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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

MEDIUM AND HEAVY DUTY TRUCKS TECHNOLOGY AND COST INFORMATION

SEPTEMBER 1974

U.S. Environmental Protection Agency
Washington, D.C. 20460

550/9-74-015

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PREPARED BY

U.S. Environmental Protection Agency
Washington, D.C. 20460

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APPENDICES

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SUMMARY

The subjects addressed in this document are intended to provide background information on various aspects associated with the development of regulations relative to noise emission from newly manufactured trucks.

Section 1 - "Prologue" sets forth the legal basis for the regulations which may be promulgated under the authority of the Noise Control Act of 1972, the procedure followed in the promulgation of such regulations and a brief statement relative to preemption of state and local regulations by Federal regulations.

Section 2 - "Identification of Medium and Heavy Duty Trucks as a Major Source of Noise." This section addresses the acoustic energy radiated by medium and heavy duty trucks.

Section 3 - "The Truck Industry." This section presents general information about the U. S. truck industry. It covers industry statistics on sales, number of trucks manufactured, financial data on manufacturers, weight classification system and other useful descriptive material.

Section 4 - "Information Base," provides a synopsis of the sources of information utilized in the preparation of this document. It also presents baseline data on noise generated by currently new trucks. The data are given for both diesel- and gasoline-powered trucks.

Section 5 - "Available Noise Abatement Technology." In order to establish regulations restricting truck noise emissions it is necessary to know how much noise reduction it is presently possible to achieve. Sec-

tion 5 reviews the various components of truck noise: noise radiated from the engine surface, fan, intake, exhaust and tire noise.

This discussion includes both the noise generation process and noise quieting techniques. Consideration is given to the total truck noise control problem. The technology will be examined to determine what modifications or redesign work must be performed on trucks in order to quiet them to levels below those which presently exist. Data are given (Appendix I) which array costs to reduce sound levels for some present day trucks to varying levels. These data serve as a basis for development of the cost and economic analyses presented in section 7.

Section 6 - "Health and Welfare." In terms of health and welfare, this section addresses how much improvement various standards, or sequences of regulatory standards, would provide. An analysis using traffic streams and population densities is employed to compute the noise impact prior to and subsequent to the enactment of the various regulatory standards. The percent reduction in impacted population is considered as an approximate estimate of the effectiveness of a regulation.

The second method of assessment is directed at health and welfare in terms of specific cases. It considers a set of specific scenarios in which people are engaged in activities such as conversing, doing work requiring mental concentration, sleeping, etc. These activities are conducted in various well defined interior spaces (homes, offices, apartments) or outdoors. Each scenario is located at a specific distance from a highway traversed by trucks. Associated with each scenario is an ambient level appropriate to the particular activity. The passby noise produced by each separate truck is considered as an intrusion and the extent to which it exceeds the ambient is a measure of the annoyance produced. A nominal increment of 10 dB(A) is employed, and the noise outputs of trucks which will produce this increment are computed. The 10 dB(A) increment is arbitrary; however, it is presented as the level at which severe annoyance begins. The scenarios are presented in tables which permit ready identification of those cases which are satsifactory and those which are not when it is assumed that a truck produces a specified noise level.

Section 7 - "Economic Consequences of Noise Control." In this section costs are developed for the basic engineering changes required to achieve various levels. Changes in costs due to changes in operational efficiency are also included. Using these data as a basis, the impacts on truck manufacturers, truck users, and truck associated industries are evaluated.

Section 8 - "Truck Acoustic Energy Changes and Lead Time Requirements." In this section the population statistics of trucks are presented. The number of trucks presently in operation, the rate of truck retirement, and truck annual mileage are also given. These are combined to show population distribution of trucks corresponding to the various standards which could be proposed.

A mileage-weighted acoustic energy level is presented for each of the various possible regulatory options.

Lead times required for various equipment modifications are discussed. The problems and the time required for the industry to solve them are considered.

Section 9 - "Measurement Methodology." This section addresses EPA test procedures which could be associated with new truck regulations.

