequency spectra containing a dominant tone are more annoying than those without such tones, although A-weighted levels may be the same. Dominant tones in

---

[16] The Jacobs company feels that it is inaccurate, unfair, and perhaps illegal to use their trademarked name in the generic sounding "NO JAKE BRAKES" signs, especially since some of their other jake brakes are quiet, and noisy compression release engine brakes are also made by other companies.

vehicle noise spectra occur mainly from engine-speed-related frequencies such as the firing frequency and its harmonics, from toothed wheels in the transmission, from the tire tread patterns, and from tires rolling over laterally grooved road surfaces. Since the engine, exhaust and transmission contributions to overall noise have decreased with time, this should have improved the situation. However, at the same time, tire/road noise seems to have become more spectrally concentrated, see Fig. 22, and in some cases it has been noted that one might even apply a tonal correction to tire/road noise according to ISO 1996-2, see section 10.5 in Sandberg and Ejsmont [Sandberg & Ejsmont, 2002].

The tread pattern problem has been known for a long time, and tread pattern randomization was sometimes utilized in the 1940s. However, in later decades, tread randomization has become more effective, and it is less common to hear tonal tire/road noise. In the USA, for example, the so-called pocket retread tires that gave a highly tonal noise (nickname "Singing Sam"), were eliminated due to a regulation in the 1970s. Fortunately, good tread randomization is necessary for commercial reasons, at least for car tires, because tread pattern noise may also be annoying to the driver. Regarding grooved surfaces, randomization is mostly used now, if lateral grooving is used at all.

Brake squeal noise was a problem in earlier decades, but is not frequently heard today. This type of noise has a very marked tonal as well as temporal quality and may be perceived as being connected with dangerous situations. It may have an alerting effect on people exposed to this type of noise.

Consequently, indications rather consistently give a picture of improvements in temporal as well as spectral characteristics over the more recent decades. This is a bonus that should be considered on top of overall level decreases.

15. Other Effects

15.1 Tires

Refer here to the section 9 on tire noise emission limits. Additionally, it should be mentioned that the use of studded tires has changed during the more recent decades. Studded tires emit noise which is several decibels higher than the noise emissions from conventional non-studded tires. In Sweden and Finland, the use has increased while in Norway, authorities have attempted to limit their use in cities. In Japan, studded tires were banned in 1991 in specially-designated areas where such tires could normally have been used earlier, although a few areas with exceptional winter conditions were exempted [Anon., 1999]. In some areas in Japan, it is likely that this could have had a small beneficial acoustical effect. The reason for the limitations in Norway and Japan is the problem with dust generation, not primarily noise.

15.2 Road Surfaces

The preferences for certain types of road surfaces have changed in the last 30 years. In many countries, chip seals with quite rough textures were increasingly used in the 1970s, because of economic problems (the oil crisis had some effect), but when it was realized that this caused noise problems, a switchover to somewhat smaller chippings occurred.

Porous asphalt surfaces are increasingly used in many countries, starting mainly as experimental sections in the 1970s but coming on strong in the late 1980s and early 1990s. They are known to be generally (but not always) less "noisy" than dense asphalt surfaces. It is common to record 3-5 dB(A) of noise reduction compared with conventional dense asphalt surfaces when they are in new condition. Especially in the Netherlands, there is a large national program to replace old dense surfaces with porous asphalt on the highway and motorway system, and most of this is already complete. In Japan, the use of porous surfaces on expressways became mandatory a few years ago, and already more than 1000 km of such roads are covered with porous asphalt surfaces. In New Zealand, the extra-urban road network is already covered to a large extent with porous surfaces, albeit not the quietest type. Other countries that use such surfaces to a large extent are Italy, France, and Spain.

In the 1990s, a type of surface called Stone Mastics Asphalt (SMA) has become very popular in many countries. Its texture resembles that of porous asphalt, but it has no porosity. Provided large chippings are not used as part of the aggregate, it is generally 1-2 dB(A) less "noisy" than a dense asphalt concrete or chip seal surface, which it often replaces. Unfortunately, in Sweden and some other Nordic countries, SMA with a 16 mm maximum chipping size has been widely used for a few years. This has increased noise on many roads by approximately 1 dB(A).

"Noisy" types of cement concrete surfaces have progressively been replaced with less "noisy" ones in more recent years. In the U.K., the Department of the Environment, Transport and the Regions has a 10 year plan according to which an increased level of investment should enable them to deliver a number of improvements over the next decade, one of which is quieter surfaces installed on over 60% of the network, including all concrete stretches. The use of traditional surfaces such as hot rolled asphalt and brushed concrete, which are considered as somewhat "noisy," is already restricted on high-speed roads in England and Wales.

In the USA, essentially in the latest decade, there has been an increased concern for traffic noise emission on "noisy" types of cement concrete surfaces—notably surfaces with lateral texture to increase wet tire/road friction that show elevated levels, and several projects are under way to optimize such textures. These problems, however, existed in the 1960s-1970s, but the awareness of them has probably increased recently.

The condition and maintenance of surfaces affect traffic noise emission. Surface condition directly affects tire/road noise generation because the texture (and possibly porosity) change, but it also can create other noise such as rattling of loose parts or loads on vehicles—a type of sound which is particularly irritating. The maintenance of roads has changed somewhat with the economic situation. For example, it has probably improved in Japan over the time period studied. In the USA, it has probably deteriorated, at least until the major road improvement programs SHARP and ISTEA of the 1990s began.

In order to control vehicle speeds, street bumps and surface corrugations have been introduced in recent decades in several countries in Europe and in Australia. It is common to install them on 50 km/h streets but drivers need to slow down to 25-30 km/h. In Europe, it is popular among road authorities to lay a special, often more noisy, surface on or at pedestrian crossings and on bumps. These generally reduce speeds and thus reduce average noise levels, but also increase temporal changes in noise that affect maximum levels and how noise is perceived. A special and very serious problem that often causes many complaints is the rattling of loose parts on vehicles passing over street bumps.

16. Reasons for Limited Effectiveness of the Regulations

16.1 Reasons Identified

The reasons for the limited effectiveness of the regulations are assumed to be a combination of the following:

- A lower floor to achievable overall noise reductions caused by tire/road noise
- Not strict enough limits in the first years
- The inertia effect; slow exchange of old to new vehicles
- General counteracting trends towards bigger and more powerful vehicles
- Lack of control of in-service vehicles
- Lack of realism and representiveness of driving conditions in the measuring method on which type approval is based

16.2 Not Strict Enough Limits in the First Years

The first limits that were established were not strict enough to eliminate a substantial number of vehicles. In Europe, at least one decade was "lost" in this way. Countries such as Switzerland and Japan were more progressive in their regulations in these "early" years. Refer also to the discussion about tolerances in section 16.8 below. Note that the present car noise limits in Europe were complied with 20 years ago by many vehicles.

Judging from Table 5 and the discussion in section 7.7, it seems that the first regulations against truck noise introduced in the USA and in California in 1968 were sufficiently restrictive, relative to the noise emitted by in-service and new trucks of that time, to produce significant effects.

16.3 The Inertia Effect: Slow Exchange of Old to New Vehicles

Since the average lifetime of road vehicles is 10-20 years, it takes a long time for old, and presumably noisy, vehicles to be replaced by new, and presumably less noisy, vehicles; what we call the "inertia effect," see the example in Fig. 21.

The problem is aggravated by the fact that both maximum and equivalent levels in road traffic are most influenced by the noisier vehicles. For example, if "old" vehicles emit 3 dB(A) more noise than "new"" ones, the "old" vehicles as a whole emit more sound power than the "new" ones as long as their proportion in traffic exceeds 29% (against 71% for the "new" vehicles).

16.4 General Counteracting Trend Towards Bigger and More Powerful Vehicles

In the time period studied, in general, new vehicles have been equipped with more powerful engines. This does not necessarily mean more noise, but the risk is evident. Particularly for the heavy vehicle class, larger vehicles have been introduced and loads have increased. These changes have required the use of more tires on individual vehicles. More tires mean more tire/road noise. The trends are caused by requirements of more efficient and economical freight and passenger transportation and increasing road transportation needs. During the 1970-98 time period, freight transportation expressed as overall ton-km for 16 European countries has increased by a factor 3.0. More vehicles than earlier are now utilizing the maximum size and weight limits. It is difficult to avoid the trend towards increasing size, load and power, which results in higher noise generation. The increased power is, of course, utilized to carry more cargo—within limitations imposed by road authorities—but it could mostly also be used to make possible higher speeds. It should be recognized, however, that the increasing importance of fuel consumption is a limiting factor for the power increases.

According to Nylin [Nylin, 1992], the gross vehicle weight for the heaviest trucks with trailers in Sweden has changed as follows:

1950	18 tons
1960	33 tons
1972	51 tons
1992	56 tons

A somewhat similar trend, but with totally different causes, is that of increased use of vans or 4WD vehicles which are designed for both off- and on-road driving and which are often classified as light commercial vehicles or light trucks. Terms used include "sports utility vehicles (SUV)" and "light trucks & vans (LTV)". These are frequently used for transportation of driver/passengers, which could just as well be accomplished with a normal car—but where the larger vehicle is preferred for various reasons. Such vehicles are generally allowed one or two dB of "bonus" in the limits; they mostly run on tires that have more aggressive treads and are larger than on cars able to carry the same transportation load. This trend has been quite pronounced in many countries, in particular the USA, during the last 10-20 years, especially where there is plenty of space available for off-road vehicles.

A very interesting analysis of one of the major reasons for lack of efficiency of vehicle noise emission regulations has been made in the Netherlands based on the modeling work of van Blokland and Graaff [van Blokland & de Graaff, 2001]. According to Dutch vehicle statistics, which are not very different from other EU countries, the share of delivery vans (<3.5 tons) in traffic has increased from 6% in 1980 to 14% in 2000. Since these emit somewhat higher noise levels, their share of the total traffic noise emission in urban areas has increased from 12% in 1980 to 32% in 2000. Diesel cars share a similar trend, and these, together with diesel and petrol vans in 2000, contribute about the same as petrol cars to traffic noise emission; see Fig. 27.

Whereas the noise limits for cars have been reduced by 8 dB (nominal values) since 1980, the limits for vans[17] have been reduced by only 6 dB. Especially diesel vans emit substantially higher noise levels than petrol cars and diesel cars generally emit higher noise levels than petrol cars (they have an extra dB of allowance). This means that relatively quiet vehicles (petrol cars) are progressively replaced by noisier vehicles (diesel cars and vans), and this upsets the noise reductions that may be the result of the general lowering of noise limits. In reality, of course, the number of petrol cars does not decrease; it is the van fleet that increases rapidly. This trend is likely to continue, and the Dutch authors project that diesel vans will be the most important traffic noise source beginning in 2004.