Section 10 - "Enforcement." Enforcement of new product noise emission standards applicable to new medium and heavy duty trucks are discussed through production verification testing of vehicle configurations, assembly line testing using selective enforcement auditing or continuous testing (sample testing or 100% testing) of production vehicles and in-use compliance requirements. EPA consideration of the measurement methodology which could be used both for production verification testing and assembly line vehicle testing is based upon the SAE J366b and SAEXJ57 tests. Additional tests are outlined in this document for consideration.

Section 11 - "Environmental Effects." Whenever action is taken to control one form of environmental pollution, there are possible spinoff effects on other environmental or natural resource factors. In this section the single effects of truck noise control on air and water pollution, solid waste disposal, energy and natural resource consumption, and land use considerations are evaluated.

The discussion indicates that the process of quieting new trucks will produce no significant adverse environmental effects. It will result in a modest saving of fuel, however, if it is credited with the benefits associated with thermostatically controlled fans.

Finally, this document constitutes an exposition of the studies made by EPA and its contractors of the many areas associated with the promulgation of a noise emission regulation for new trucks. An effort has been made to produce a document covering all the major issues and it is hoped that it will be found useful.

Throughout the document, there are references to three data collection points at which technology, cost, and health and welfare data were collected and evaluated. Interpolations between the points or extrapolation to levels below the points provide information from which determination can be made as to truck noise emission which technology may achieve, the levels at which health and welfare criteria may be assessed, and the costs and economic impacts associated with various levels.

SECTION ONE

PROLOGUE

Statutory Basis for Action

Through the Noise Control Act of 1972 (86 Stat. 1234), Congress established a national policy "to promote an environment for all Americans free from noise that jeopardizes their health and welfare." In pursuit of that policy, Congress stated, in Section 2 of the Act, "that, while primary responsibility for control of noise rests with State and local governments, Federal action is essential to deal with major noise sources in commerce, control of which requires national uniformity of treatment." As part of that essential Federal action, subsection 5(b)(1) requires the Administrator, after consultation with appropriate Federal agencies, to publish a report or series of reports "identifying products (or classes of products) which in his judgment are major sources of noise." Further, section 6 of the Act requires the Administrator to publish proposed regulations for each product, which is identified or which is part of a product class identified as a major source of noise, where in his judgment noise standards are feasible and fall into various categories of which transportation equipment (including recreational vehicles and related equipment) is one.

Pursuant to subsection 5(b)(1), the Administrator has published a report which identifies new medium and heavy duty trucks as a major source of noise. As required by Section 6, the Administrator shall prescribe regulations for such trucks, which are "requisite to protect the public health and welfare, taking into account the magnitude and conditions of use of new medium and heavy duty trucks, the degree of noise reduction achievable through the application of the best available technology, and the cost of compliance."

Preemption

Under subsection 6(e)(1) of the Noise Control Act, after the effective date of a regulation under Section 6 of noise emissions from a new product, no State or political subdivision thereof may adopt or enforce any law or regulation which sets a limit of noise emissions from such new product, or components of such new product, which is not identical to the standard prescribed by the Federal regulation. Subsection 6(e)(2), however, provides that nothing in Section 6 precludes or denies the right of any State or political subdivision thereof to establish and enforce controls on environmental noise (or one or more sources thereof) through the licensing, regulation or restriction of the use, operation or movement of any product or combination or products.

The noise controls which are reserved to State and local authority by subsection 6(e)(2) include, but are not limited to, the following:

1. Controls on the manner of operation of products
2. Controls on the time in which products may be operated
3. Controls on the places in which products may be operated
4. Controls on the number of products which may be operated together
5. Controls on noise emissions from the property on which products are used
6. Controls on the licensing of products
7. Controls on environmental noise levels

Federal regulations promulgated under section 6 preempt State or local regulations which set limits on permissible noise emissions from the new products covered by the Federal regulations at the time of sale of such products, if they differ from the Federal regulations.

Conversely, State and local authorities are free to enact regulations on new products offered for sale which are identical to Federal regulations.

SECTION 2

IDENTIFICATION OF TRUCKS AS A MAJOR SOURCE OF NOISE

In pursuit of subsection 5(b) of the Noise Control Act of 1972, the Administrator has published a report (FEDERAL REGISTER, Vol. 39, No. 121, pp. 22297-9) which "identifies medium and heavy duty trucks having a gross vehicle weight rating (GVWR) in excess of 10,000 pounds as a major source of noise." GVWR means the value specified by the manufacturer as the loaded weight of a single vehicle.

The following paragraphs will briefly describe the basis on which trucks with a GVWR of 10,000 pounds or more were identified as a major source of noise.

LEGISLATIVE BASIS

Subsection 6(a) of the Noise Control Act sets forth four categories of products for which a noise emission standard can be proposed for each product identified as a major source of noise. The categories are:

1. Construction equipment
2. Transportation equipment (including recreational vehicles and related equipment)
3. Any motor or engine (including any equipment of which an engine or a motor is an integral part)
4. Electrical or electronic equipment

PRIORITY BASIS

The criteria developed by EPA to identify products which are major sources of noise and for which noise emission standards are requisite to protect the public health and welfare stipulate that at this time first priority has been given to products that contribute to community noise exposure. Community noise exposure is that exposure experienced by the community as a whole as a result of the operation of a product as opposed to that exposure experienced by the users of the product.

DAY-NIGHT SOUND LEVEL BASIS

The day-night sound level, Lnd, has been specifically developed as a measure of community noise. Since it is a cumulative energy measure, it can be used to identify areas where noise sources operate continuously or where sources operate intermittently but are present enough of the time to emit a substantial amount of sound energy in a 24 hour period.

EPA has identified an outdoor Ldn of 55 dB as the day-night sound level requisite to protect the public from all long-term adverse public health and welfare effects in residential areas, and an Leq of 70 (roughly equivalent to an Ldn 70) as the threshold of hearing impairment.

POPULATION BASIS

The estimated number of people in residential areas who are subjected to urban traffic noise and freeway traffic noise at or above an outdoor Ldn of 70, 65 and 60 dB is shown in Table 2-1 below:

TABLE 2-1

NUMBER OF PEOPLE SUBJECTED (IN MILLIONS)

Outdoor Ldn (dB)	Urban Traffic Noise	Freeway Traffic Noise
70	4-12	1-4
65	15-33	2-6
60	40-70	3-6

Source: BBN Report No. 2636, September 1973.

As indicated by Table 2-1, more than 70 million people in residential areas are subjected to noise from surface transportation equipment at or the outdoor Ldn of 60 dB. Thus, the surface transportation equipment category has been selected by EPA for regulatory attention because of the extensive community exposure to noise emanating from products in this category.

PRODUCT BASIS

A two-step approach has been used to identify products within the surface transportation equipment category which are major contributors to community noise exposure. First, the Ldn has been used to identify residential areas selected from a composite derived from a cross section of U. S. towns and cities where a large number of people are exposed to high Ldn. Second, in these high Ldn areas, products which are major contributors to the Ldn have been identified.

Table 2-2 lists the products in the highway surface transportation equipment categories that are presently considered as major sources of noise, and indicates both the typical sound pressure level (SPL) at 50 feet associated with each product and the estimated total sound energy emitted per day by all existing models of each product.

TABLE 2-2
MEASURES OF NOISE ASSOCIATED WITH TRANSPORTATION VEHICLES

Products in the Transportation Equipment Category	Typical SPL at 50 feet dB(A)	Estimated Total Sound Energy Per Day (Kilowatt-hrs)
Trucks (greater than 10,000 lbs GVWR)	84	5800
Automobiles (sports compacts)	75	1150
Automobiles (passenger)	69	800
Trucks (less than 10,000 lbs GVWR)	72	570
Motorcycles (highway)	82	325
Buses (city and school)	73	20
Buses (highway)	82	12

Source: BBN Report No. 2636, September 1973.