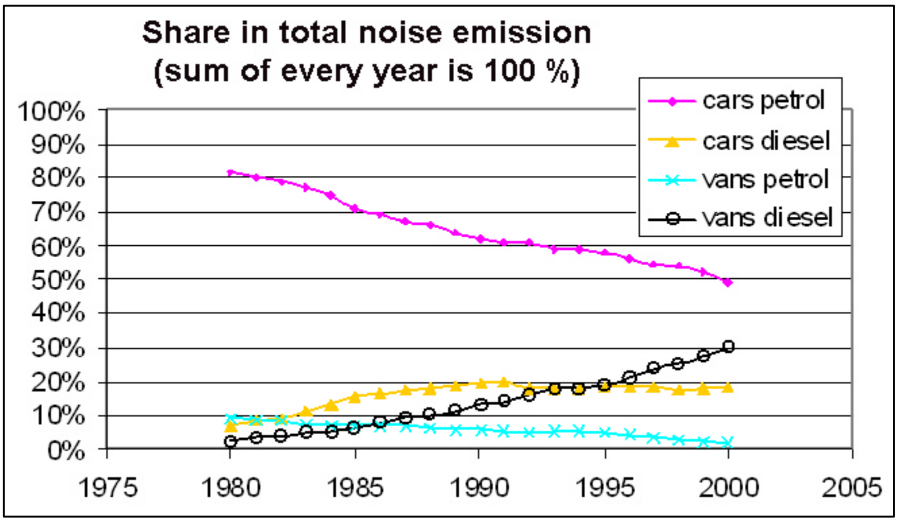


Fig. 27. Noise emission share (energy-based) of various light vehicle types, according to van Blokland and de Graaff [van Blokland & de Graaff, 2001].

The development described for the Netherlands has been going on for an even longer time in the USA. In 1999, the share of traffic by light trucks (basically SUVs and LTVs) in the USA was 37% of the total light vehicle traffic (vehicle-km), which is 2-3 times the current share in the Netherlands. Between 1980 and 1996, the sales of light trucks (commercial vehicles < 6000 pounds) increased in the USA by seven times. It is probable that the problem predicted for the Netherlands is already a fact in some countries.

16.5 Lack of Control of In-service Vehicles

Most countries have no effective control of in-service vehicles. This means that it may be only a few years while the vehicles are in new condition that noise reduction is really effective. For example, city buses emitting about 77 dB(A) during ISO 362 testing have been in wide use in Sweden since the mid-1970s. To a significant extent, noise reductions have been achieved by mounting of engine screens and enclosures, especially on the earlier models. It has been a problem that when such vehicles are serviced, it is tempting for the service personnel not to be careful when refitting the screens or enclosures. The same problem was sometimes noted for the "80dB" trucks and buses that were required for transit traffic in Austria some five years before all EU heavy vehicles had to meet this limit, the so called Nachtfahrverbot, see section 7.3. Such trucks and buses were and are still marked with an "L" plate (L for Lärmarmer Fahrzeug—low noise vehicle), and they are nowadays required to carry a list in each vehicle with all noise-reducing enclosures identified. In this way, the authorities may check to see that they are still in original "low-noise" condition.

Furthermore, it is not uncommon for private vehicles to have their original exhaust silencers replaced by non-original ones, often of poorer quality, and sometimes even illegal. The latter may give the vehicle a more "sporty" impression in the eyes and ears of some vehicle owners.

Non-original silencers are also a problem for heavy vehicles. Replacement exhaust silencer systems (RESS) have slightly less stringent noise requirements to meet, and can therefore be utilized to slightly lower fuel consumption—something that may be attractive to some vehicle owners.

The vehicle owners may also fit tires that are noisier than the original equipment tires. For example, it has been popular to fit much wider tires to some vehicles than the nominal sizes, in order to give a more "sporty" impression.

The data referenced in this report do not confirm that there would be a significant degradation in noise reduction of cars with age; rather it seems that there is indeed very little degradation [Kemper, 1979], [Phillips, 1999], possibly with an exception for certain car types [Steven, 2001-3]. It may be that the number of "degraded" vehicles is relatively few and does not affect the averages significantly. However, it is likely that this may be a much more serious problem for heavy vehicles.

With regard to motorcycles and mopeds, there is no doubt that in-service noise levels on the motorcycle fleet in total are much higher than for new vehicles. This is most often caused deliberately by the drivers/owners themselves, and this is one of the most serious problems in road traffic noise abatement. It is extremely important to prohibit tampering with replacement silencers and to enforce this effectively.

A factor that may affect the efficiency of the type-approval-based regulations is that type approval of some vehicle types is made on a vehicle with just a chassis; not including the body. For example, bus manufacturers often produce "only" the chassis and the body is produced later by a special body manufacturing company. The vehicle manufacturer puts on its chassis some temporary noise reduction intended to be provided by the body and then requires body manufacturers to apply similar noise reduction measures. However, full control of how well seals and enclosures of importance to noise reduction are preserved or maintained may be lost by the vehicle manufacturer who is responsible

[17] Here the term "van" includes SUVs and LTVs according to the above.

for noise approval, unless they apply special routines for checking these seals and enclosures. In the worst case, the vehicle in use may be different from the vehicle which has been type approved. On the other hand, the body may help with some additional screening but it may also result in some unwanted reflections, so the net effect is difficult to assess. The problem does not occur for cars, which are generally produced entirely by the same manufacturer.

Again, as mentioned in section 16.3, the problem is made worse by the fact that both maximum and equivalent levels in road traffic are most influenced by the noisier vehicles, which means that the latter will give a disproportionally large contribution to the overall level, be it L_{max}, L_{eq}, L_{dn}, or L_{den}.

It is not that easy to control in-service noise. The reason is the lack of a good measurement method. The ISO 362 method is impractical and too difficult to apply in such general use that would be required; basically either as on-the-road tests or tests at regular vehicle inspections. The ISO 5130 method, based on stationary tests mainly of exhaust noise, is assumed to do this job, but on-going ISO work has shown this method to have a poor correlation with noise during actual driving or type approval full-throttle acceleration noise; for commercial vehicles even no correlation [Steven, 2001-3], [Berge, 2001]. As stated before, today the exhaust system is not the dominating noise source that it was earlier—with the exception of the motorcycle/moped case.

16.6 Lack of Realism and Representativity in the Measuring Method

The problems with the measurement method used for type testing of cars (corresponding to ISO 362) were identified in [CCMC, 1980]. This organization[18] accurately predicted that the use of the ISO 362 method would not lead to any major traffic noise reduction and argued in favor of a switchover to the ISO 7188 standard. This was further analyzed and explained in a publication by Biegstraaten and Tukker [Biegstraaten & Tukker, 1982], where it is shown that a limit based on ISO 362 does not reject many of the “noisy” cars but rejects some “quiet” cars. The Dutch authors tested the effect of lowering the limit by 2 dB(A). Using ISO 362, the non-rejected type approved cars had an L_{Aeq} in “representative” driving of 66.3 dB(A) which was only 0.4 dB(A) lower than the value when all cars were included, whereas when using ISO 7188 the gain would be 1.8 dB(A)—which is near the ideal 2 dB(A). They concluded that the ISO 7188 method is far superior in that it rejects more of the noisy but fewer of the quiet cars.

The Working Party has not been able to identify a corresponding study regarding heavy vehicles. However, it is commonly agreed that there are problems with also the heavy vehicle test procedure.

In Japan, the type approval procedure utilizes a variant of ISO 362 that is more adapted to actual driving conditions. For example, the Japanese method requires heavy vehicles to be loaded during testing, whereas the EU and ECE regulations requires that unloaded vehicles be tested. Since the noise reductions measured in actual traffic appear to be more significant in Japan than in Europe, it may be that the use of a more realistic driving condition during type approval is one of the main reasons. As mentioned in section 7.8, control of in-service vehicles may be another reason.

The problem has been recognized internationally, and ISO has established a working group to deal with the problem: ISO/TC 43/SC 1/WG 42. This group has already issued some proposals for improving the “old” ISO 362 method and its derivatives in the EU and ECE. These proposals have already been approved. With regard to a new measuring method, only informal proposals have been circulated, essentially based on proposals from the European vehicle manufacturers' association, ACEA. The proposals have been very comprehensive and aimed at obtaining a better correlation between type approval noise and noise emission in average urban traffic. To this end, the methods are intended to use much more representative driving conditions than the current methods. For heavy vehicles, a full-throttle acceleration is still considered to be the appropriate driving condition (although with an appropriately loaded vehicle), while for light vehicles full-throttle and constant speed operations are the only practical test conditions albeit not the best ones from the representativity point of view. However, ACEA considers that a certain combination of such operating conditions may represent a more desirable partial-throttle operation.

The criticism of ISO 362 and its derivatives in the EU and ECE have varied. In the 1990s, it was very serious but the most recent trend seems to this author to be somewhat less critical of ISO 362. This is illustrated in Fig. 28, which is taken from Steven [Steven, 2001-1]. The figure is a result of using a modified version of the German prediction model, MOBILEV, and shows the distribution of vehicle noise levels during driving of a typical medium-size car in an urban area, assuming that the car just meets the various noise limits that have been regulated in the EU and ECE (the three distributions on the right). The two distributions to the left are hypothetical cases in which the limits have been reduced to 71 and 68 dB, using a balanced reduction of tire and power unit noise sources. The assumptions are, of course, influenced by the subjective judgments of Steven of this balance in reduction measures, but he is a world authority on this, and the results are worth serious consideration. Figure 28 shows that limit values based on ISO 362 may be effective in reducing urban traffic noise after all, but it was only when the present limit was reached in 1996 that any significant effect could be anticipated.

16.7 A Lower Floor Caused by Tire/Road Noise

The dominance of the source that emits the highest levels, on L_{eq} and L_{max} values, is a problem in yet another respect. When all noise sources but one have been reduced to a level significantly lower than the remaining source, this remaining source will almost entirely determine the overall noise level. Since tire/road noise historically has not been very much affected by the legal noise control procedures, it means that often all other sources, which have been affected by the procedures, have been reduced down to levels below those of tire/road noise in actual traffic. Consequently, in such cases, tire/road noise has placed a limit on what is achievable. This is illustrated in Figs. 29-30.