The typical sound pressure level in dB(A) at 50 feet is a measure of the perceived loudness at that distance from the product when it is operating. This measure suggests which products, when they are operated alone, will be perceived as noisy by the community. The estimated total sound energy per day is useful because it is an aggregate measure that takes into account the sound energy emission rate of the product, the number of products operating and the amount of time they are operated each day. For trucks with a GVWR of 10,000 pounds or more, this measure was estimated on the basis that there are about 3.5 million trucks in use for an average of 4 hours per day. These estimates are for a composite of both urban and freeway traffic conditions.

As indicated by Table 2-2, trucks with a GVWR of 10,000 pounds or more are louder than other transportation vehicles and contribute the most daily sound energy to the community environment of any product in the surface transportation equipment category.

SECTION 3

THE TRUCK INDUSTRY

THE ROLE OF TRUCKS IN DOMESTIC TRANSPORTATION MARKETS

Of the major means by which goods are transported, Table 3-1 implies that trucks are far from being the least expensive; yet, because of convenience, trucks account for over 80% of the total dollars spent on moving domestic freight.

As shown in Table 3-1, trucks carry the largest share in tons of domestic freight. The cost per ton-mile (approximately 17 cents) is considerably more expensive than the cost (approximately 1.5 cents per ton-mile) for shipping by rail, the next largest carrier of goods. However, as can be inferred from Table 3-1, trucks on the average carry more goods over shorter distances, and provide a flexibility that cannot be achieved by other modes of transportation. Thus, the accepted presence of trucks on the nation's highways is supplemented by their pervasive presence in virtually every street and roadway of the country.

Over the period 1967 to 1972, total new truck sales increased 1.3 times faster than the gross national product; new heavy duty truck sales increased more than 2.5 times faster (Reference 1). The trend over the past several years has been for more and more goods to be moved by truck. It is expected that this trend will continue and that each year there will be more trucks on the nation's freeways, highways, and city and residential streets.

TABLE 3-1
DOMESTIC FREIGHT TRANSPORTATION MARKET, 1970

Mode Transportation	Tons Millions	Tons Percent	Ton-Miles Millions	Ton-Miles Percent	Revenue Dollars Millions	Revenue Dollars Percent
Truck	1,684	34.2	412,000	18.7	$69,084	81.3
Rail	1,572	32.1	771,000	34.8	11,869	14.0
Water*	867	17.6	595,000	26.9	1,902	2.3
Pipeline	790	16.1	431,000	19.5	1,396	1.6
Air	3	0.0	3,400	0.1	720	.8
Totals	4,916	100.0	2,212,000	100.0	$84,971	100.0

* Includes Domestic Deepsea, Great Lakes and Inland Waterways.

Source: Transportation Facts and Trends, TAA Quarterly Supplement, April 1973.