---

[18] The Committee of Common Market Automobile Constructors (CCMC, from the corresponding French name)

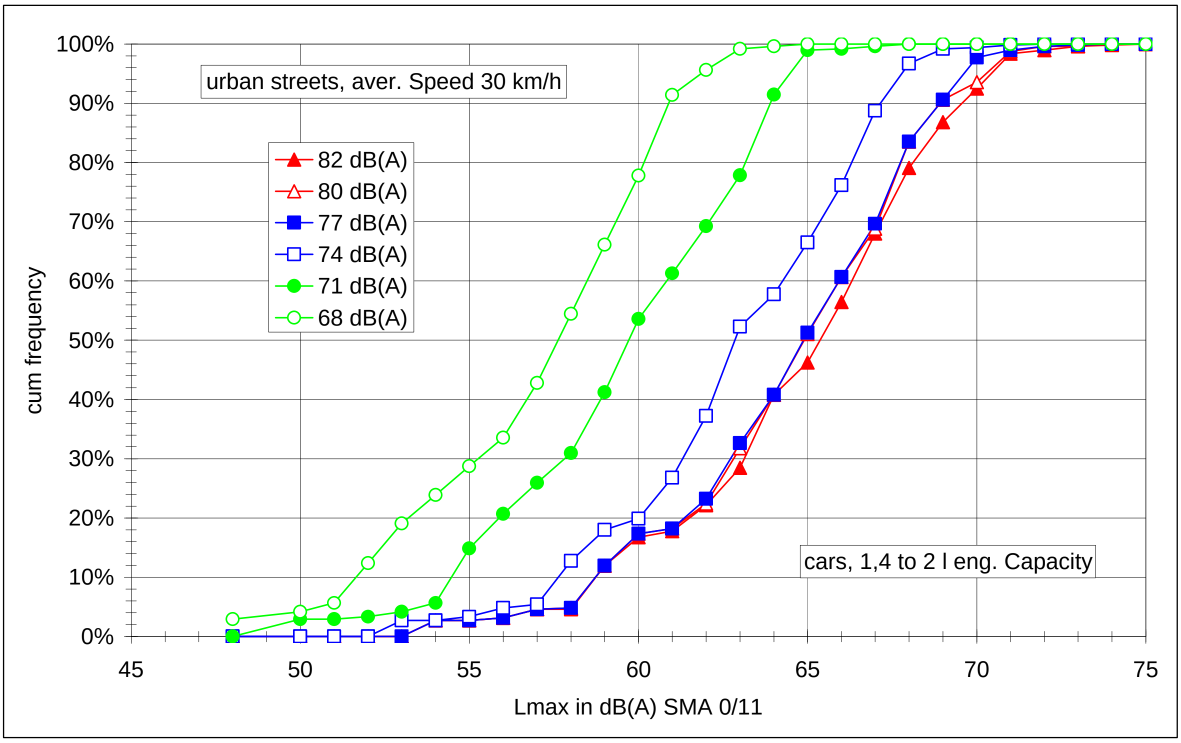


Fig. 28. Distribution of noise levels from driving a car in an urban cycle, at an average speed of 30 km/h, with the car designed to just meet the noise emission limits indicated in the insert. From Steven [Steven 2001-1].

Figure 29 shows recent measurements on a Volvo S40 car, for which pass-by noise measurements were made under all possible driving conditions. The figure shows that at constant speeds, the overall vehicle noise levels are very close to the levels at coast-by (engine switched-off). This implies that any reduction of power unit noise will produce a negligible reduction of overall noise. The exception is driving in first gear. Similar data are available for acceleration, in which case the overall vehicle curves are significantly higher than the coast-by curve for both the first and second gears.

Figure 30 shows a similar case for two heavy trucks meeting the 80 dB(A) EU and ECE limit. It appears that even if *all* power unit noise could be eliminated, tire/road noise[19] would limit the noise reductions at 70-90 km/h to 1-2 dB(A). Even at 50 km/h, achievable reductions would be limited to 1-3 dB(A) if tire/road noise were not simultaneously reduced.

Generally speaking, one can say that for the modern vehicles, tire/road noise and not power unit noise is the determining factor for all constant-speed driving conditions. Heavy vehicles driving at speeds lower than 50 km/h are the exception, but constant-speed operation is rare at such low speeds. This does not by any means make power unit noise reductions unnecessary, since many of the noisiest situations involve stop-and-go operation, but power unit noise reductions must be supplemented by measures affecting tire/road noise. When traffic is congested, which is too often the case, power unit noise will be the important factor and may also need further reductions.

16.8 Safety Margins of Tolerances in Limiting Values

When noise regulations are applied, they sometimes allow certain tolerances or “safety margins” when comparing measured values with legal limiting values. In Europe, in the EU as well as ECE regulations, and in Australia, manufacturers are allowed a safety margin of 1 dB, i.e., 1 dB is subtracted from the measured values before they are compared with the limits. This is meant to be a compensation for possible inaccuracies in the measurement procedure and instrumentation in order that no vehicle will have to meet a more stringent requirement than the nominal one. Originally, the “lack of tolerance subtraction” was assumed to be motivated by poor measuring instruments and acoustical conditions; later by a large variation due to a non-standardized test surface. Now, the test surface is standardized (ISO 10844), and the largest potential errors are considered to be some remaining road surface variations and the temperature variation (0-40 ^{o}C). Finally, in Conformity of Production testing, another extra dB of tolerance is allowed, but due to a vehicle-to-vehicle variation of typically 2 dB in production, this is most often not possible to use as an extra allowance for an “average” vehicle. All this in practice means an “extra allowance” of up to 1-2 dB.

In Japan, on the other hand, if a formal limit is (say) 83 dB(A), the vehicles must not be measured to emit more than this even in mass production. This means that new vehicles are designed for 82 dB(A) or lower, i.e., one applies a safety margin of at least 1 dB for protection of the environment. Also, measured values are rounded upwards. Note that these two policies are contrary: In Europe an allowance of up to 2 dB is in favor of the manufacturers, while in Japan an addition of 1 dB (1.9 including the rounding effect) is intended to give a margin for the environment. If numerical limits

[19] Note that the coast-by curve may give a small underestimation of tire/road noise at cruise- and drive-by since there may be an increase due to the torque on the drive tires. This note is valid for both Fig. 29 and Fig. 30.

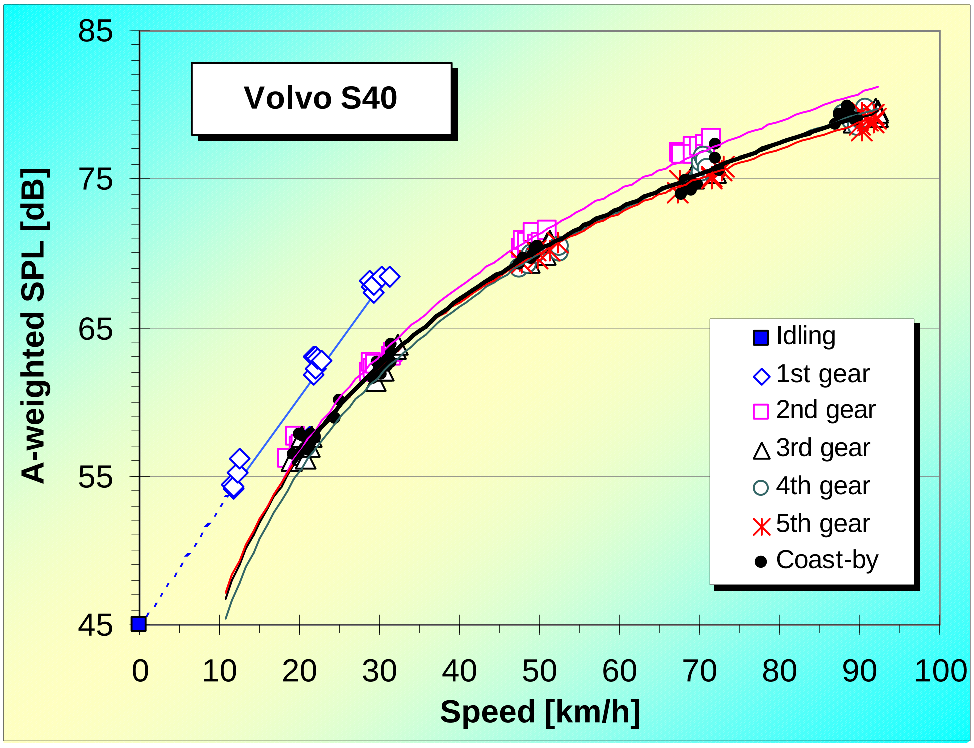


Fig.29. Typical overall vehicle noise (thin lines) versus speed for a medium-size car driven at constant speed on different gears. Also coast-by noise (bold line) is shown; this is equivalent to tire/road noise. Dense asphalt concrete surface. From Sandberg et al. [Sandberg et al., 2001].

and measurement procedures were identical in Europe and Japan, which they are not, vehicles in Japan would have to be 2-3 dB(A) less noisy than in Europe.

In the USA, no deduction is allowed for lack of measurement tolerances. The US state and federal regulation models are in this way more similar to the Japanese than the EU model.

These differences should have meant a better efficiency of Japanese and US limits than of European limits, in relation to what is apparent when just comparing the nominal limits. However, this may at least be partly compensated for by a difference in the nominal limits (see Fig. 1).

The European philosophy in this matter is a little hard for some to understand. On the one hand, the limits are intended to be maximum limits; on the other hand, no vehicle shall have to meet more stringent requirements than the nominal one due to measurement tolerances. Some people also claim that since the limits are intended to protect the environment, the tolerances shall be such that they are favorable to the environment rather than to the manufacturers.

The vehicle industry does not assume responsibility for the “extra allowance” or “tolerances”, it just makes things complicated on the world market. Rather, at least ACEA seems to prefer one worldwide measuring standard and system of limits.

16.9 The *Boom Car* Problem

Power unit or tire/road noise do not always dominate the noise emissions from a vehicle. During the period studied, a new source has become evident. Some car or van owners have installed music reproduction systems in their vehicles that make it possible to play extremely loud music. These vehicles have been named *Boom Box* or *Boom Car*. The problem has grown extremely rapidly, and is now a major concern in local communities and cities all over the world—perhaps most of all in the USA. See, for example, the home page of the Noise Pollution Clearinghouse [NPC, 2001]. It is not uncommon for one to hear the noise of such a sound system much earlier than one hears the normal vehicle noise of an approaching car or van.

The phenomenon is connected to a new “sport” called *dB Drag Racing*. The idea is to produce the loudest possible (persistent) sound in the car with a loudspeaker system. The world record is said to be 176 dB. To achieve such sound pressure levels, the car body and windows need to be reinforced. Most of the vehicles that hit the big numbers have windows of Plexiglas that are thicker than 50 mm.

Many local communities have established ordinances with regard to Boom Cars but the problem seems to receive wider attention. In 2000, the Oklahoma House of Representatives attempted to pass an “anti-car stereo noise bill” that would apply statewide, but it is not known whether it has been finally accepted (much final language needed adjustments).

The Boom Car may not be a reason for the limited success of the vehicle noise regulations, but it is a vehicle-related noise problem that has indeed grown rapidly and will most probably grow much more.

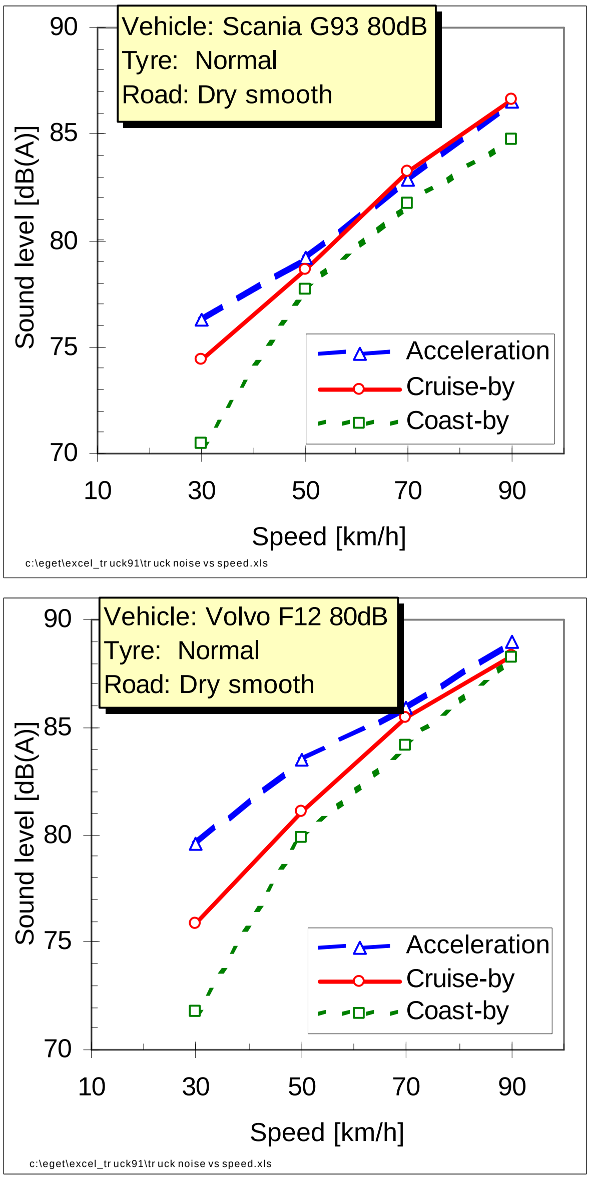


Fig. 30. Typical overall vehicle noise at acceleration and cruise-by (constant speed) versus speed for two heavy trucks, when using typical gears. Also coast-by noise (dotted line) is shown; this is equivalent to tire/road noise. Dense asphalt concrete surface. From [Sandberg, 1992].

16.10 Discussion of a Scenario Without Any Vehicle Noise Regulations

It is interesting to speculate about the hypothetical case in which no vehicle noise emission regulations had ever been introduced. Would road traffic noise have been much worse than it actually is today?

It is, of course, not possible to answer this question with a high degree of confidence. However, since tire/road noise has not been significantly affected by today's regulations, it can be argued that this gives a clear indication of the situation with no regulation policy. This argument would mean that a non-regulation policy would have resulted essentially in status quo or even a slight increase in noise emission from individual vehicles, as it has from tires.

In the USA, there have been no federal noise regulations for cars and it would be interesting to compare the situation with Europe. For cars at highway speeds, it seems that the changes in noise levels in Europe and the USA have been quite similar. This is probably because tire/road noise has totally dominated over the entire period studied, and there have been no regulations effective for this in either Europe or the United States. For cars at low speeds, the available data (Table 5c) seem to indicate a slight noise increase with time in the United States but a corresponding decrease in Europe and Japan. The US increase could be due to the increased frequency of light trucks and SUVs in traffic. But the differences are not sufficiently large to be able to make any robust statement. For trucks, the European and US situations seem to have changed in approximately the same way over the time period 1975-1995. Note, however, that the effective limits have been quite similar over this time period. But in the period after 1995, i.e., after the latest lowering of limits in Europe, it seems that the noise reduction effects in Europe have been substantial. There is no reason to expect any matching effects of that magnitude in the United States, since the latest lowering of limit occurred in 1989. This is an indication of an improved effect due to tightened regulations.

What then would voluntary commitments by the vehicle industry be like in the case of no vehicle noise regulations? This is of course very different from manufacturer to manufacturer and from type to type. However, a report from the CCMC in 1980 estimated that in order to reduce car noise emission from 80 to 77 dB(A), an increase of approximately 2% of car purchase costs would apply, and to reduce noise emission from 80 to 75 dB(A), a cost increase of 5-10% was estimated [CCMC, 1980]. For heavy vehicles, CCMC estimated cost increases of 1-3% to go from 90 to 86 dB(A) and 5-12% from 90 to 80 dB(A). Although the CCMC said that it was in favor of traffic noise reduction, including vehicle noise, it is not very likely that the vehicle manufacturers would have made major noise reduction efforts without the existence of forcing regulations—bearing in mind the estimated cost increases[20].

As a comment on the reduction from 77 to 74 dB(A) in the EU/ECE in 1995/96, a representative of a major US vehicle manufacturer wrote that the US manufacturers were opposed to this, and further that "*under this premise, a limit value below 77 dB for the type approval test is insupportable because, even under the old 80 dB light vehicle noise limit, vehicle manufacturers had already met their ecological responsibilities*" [Cherne, 1993].

There are several other statements by industry representatives in the literature and in documents from regulatory meetings that are consistent with the two preceding paragraphs. Thus, it is reasonable to assume that without vehicle noise regulations, but in a tough commercial competition, the voluntary commitment by the industry to reduce *exterior* noise would have been marginal.

Notwithstanding the above examples of statements, market forces might have made a change. For cars, it is probable that market forces would have had some effect regarding noise emission at low speeds. For example, Figs. 10-11 show that there has always been a fairly good margin between legal noise limits and actual car population means—particularly in the early years. One can say that the industry seems to have been somewhat ahead of the limits, and this

[20] Cost increases due to exterior noise reduction on today's European 74 and 80 dB vehicles are normally considered to be far below the values stated in the CCMC report.

could be an indicator of a voluntary commitment to produce quieter cars—although this may not have been directly aimed at exterior noise. Not only low interior noise, but also, to some degree, low exterior noise, would be perceived by the car buyer as an indication of a somewhat luxurious car and vice versa. In addition, efforts to reduce interior noise have required changes in the power units that have had some beneficial effects on exterior noise. The improvements with regard to interior noise have, therefore, most probably had positive side effects on exterior noise.

In contrast to the above, vehicle owners who like "sporty" cars and motorcycles do not generally consider low exterior noise as an advantage—rather the contrary. They would like to have a conspicuous and individually recognizable sound from their vehicle. Thus, in a non-regulated world, we would most likely have had substantially noisier sport cars and motorcycles—albeit with a sound generation perceived by the drivers as pleasant and tailored to meet their expectations of power, etc. That is not to say that such cars would be noisier under most conditions—probably only during idling, low constant speeds and fast accelerations [Sandberg et al., 2001].

Market forces may also have had effects with regard to heavy vehicles. For example, freight and public transportation companies must meet health regulations, and thus make sure that their vehicles have interior noise levels well below any such limits. Today, customers also want to have vehicle cabins that are comfortable for their employees to work in for 8 hours. This has put some pressure on the market for lower interior noise, which no doubt also has significant bearing on exterior noise. Some companies also want to display a "green profile," i.e., they want their vehicles to be perceived as environmentally friendly. This may make it easier for them to get contracts for transportation work in urban areas.

Regarding city buses, many public transportation authorities and their companies have been environmentally conscious and responsive to demands of low traffic noise emission in urban areas and have established their own voluntary criteria for exterior noise of their buses [Kaellberg, 1979]. Irrespective of international or national regulations, it is likely that this has resulted in pressure to produce quieter city buses.

One should consider the fact that the vehicle market is worldwide. If one of the major markets has strict regulations, most manufacturers will adapt to this one. It may be that some minor cost savings may be achieved if a noisier vehicle version is offered on the non-regulated or not so strictly regulated market, but this option is only partly utilized. Although it is not always the case, it means that countries or states where there are no vehicle noise regulations, or where they are not as strict as the "normal" ones, will also benefit from the stricter regulations in other countries.

In general, the Working Party believes that with a non-regulation noise policy for vehicles, it is likely that some minor reductions at low speeds would have occurred regarding the majority of cars and city buses. For sport cars and motorcycles, a contrary trend would have occurred. Regarding trucks, market forces would have created a certain pressure for lower noise vehicles, but the improvements might have been at least partly nullified by compensating noise-increasing trends such as larger vehicles and more powerful engines, and it is not easy to say how large the net effect would have been. However, the effects of a non-regulated policy would not likely have resulted in any *major* noise reductions. Consequently, the regulations are believed to have had a clearly positive effect despite the lack of efficiency at driving conditions where (the non-regulated) tire/road noise dominates.

17. Recommendations

Based on this report and the assumption that society needs a considerable traffic noise reduction, the following recommendations for consideration in future vehicle noise emission policies are offered.

- Noise emission from tires during "normal" driving must be substantially reduced. As long as this is not done, vehicle noise regulations are likely to be very ineffective. See Fig. 31, which compares three different policies for five different traffic conditions: power unit reductions by 6 dB, tire/road noise reductions by 6 dB, and reduction of power unit noise for heavy vehicles (only) by 6 dB in combination with tire noise reductions by 6 dB for all vehicles. The scenarios and the results are based on a new German model for noise predictions named MOBILEV [Steven, 2001-3].