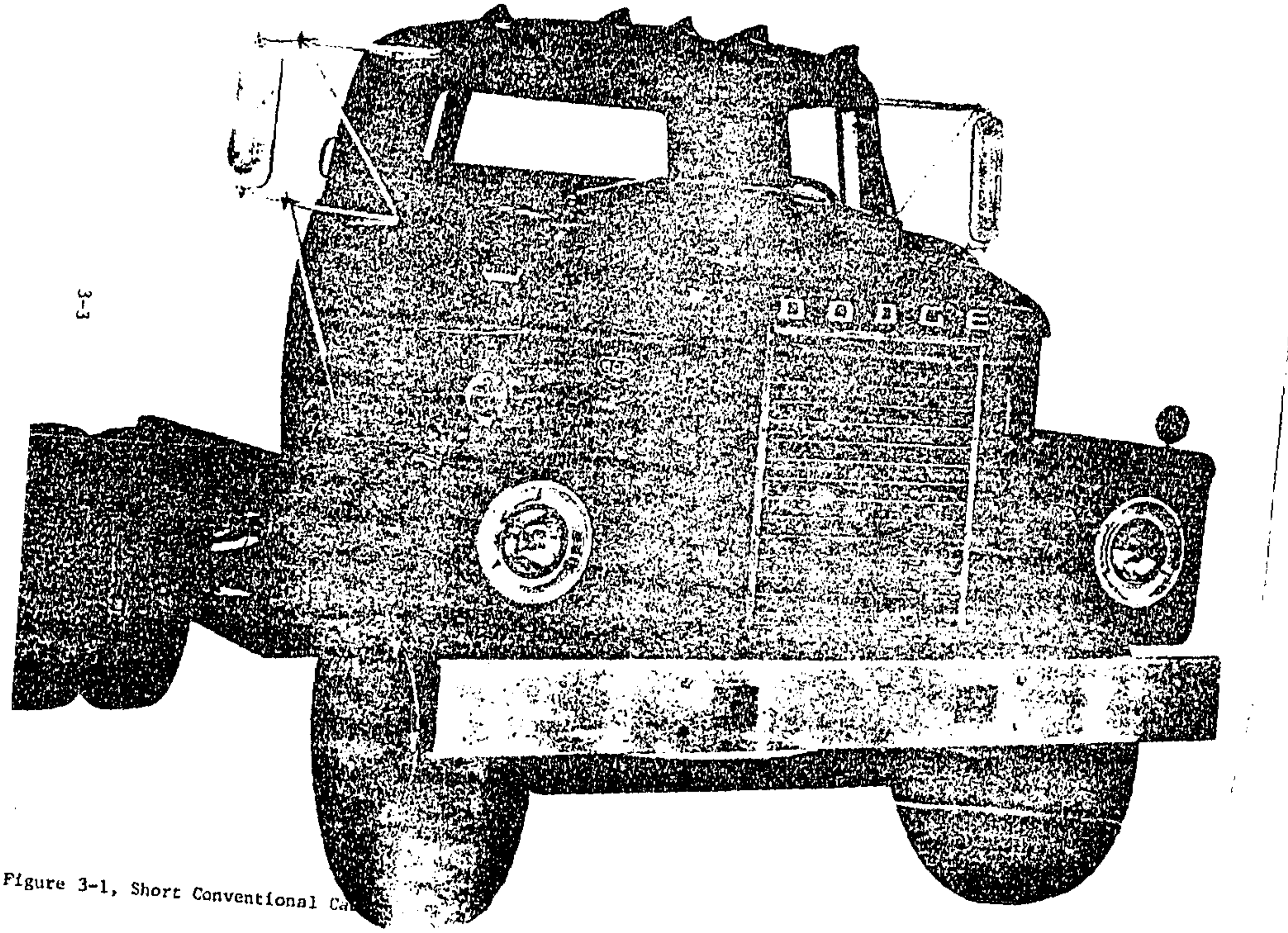

Figure 3-1, Short Conventional Ca

TRUCK DESCRIPTION FOR GENERAL PURPOSES

In describing trucks with gross
TRUCK DESCRIPTION FOR GENERAL PURPOSES

In describing trucks with gross vehicle weight ratings (GVWR) greater than 10,000 pounds, a wide range of vehicle types are involved. At one extreme of the vehicle characteristics for different types of trucks there are gasoline-powered 2-axle single vehicles with 4 wheels and GVWR of less than 13,000 pounds. At the other extreme there are 11-axle combination vehicles with 42 wheels, turbocharged diesel engines and GCWR in excess of 130,000 pounds. Here GCWR, the gross combination weight rating, means the value specified by the manufacturer as the maximum loaded weight of a combination vehicle for which it is designed.

Trucks can be described in terms of the following attributes: the gross vehicle weight rating, the major designed use, the number of axles, the type and size of engine, and the style of the cab.

Truck designation in terms of GVWR for trucks with GCWR over 10,000 pounds has been defined by the Motor Vehicle Manufacturers Association (MVMA) and is shown in Table 3-2.

TABLE 3.2

TRUCK DESIGNATION BY GVWR (POUNDS)

10,001 - 14,000
14,001 - 16,000
16,001 - 19,500
19,501 - 26,000
26,001 - 33,000
over 33,000

Source: MVMA's 1973 Motor Truck Facts.