- Tire/road noise reductions may be achieved by use of a regulation such as the amendment to the EU tire directive, but the limits must be substantially reduced to have any effect. It is likely that a lowering of the current vehicle noise limits for light vehicles, where such exist, may also have an effect on tire/road noise.

- It is important that such tire regulations do not exempt significant parts of the tire market, such as retreaded tires, since any remaining noisy tires will have a disproportionally large influence on noise levels.

- Since noise emission from in-service tires may be quite different from that of new tires, it is important to determine means to ensure that worn tires do not become significantly noisier than they were when new.

- Not only should tires be subject to noise limitations, but the role of the road surface in excitation or otherwise affecting tire/road noise emission should also be limited, which is the responsibility of road or environmental authorities. Preparations and plans for such measures have already been made, but it is important that they be followed up. As for tires, it is important that in-service characteristics are also controlled.

- A new measurement procedure for use during type approval of vehicles should be developed. It should require that the major noise sources of a vehicle be measured, i.e., these that are expected to be perceived as noisy by the people exposed to the noise.

- The Working Party does not take a stand on the question of whether power unit noise and tire noise should be separated in such a new method, but if they are separated, tire/road noise may be controlled by the separate tire noise regulation discussed above. In such a case, it is recommended that a speed lower than the test speeds required in the EU tire directive be added to the tire noise regulation.

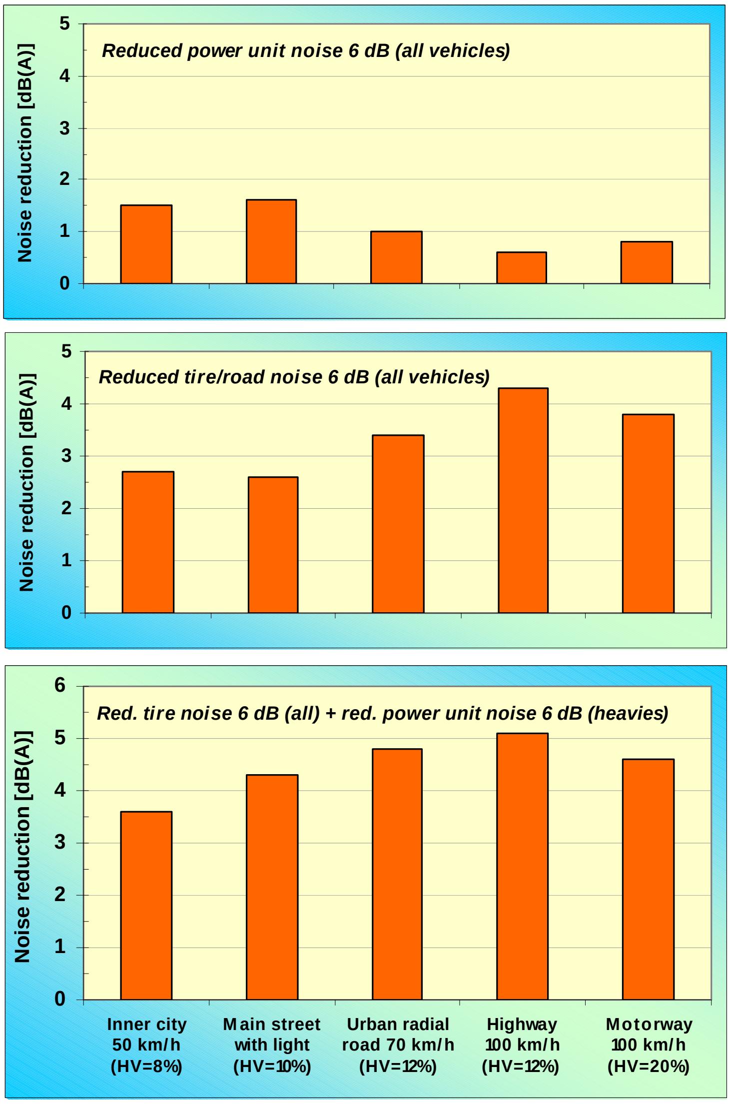


Fig. 31. Anticipated effect of lowering noise limits by 6 dB by three different policies (one for each part of the figure). Figure based on data by Steven [Steven, 2001-3].
Note:
HV = Heavy vehicle proportion of total traffic volume.

- Not only vehicles in new condition, but also vehicles in service should be regulated and checked with respect to noise. This may possibly not need to apply to cars. Consideration should be given to a review of the extra allowance for replacement exhaust silencer systems (RESS) that exists in some regulations and instead require the same performance of such systems on a specific vehicle as the original exhaust system. Otherwise, RESS may sometimes sacrifice higher noise for lower cost and lower fuel consumption. With regard to in-service motorcycle noise and "anti-tampering" measures regarding exhaust silencers, this is of extremely high importance in order to reduce public annoyance.

- Limiting values should be sufficiently stringent in order to really affect the vehicle or tire population and not only very few of the noisiest vehicles or tires. Otherwise, the public will not perceive any positive effects of the regulations. It is important to avoid repeating the mistakes in this respect in the earlier noise regulation policies.

- The "bonus" of one dB in limiting values for light vehicles with diesel engines should be removed.

- Substantial effects in terms of noise reduction may be achieved if the extra decibels of allowance for sport utility vehicles and light trucks and vans (<3.5 tons) are removed to make them meet the same requirements as other light vehicles (cars). Some of these are often marketed as very comfortable and luxurious vehicles comparable in performance and comfort to conventional cars. This vehicle category is rapidly increasing in popularity and will soon be the dominating noise[21] source if nothing is done to avoid it.

- Vehicle noise emission, in particular public annoyance, may also be affected by change of driving behavior [Sandberg et al., 2001]. With regard to noise, this is most important concerning motorcycle and moped drivers. However, to achieve such driver changes is easier said than done. One may want to consider ways to encourage a wider use of automatic transmissions outside North America, and one may want to consider improved driver education on low noise, fuel saving or environmentally friendly driving behavior.

- Regulating maximum noise levels of vehicles is not sufficient if maximum efficiency of noise control is desired, since this will only affect a fraction of the vehicle population. It would be desirable if means of affecting the noise levels of also the vehicles that emit medium and low noise levels can be found and applied. Introduction of some commercial arguments for lower exterior noise emission would be beneficial, as is illustrated for interior noise in Fig. 23 and as a result of the Austrian Nachtfahrverbot discussed in connection with Fig. 11. Means for encouraging the use of vehicles as quiet as possible may include tax incentives connected with noise levels, exemption from toll for low-noise vehicles, limitation of travel based on a quota system with "environment-affecting" points, as well as permits (connected with noise classification) to travel in restricted low-noise areas, on restricted roads or at restricted

[21] This may already be the case in some countries.

times. The Working Party has not evaluated such concepts, but points out that it is desirable that they be based on more justified and fair measurement methods than available so far.

- It is important that the state of development be assessed at frequent intervals to detect in due time inefficiencies and unwanted effects, in order to be able to correct development trends without too much time inertia. For example, a study like this one should have been done at least 15 years ago. Assessments are dependent on the availability of measurement data comparable from time to time, and authorities are encouraged to establish programs with a goal of collecting such data.

18. Conclusions

As an introductory remark, it is worth noting that the rather modest reductions in actual traffic noise that have been identified should be put into context with the very significant reductions necessary if people living near busy roads are to enjoy anything like the recommended community noise levels. For example, to meet a criterion of L_{eq} of 55 dB(A) from a road carrying 2000 vehicles/h (10% heavies), a road-dwelling separation distance of about 80 m is required [Lawrence, 1984]. This is not often possible and may require either accepting a poor environment or achieving the reduction by alternative and very expensive means. To put it very simply, if vehicle noise emission could be reduced by 3 dB(A), it is generally equivalent to halving separation distances for the same noise level at the dwelling. Ideally one would wish the reductions to be more like 10-20 dB(A) than the few dB which have been recorded. Although such reductions generally do not seem realistic in our lifetime, it is important to try to achieve as much as is practical/economical in order to relax the needs for other noise reduction measures.

The conclusions from this study are as follows.

This study is the first and only one that attempts a global assessment of the effects of vehicle noise emission regulations in the past.

Since vehicle noise emission limits were introduced during the period 1970-80 in most industrialized countries, limiting values have been tightened by 7-16 dB(A) for various vehicle categories in the EU and for countries honoring the ECE regulations, lower values for light vehicles and higher for heavy vehicles. In Japan, corresponding limit reductions have been 8-11 dB(A) and in the USA a 3 dB(A) reduction has been enforced for trucks. In these values, account has been taken of changes in the measurement procedures that have required or allowed a change in noise emission. These are quite remarkable reductions for all vehicle categories; changes which have not been free of charge. The heaviest trucks in particular have faced much more stringent requirements; for example the trucks in the EU currently have to meet the same nominal limit as cars had to meet up to 1989, i.e., cars which still represent a considerable part of the traffic. Another example is that a new articulated truck in Europe, and in the USA as well, which may have a total mass of 40-50 tons, has to comply with a limit which is nominally the same as for a large motorcycle, having a mass of less than 1% of the truck.

Vehicle noise emission limits are preferably harmonized internationally. Separate limits and inconsistent regulations from country to country will mean much extra work, administration and expenditure for vehicle manufacturers and vehicle owners—and even for authorities. In the European Union (EU), and some other European countries having trade agreements with the EU, the vehicle noise regulations are the same in all countries. Also the United Nations Economic Commission for Europe (ECE) tries to harmonize the regulations internationally, and it even provides a forum for harmonization discussions with non-European countries. Nevertheless, one can see three major families of noise emission regulations: those in Europe, USA and Japan. They contain many similar elements—especially in European and Japanese requirements. For the particular objective of this study, such differences are interesting, but, in general, better harmonization is desirable.

Limiting values are generally confined to new vehicles, most commonly at type approval. A few countries or states have introduced their own requirements regarding in-service vehicles, but globally these can rather be seen as exceptions. The measurement procedure selected for type approval relies on driving conditions that result in high proportions of power unit noise, but, up to the mid-1990s in Europe, made tire/road noise quite insignificant. As soon as the noise limits have become difficult to comply with, vehicles have been optimized for the new situation, so that power unit noise has been highly affected by the requirements but tires have been virtually unaffected. In Japan, this tire/road noise contribution in the acceleration test became significant a little later than in Europe, but for many years there has been a supplementary Japanese constant-speed test in which tire/road noise dominates.

The type approval measurement procedure determines noise emission in a way that seems to correlate rather poorly with community noise levels or even levels at the roadside typical of actual traffic. This may be one of the reasons why the effects of the noise emission regulations measured in actual traffic are lower than the nominal changes of limit would suggest. For accelerating traffic at low speeds, roughly half of the nominal changes in noise requirements have been recorded as a reduction of individual vehicle pass-by noise in actual traffic streams. For light vehicle traffic at constant speeds, there has been no significant improvement at all resulting from the regulations, except at very low speeds. For heavy vehicle traffic at constant speed, an improvement of roughly half the nominal change of limits seems to have occurred at low speeds, but very little at high speeds.

The single regulation-related event that seems to have had the most important effect on noise emission of heavy traffic at low speeds is probably the ban against nighttime transit traffic in Austria (Nachtfahrverbot). This was a national regulation with a very limited application, but since it addressed commercial transportation problems that affected several countries, most European truck manufacturers very soon adapted to it and supplied “80-dB-trucks” to most of the European market. This was in remarkable contrast to the “88-dB-trucks” that were standard a few years earlier. Not everyone was happy with this, but it seems to have had identifiable effects that were substantial, far beyond Austrian transit highways over and through the Alps.

Tire/road noise has constituted a lower limit to all improvements at constant speeds. For the current limits in Europe and Japan, tire/road noise is significant also under the type approval conditions at which this type of noise traditionally has been assumed to be negligible.

The above suggests that vehicle noise emission limits have been disappointingly inefficient. But this is not entirely true. For example, there is an "inertia effect" due to the slow exchange of older to new vehicles in the traffic, in combination with the noisier vehicles contributing disproportionally to the common community noise indices. It means that the latest European and Japanese lowering of limits has not yet shown its full effect in terms of traffic noise reduction. For example, in Europe one may expect at least one extra dB of noise reduction by limit changes already decreed when all old vehicles have been replaced by modern ones.

The effects mentioned above are measured as levels typical of vehicles as a whole in a traffic stream. However, when studying the noisiest vehicles in a traffic stream, the effects of the limits have been much better and actually rather close to the limit changes. From the noise emission point of view, vehicles of similar ages have become much more uniform, both within each vehicle category and between them. For protection of individuals against maximum level effects such as awakening at night, this development is very positive.

Furthermore, there are indications that the regulations have had more positive effects that are not immediately obvious, such as decreased source height and changes in the noise emission pattern of a temporal as well as of a spectral nature. These are, however, difficult to quantify.

Speculation regarding the situation if no noise regulations had existed, suggest that noise levels would then not have decreased to any significant degree. Some development towards quieter vehicles would have been driven by market forces, but it is doubtful as to what extent this would have matched or possibly exceeded the increased performance of most vehicles that have taken place, such as increased power, increased speed capacity, increased weight and higher load capacity. This would probably have meant that compensation for the noise of increased traffic volume would not have occurred and the total situation would have been extremely cumbersome.

The Working Party has analyzed the reasons for the limited success of the emission limits and arrived at the following conclusions. Limits were not strict enough the first years. It took a decade or more until they were lowered to a level where they really seemed to affect the vehicle population significantly. The exchange rate from old to new vehicles has slowed down the noise reduction with time more than most people have realized. This is because the old noisier vehicles maintain a dominance in equivalent as well as maximum noise levels for a disproportionally long time, but also because vehicles in-service are not generally controlled with respect to noise. Type approval mainly controls vehicles in new condition, which is often different from the "same" vehicles used in traffic.

Over the time period studied, at least for heavy vehicles, there has been a general trend towards larger and more powerful vehicles having more tires and being more optimally loaded. This has counteracted the lowering of noise emission limits. Another important effect limiting the efficiency of the limits is the lack of realism and representativity of driving conditions in the measuring method on which type approval is based. For example, in Europe and most other countries, vehicles are tested unloaded. In combination with the extreme power now available and the driving condition, this often results in extreme testing conditions which are not representative of actual traffic. This probably results in sub-optimizations of noise reduction measures. In Japan, the test method is somewhat different which may be one explanation for the apparent better effect of the regulations in Japan than in Europe.

In recent years, the popularity of some light vehicles that are somewhat larger than passenger cars, such as sports utility vehicles, light trucks, and delivery vans, have grown rapidly. Since these vehicles generally have higher noise emissions than cars, in particular if they have diesel engines, and their proportion in traffic has become significant, the contribution that they now make to overall traffic noise is constantly increasing. It is projected that this group in some countries will very soon contribute more to traffic noise than any other group of vehicles.

Finally, one of the major reasons for the poor efficiency of the limits is that the lack of any significant effect on tire/road noise of the type approval procedure for vehicles, until after 1995 in Europe, has left tire/road noise with no substantial improvement. In the worst case, it may even have increased over the time period studied. In too many cases, tire/road noise has limited the achievable overall noise reductions, since no matter how much power unit noise has been reduced, there is still tire/road noise remaining and unaffected. Human perception concentrates on the dominating noise. Generally speaking, one can say that for a fleet of modern vehicles, tire/road noise and not power unit noise is the determining factor for all constant-speed driving conditions. Heavy vehicles driving at speeds lower than 50 km/h would be the exception, but constant-speed operation is very rare at such low speeds for these vehicles. This does not in any way make power unit noise reductions unnecessary, because many of the noisiest situations involve stop-and-go operation, but they must be supplemented by measures affecting tire/road noise.

The Working Party gives some recommendations. It is clear that future regulations must take tire/road noise into proper account, for example by separate limits such as decided upon in the EU, for inclusion in the EU tire directive. However, the limit values that have been decided upon are expected to give no measurable effect on traffic noise for the foreseeable future. In this way, the EU is currently repeating one of the fundamental mistakes that have been identified in this work as being responsible for delaying noise reduction by many years, namely not strict enough limits for the first years and a long lead-time until this is corrected. It is also recommended that a measurement method which better represents the noise of vehicles in urban driving be developed. Not only vehicles in new condition, but also in-service vehicles should be subject to noise control and regular or spot checks. This is of special importance for motorcycle noise emissions, since the fitting of illegal exhaust systems is very common and leads to exceptionally high noise emissions.

A new and somewhat odd vehicle noise problem has emerged during the period studied, namely the *Boom car*. The use of high-power music reproduction systems in cars, vans and light trucks in recent years has become a significant nuisance to many people, resulting in regulations or ordinances in many local jurisdictions. The sound of such systems may largely exceed that of the vehicle operation. It is difficult to see how this problem could be handled within a system of vehicle noise regulations such as discussed in this report, but the problem needs to be addressed in some way.

The vehicle industry has succeeded in doing what is required in order to be able to sell vehicles that are attractive for customers as well as meeting the authorities' requirements. The customer's requirements have resulted in a great success in terms of interior noise reduction; the authorities' requirements on exterior noise have been a partial failure—although the latter have also had many and substantial benefits to society. This illustrates how important it is to design requirements in an effective and comprehensive way.

It must be emphasized that, although the vehicle noise reductions in actual traffic have been less than anticipated, there have been many and major positive effects. The discrepancy between anticipated effect and actual effect is not due to failure of the industry or a lack of technical competence or knowledge. In fact, one can say that the regulations have essentially succeeded in reducing power unit noise in traffic as much as one could reasonably demand. It is mainly our *expectations* that have been wrong. These expectations, except perhaps within the vehicle industry and researchers in the area, have been unrealistic in that, for a long time, the importance of tire/road noise was neglected, and not the subject of any regulations. This was combined with a selection of noise limits during the first time period that were too conservative and were tightened too slowly.

The Working Party has shown that it is very important to monitor the effect of regulations, in order that poor effectiveness and other problems be identified at an early stage and corrective actions be taken without too much time inertia. Had this been done, one would have realized much earlier that the present regulations must be supplemented with a limitation directed towards the tire/road system and that the measurement method, based on ISO 362, should be replaced or modified. Authorities are therefore advised to engage independent technical and scientific expertise to estimate in advance the effects of new noise legislative actions, and then to monitor and evaluate regularly the actual effect!

The challenge is now to create a sustainable acoustical environment around the roads and streets, in a time of continued traffic growth, building of more roads and streets, and with a likely continued trend towards larger and more powerful vehicles on the roads. It is difficult to imagine a development in that direction without the use of more stringent vehicle and tire/road noise emission limits. It is hoped that this report will aid in designing a system of efficient and economical regulations.

19. Acknowledgments

The Working Party members have been active in the collection of data and in reviewing and supplementing the first draft version of this final report. Some members have contributed with parts of the text and with figures, and some have also contributed significantly to the update of the report that is presented here. The author is indeed very grateful for all the assistance provided by the Working Party members.

Although no co-authors are formally listed, it must be recognized that this paper is produced in cooperation between the members of the Working Party (see the Foreword) most of whom have contributed with data, suggestions regarding the contents of the paper and by checking the manuscript. Apart from the assistance of the Working Party members, some experts have contributed very important information. The author would like to especially acknowledge the substantial supply of data and/or other contributions made by the following individuals:

T. Berge, Norway (member)
E. de Graaff, Netherlands (member)
R. Hillquist, USA (member)
J. Kragh, Denmark (member)
A. Lawrence, Australia (member)
R. Stenschke, Germany (member)
H. Tachibana, Japan (member)
G. Fleming, Volpe Center, USA
M. Klopotek, Scania Trucks, Sweden
T. Miyazaki, Environment Agency, Japan
Y. Oshino, JARI, Japan
H. Steven, TÜV Fahrzeug GmbH, Germany

Finally, the invaluable work of the author's assistant, Mrs. M. Dong, with production of numerous figures must be acknowledged.

It is gratefully acknowledged that this author's work with the evaluations and reporting in 1993-95 was sponsored by the Swedish Transport and Communications Research Board (KFB), and that the production of this final report has been supported by the Swedish Agency for Innovation Systems (VINNOVA).

20. References

Anderton, D. (1992): "Trends in I.C. engine noise generation and its effect on vehicle noise," ATA International Conference on Vehicle Comfort; ergonomic vibration noise and thermal aspects, Bologna, 14-16 October 1992 (author retired from ISVR, Southampton, U.K.).

Anon. (1992): "The future policy for motor vehicle noise reduction," Interim report of inquiry 108, Nov. 30 1992, Central Council for Environmental Pollution Control, Environment Agency, Tokyo.

Anon. (1993): "Motor Vehicle Pollution Control in Japan (4th Revision)," August 1993, Air Quality Bureau, Environment Agency, Japan.

Anon. (1999): "Motor Vehicle Environmental Pollution Control in Japan," Air Quality Bureau, Environment Agency, Japan, 1999 March.

Bendtsen, H. (1999): "Planning as a tool to reduce noise." Proc. of the 2nd European Road Research Conference, Brussels, 7-9 June 1999 (CD-ROM produced by the EU Commission).

Berge, T. (1994): "Vehicle Noise Emission Limits - Influence on Traffic Noise Levels Past and Future," *Noise Control Eng. J.* **42 (2),** 1994 Mar-Apr.

Berge, T. (1994): Personal communication with T. Berge, SINTEF/DELAB, Trondheim, Norway.

Berge, T. (2001): Personal communication with T. Berge, SINTEF/Telecom and Informatics, Trondheim, Norway.

Biegstraaten, F.J.W.; Tukker, J.C. (1982): "Noise Emission by Passenger Cars in Urban Traffic," Report No. 107.833A, TPD Technisch Physische Dienst TNO-TH, Delft, the Netherlands.

CCMC (1980): "Estimation of the economic and technical consequences of a further reduction in permissible motor vehicle noise levels," Ref N/20/80 July 1980, Committee of Common Market Automobile Constructors (CCMC), Brussels.

Cheng, M. (1994): "Noise Legislation and Criteria in China," Proceedings of INTER-NOISE 94, Yokohama, Japan, pp. 2149-2152.

Cherne, K. (1993): "Motor Vehicle Noise Regulations," SAE paper 931281, Proc. of the 1993 Noise and Vibration Conference, Soc. of Automotive Eng., Warrendale, PA, USA.

Close, W.H. (2001): "A Review of the Noise Related Australian Design Rules and Engine Brake Noise," National Road Transport Commission, Australia (the document may be downloaded at http://www.nrtc.gov.au/publications/report-60.asp?lo=public).

de Graaff, D.F. (2000-1): "Evaluation of European noise type approval results 1980-2000," Report No. M+P.MTM.99.4.1, February 17th 2000, M+P Raadgevende ingenieurs bv., 's-Hertogenbosch, the Netherlands.

de Graaff, D.F. (2000-2): "Noise of passenger cars 1974-1999 - The paradox of a 2 dB(A) increase in traffic noise and a 8 dB(A) decrease in type approval limits," Executive summary of interim results of VROM project 2000130079, June 15th 2000, M+P Raadgevende ingenieurs bv., 's-Hertogenbosch, the Netherlands.

de Graaff, D.F. (2001): Unpublished data; personal communication with Erik de Graaff, M+P Raadgevende ingenieurs bv., 's-Hertogenbosch, the Netherlands.

de Jong, R.G.; Opmeer, C.H.J.M.; Miedema, H.M.E. (1995): "Annoyance caused by environmental pollutants in the Netherlands," Proc. of the 15th International Congress on Acoustics, Trondheim, Norway, 26-30 June 1995, Vol. II, pp. 65-68.

de Veer, H.; Ullrich, S. (1991): "Die Entwicklung der Geräuschemission von Pkw und Lkw im Zeitraum von 1970 bis 1990," Strasse + Autobahn 11/91, pp. 641-643.

Descornet, G. (1992): "Report on two series of measurements according to the 'SPB' method," Interim paper, January 1992, The Belgian Road Research Center (CRR), Belgium.

Drewitz, H.; Stiglmaier, M. (1989): "Noise Reduction on Trucks of 6 to 10 t gvw through Engine Encapsulation," *Noise Control Eng. J.,* 5-10, **33(1).**

Eiser, C.; Scott, W. (1994): "Noise Control via Legislation for In-use Vehicles: The New South Wales Experience," Proc. of INTER-NOISE 94, Yokohama, Japan, pp. 327-332

FIGE (1986): "Tendenzen bei der Geräuschemission von Kraftfahrzeugen, Bedeutung des Reifengeräusches," Conference manuscript, by FIGE GmbH, Herzogenrath, Germany (1986). (Personal communication with H. Steven). See also: "Ergänzungen zum Bericht über Änderungen der Geräuschemission von Kraftfahrzeugen im Stadtbetriebe," Forschungsbericht 82-10505128, FIGE.

Fleming, G. (1996): Personal communication with Gregg Fleming, Volpe Center, US DoT, Cambridge, MA, USA.

Friberg, G.; Norberg, P. (1989): "Bulleremissioner från lastbilar (Noise Emissions from Trucks),". Report 3643, Swedish Environment Protection Board, Solna, Sweden (in Swedish).

Hendriks, R. (1987): "California Vehicle Noise Emission Levels (Final report)," Report No. FHWA/CA/TL-87/03, California Department of Transportation, Sacramento, CA, USA.

Hooghwerff, J. (2001): "Herziening Reken- en Metvoorschrift Verkeerslawaai," Published in Geluid No. 1/2001, pp 5-8, March 2001.

Hooghwerff, J.; van Loon, R.C.L. (2000): "Onderverp: Diverse aandachstpunten in relatie met de herziening van de emissiekentallen in het RMV wegverkeerslawaai," MVM.99.5.3\jh, M+P Raadgevende ingenieurs bv., 's-Hertogenbosch, the Netherlands. (In Dutch)

Hunt, M. (1993): "Noise Emissions of Road Vehicles - A Submission on the New Zealand situation to the I-INCE Working Party on noise emission of road vehicles and road traffic noise."

IMMA (1996): "Motorcycle Noise: The curious silence," International Motorcycle Manufacturers Association (IMMA), Geneva. 1996.

INFRATEST (1993): Study conducted by Infratest Sozialforschung (7/93), Munich, on behalf of Verband der Automobilindustrie (VDA), Frankfurt, Germany.

Kaellberg, O. (1979): "Miljoevaenliga bussar (Environmentally friendly buses)," Vaeg- och vattenbyggaren, 5-6 1979, pp 41-45. (In Swedish)

Konishi, K. (1981): "A problem on the regulation of noise emission of automobiles," Proc. of INTER-NOISE 81, Amsterdam, the Netherlands, pp. 1131-1134.

Kragh, J. (1994): Personal communication with Mr. J. Kragh, DELTA Acoustics & Vibrations, Lyngby, Denmark

Kragh, J. (2001): Personal communication with Mr. J. Kragh, DELTA Acoustics & Vibrations, Lyngby, Denmark

Kragh, J.; Sandberg, U. (1994): "Noise Emission from Road Vehicles 1990-2010. The Development Expected by a Group of Nordic Experts," Proc. of IINTER-NOISE 94, August 29-31 1994, Yokohama, Japan, PP. 333-338.

Kruize, H.; Rademaker, B.C.; Ameling, C.B.; Staatsen, B.A.M. (1998): "Noise annoyance, subjective health, residential satisfaction and individual differences in noise annoyance," Poster paper presented at Noise Effects '98, Sydney (only an abstract is included in the proceedings). Authors at RIVM, Bilthoven, The Netherlands.

Kemper, G. (1979): "Geräuschemissionen von Kraftfahrzeugen und Möglichkeiten ihrer Minderung," Kampf dem Lärm, 26, 135-148 (1979). (In German)

Kurra, S.; Maekawa, Z.I.; Morimoto, M. (1995): "A prediction model for annoyance against transportation noise sources," Proc. of the 15th International Congress on Acoustics, Trondheim, Norway, 26-30 June 1995, Vol. II, pp 165-168.

Labban, V. (2001): Personal communication with Ms Vicki Labban of NSW-EPA, Sydney, Australia.

Labban, V.; Ryan, F. (2001): Personal communication with Ms Vicki Labban and Ms Fiona Ryan, of NSW-EPA, Sydney, Australia.

Lambert, J. (1992): "Road Traffic Noise in Western Europe - Current Situation and Future Outlook," pp. 75-81, IATSS Research, Vol. 15, No. 2, 1992.

Lawrence, A. (1984): "Transportation noise reduction - the failures of the 80's?" Proc. of INTER-NOISE 84, Honolulu, Hawaii, USA, pp. 611-616,.

Lawrence, A. (1993): "The Situation in Australia," Report to the I-INCE Working Party on noise emissions of road vehicles.

Leuner, D. (1991): "Langfristige Entwicklung der Geräuschbelastung in Bayern," Project Report No. 2/5-252-4/91, Bayerisches Landesamt für Umweltschutz, München, Germany.

Liedholm, B.L.; Zetterling, T. (1980): "Buller från motorfordon i rörelse (Noise from moving motor vehicles)," SNV PM1320, Swedish Environment Protect. Board, Solna, Sweden (in Swedish)

Liu, X. (1994): "Research on Acoustical Environment Planning of the Cities," Proceedings of INTER-NOISE 94, Yokohama, Japan, pp. 961-964.

Maurin, M. (1995): Personal communication from Mr. M. Maurin, INRETS, Lyon, France.

NPC (2001): The Noise Pollution Clearinghouse collects many news and notes about Boom Cars etc at http://www.nonoise.org/news/amp.htm

Nylin, S. (1992): "Lastbilens tekniska utveckling och betydelse i samhaellets transporter," Booklet from Scania Truck Company, Soedertaelje, Sweden.

OECD (1980): "Conference on Noise Abatement Policies, 7-9 May 1980," pp. 57-58, book published by OECD, Paris.

Phillips, S. (1999): Personal communication with Steve Phillips of the Transport Research Laboratory, U.K. (diagram presented at the 2nd European Road Research Conference, Brussels, 7-9 June 1999).

Phillips, S. (2001): "Factors affecting Statistical Pass-by measurements," Proc. of INTER-NOISE 2001, The Hague, The Netherlands, August 2001.

PORSCHE (2000): Personal communication with Mr H.-M. Gerhard, Porsche AG, Stuttgart, Germany. The diagrams in original form were first presented by P. Ehinger & S. Moser as "Traffic Noise Regulations and Their Effects on Traffic Noise" at the TA Esslingen, Symposium "Auto und Umwelt," 19-20 Sept. 1994.

Pucher, E. (1993): "Lärmbelastung in Ballungszentren - PKW-Aussengeräusche," Inst. für Verbrennungskraftmaschinen und Kraftfahrzeugbau, Techn. Univ. of Vienna.

Renew, W. (1993): "Community noise measurements," Proc. of Noise-93, St. Petersburg, Russia, pp. 225-230.

Romero, J.; Jimenez, A.; Sanchis, A.; Marín, A.; Zuita, G. (1998): "Multivariate analysis of road traffic noise Gandia (Spain) during 24 hours and its evolution in the last decades," Proc. of ICA 98, Seattle, USA.

Romick-Allen, R.K.; Lin, C.; Morgan, S.M.; Bruns, M.T. (1999): "Fitting the FHWA Traffic Noise Model Noise Emissions for Use in STAMINA 2.0," Transportation Research Record 1670, Paper No. 99-0471, Transportation Research Board, Washington, D.C., USA.

Sasor, S.R. (1997): "Truck Noise Level Update for New Jersey," Report No. FHWA/NJ-97/003, New Jersey DoT, Trenton, NJ, USA.

Sandberg, U. (1984): "Six decades of vehicle noise abatement - but what happened to the tyres?" VTI Reprint No. 100, Swedish Road and Transport Research Institute, Linköping, Sweden.

Sandberg, U. (1989): "Vehicle Noise Emission Changes During the Period 1974-1988," Proc. of INTER-NOISE 89, December 4-6, 1989, Newport Beach, CA, USA, pp. 711-714.

Sandberg, U. (1992): "Noise Emission from Heavy Trucks Meeting the 84 and 80 dB(A) Limits," Proc. of INTER-NOISE 92, Toronto, Ontario, Canada, pp. 829-834.

Sandberg, U. (1993): "Noise Emissions of Road Vehicles - Effect of Regulations. Status Report of an I-INCE Working Party," Proc. of INTER-NOISE 93, August 24-26 1993, Leuven, Belgium, pp. 45-50.

Sandberg, U.; Berge, T.; Hillquist, R.; Hunt, M.; Kragh, J.; Lawrence, A.; Maurin, M.; Stenschke, R.; Tachibana, H.; Yamashita, M. (1993): "Noise Emissions of Road Vehicles - Effect of Regulations. Interim Report, September 1993," International Institute of Noise Control Engineering.

Sandberg, U. (1994): "Noise Emissions of Road Vehicles - Effect of Regulations. Report of an I-INCE Working Party," Proc. of INTER-NOISE 94, Yokohama, Japan, pp. 67-76.

Sandberg, U. (1995): "Report by the International Institute of Noise Control Engineering Working Party on the Effect of Regulations on Road Vehicle Noise," *Noise News International*, June 1995, pp. 82-113.

Sandberg, U. (2000): Unpublished data, SPB measurements made in the period 1982-88 compared with same made in 1996, both series intended to compare road surfaces. The values considered here were for similar dense asphalt concrete pavements. Speeds 50 km/h (cars and trucks) and 80 km/h (trucks) and 100 km/h (cars).

Sandberg, U. (2001-1): "Abatement of traffic, vehicle and tire/road noise – The global perspective". Article submitted for a dedicated volume of *Noise Control Engineering Journal*, to be published 2001.

Sandberg, U. (2001-2): "Tyre/road noise – Myths and realities," Proc. of INTER-NOISE 2001, The Hague, The Netherlands, August 2001.

Sandberg, Ulf; Ejsmont, J. A. (2002): "Tyre/road noise – Reference Book," Book under production, to be published in 2002.

Sandberg, U.; Ejsmont, J. A.; Ronowski, G.; Dong, M. (2001): "EcoDriving - Effects on Vehicle Noise Emission," Publication: 2001: 53E, Swedish National Road Administration, Borlaenge, Sweden (also published at the URL www.vv.se/sparsam).

Sargent, J.W.; Fothergill, L.C. (1993): "A Survey of Environmental Noise Levels In the UK," Proceedings of Noise-93, St. Petersburg, Russia, pp. 161-166.

Sharp, B.H. (1974): "A Survey of Truck Noise Levels and the Effect of Regulations," Wyle Research Report WR 74-8 (PB-253 334), Wyle Laboratories, USA. (Available from NTIS, USA).

Spessert, B.; Reddert, H. (1999): "Fortschritte in der Dieselmotorenakustik - ein kritisches Resümee der letzten 30 Jahre," Zeitschrift für Lärmbekämpfung, 46(1999) No. 1 – January 1999, pp 23-27. (In German)

Stehno, G. (1992): "Possible ways to decrease noise emissions on roads within local populated areas," Proc. of Eurosymposium "Mitigation of Traffic Noise in Urban Areas," LCPC, Nantes, France

Stenschke, R. (1993): "The Umweltbundesamt's detailed comments," Personal communication from Mr. R. Stenschke, Umweltbundesamt, Berlin, 31 March 1993.

Stenschke, R. (1994): "Auswirkung von Massnahmen zur Geräuschminderung an motorisierten Zweirädern auf die Geräuschemission im realen Verkehr (Effects of measures for reducing noise emissions from motorcycles on noise emission levels produced in actual traffic)," VDI BERICHTE, No. 1159, 1994, VDI-Verlag GmbH, Düsseldorf, Germany. (In German)

Stenschke, R.; Vietzke, P. (2000): "Noise and use characteristics of modern car tyres (State of the art)," Paper for the 7th International Congress on Sound and Vibration, 4-7 July 2000, Garmisch-Partenkirchen, Germany.

Stenschke, R.; Vietzke, P. (2001): "Tyre/road noise emissions, rolling resistance and wet braking behaviour of modern tyres for heavy-duty vehicles (State of the art)," INTER-NOISE 2001, the Hague, the Netherlands.

Steven, H. (1994): "Ermittlung der Geräuschemissionsänderung von Kraftfahrzeugen im Strassenverkehr," Report No. 105 05 140, FIGE GmbH, Herzogenrath, Germany.

Steven, H. (1995): "Effects of Noise Limits for Powered Vehicles on Their Emissions in Real Operation," SAE paper 951257, pp. 173-182, Soc. of Automotive Engineers, USA.

Steven, H. (2001-1): "Improvement of the Type Approval Noise Limitation for Motor Vehicles," Proc. of INTER-NOISE 2001, the Hague, the Netherlands.

Steven, H. (2001-2): "Minderungspotenziale beim Strassenverkehrslärm." Zeitschrift für Lärmbekämpfung, 48(2001), No. 3 - May 2001. (In German)

Steven, H. (2001-3): Personal communication with Heinz Steven, FIGE TÜV Fahrzeug GmbH, Herzogenrath, Germany.

Sutherland, L. C. (1986): "Formulation and application of community noise assessment procedures," Proc. of Community Noise Conference, Toowoomba 1-3 October 1986, Australian Acoustical Society.

Tachibana, H. (1994): Personal communication from Hideki Tachibana, Inst. of Industrial Science, University of Tokyo.

Tachibana, H.; Oshino, Y. (1992): "Sound intensity radiation patterns of actually running automobiles," Proc. of INTER-NOISE 92, Toronto, Canada. pp. 849-852.

Takagi, T.; Tomita, T. and Okemoto, T. (1987): "Present situations of vehicle noise reduction," *J. INCE/Japan*, **11**, 237-241 (1987) (in Japanese). The figure also appears in Namba, S. (1994): "Noise - Quantity and Quality," Proceedings of Inter-Noise 94, Yokohama, pp. 3-22.

Takagi, N.; Yamashita, Y.; Tokashiki, T.; Morita, D.; Matsui, M. (1997): "Change of road traffic noise with time elapse in provincial cities," *The Journal of the Acoustical Society of Japan*, 829-836, **53, No. 11**, 1997 (In Japanese).

Takagi, N.; Yamashita, Y.; Asakawa, A.; Tokashiki, K.; Uchida, H.; Okiyama, F.; Matsui, M. (2000): "An analysis of environmental noise and road traffic noise in 38 cities in Japan," *The Journal of the Acoustical Society of Japan*, 156-166, **56, No. 3,** 2000 (In Japanese).

Takahashi, M.; Iimura, K.; Hidaka, Y.; Tachibana, H. and Kanaizumi, A. (1994): "Sound Power Levels of Road Vehicles Measured Using a Reverberant Tunnel," Proceedings of INTER-NOISE 94, Yokohama, Japan, pp. 415-419.

TNO (1994): "Hinder door Milieuverontreiniging in Nederland," Publication under production from TNO, Delft, the Netherlands.

TNO (2001): Data from survey carried out by TNO Preventive Health Care in Leiden, the Netherlands, published at the URL http://www.xs4all.nl/~rigolett/ENGELS/statistics/eh8793_e.htm

Ullrich, S. (1994): "Geräuschbelastung an klassifizierten Strassen - vergangene und zukünftige Entwicklung, Zeitschrift für Lärmbekämpfung, 41(1994), Springer Verlag, pp. 98-103. Author at Bundesanstalt für Strassenwesen, Bergisch Gladbach, Germany. (In German)

van Assche (2001): Statement at meeting 2001-06-21 of EU working group "Road Traffic Noise," van Assche is from Honda Motor Europe Ltd., but represented the motorcycle industry at the meeting.

van Blokland, G.J.; de Graaff, D.F. (2001): "The proportion of cars and vans in the urban traffic noise emission – why urban traffic noise increased in the past 20 years," Unpublished collection of Power Point diagrams, presented to the EU working group "Road Traffic Noise," Brussels, Belgium, and to ISO/TC43/SC1/WG42, June 2001. From M+P Raadgevende ingenieurs bv., 's-Hertogenbosch, the Netherlands.

Vogiatzis, C.; Psichas, K. (1993): "Traffic Noise Monitoring and Evaluation in Large and Medium Urban Areas in Greece," Proceedings of INTER-NOISE 93, Leuven, Belgium, pp. 575-579.

Waters, P.E. (1974): "Commercial road vehicle noise," *Journal of Sound and Vibration*, 155-222, **35(2),** 1974.

Waters, P.E. (1995): "Noise Induced Hearing Loss in Truck Drivers," SAE paper 951258, pp 183-190, Soc. of Automotive Engineers, USA.

Wayson, R.L.; Ogle, T.W.A. (1992): "Extension of Reference Emission Factors for the STAMINA 2.0 Model to Include 55-65 MPH," FL/DOT/RMC/0534-3510, July 20 1992, University of Central Florida, Orlando, USA.

Wolschendorf, J.; et al. (1991): "The IDI Diesel Engine and Its Combustion Noise Variations," SAE Paper No. 910228, Warrendale, PA, USA.

Wu, S. (1996): "Traffic Noise Research and Control in China," Dept. of Architecture, South China University of Technology, Guangzhou, China.

Yamashita, M.; Tachibana, H. (1993): "Motor Vehicle Noise and Its Effect in Japan," Paper from Kobayashi Institute of Physical Research and Institute of Industrial Science, August 1993.