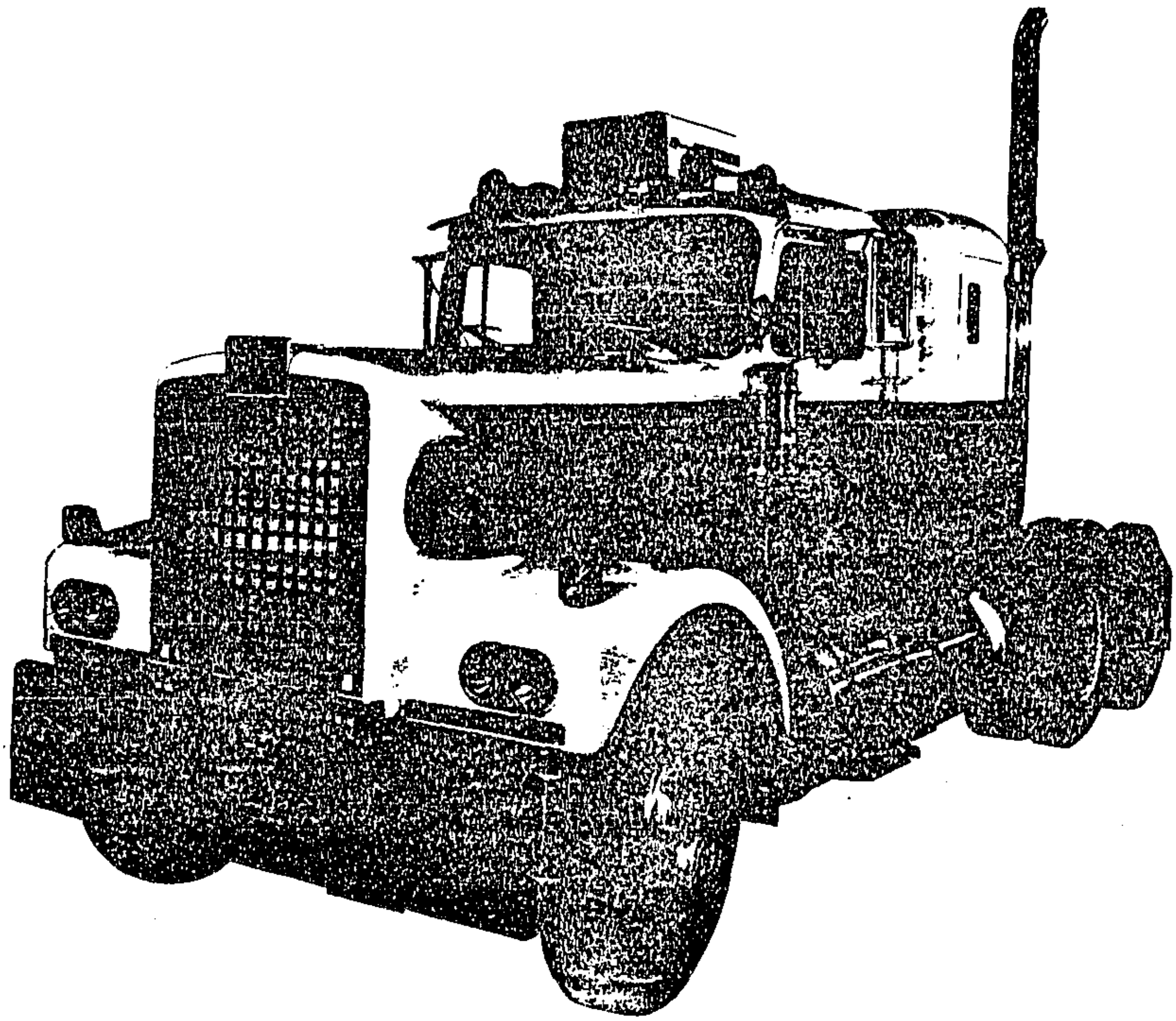

Figure 3-2, Long Conventional Cab

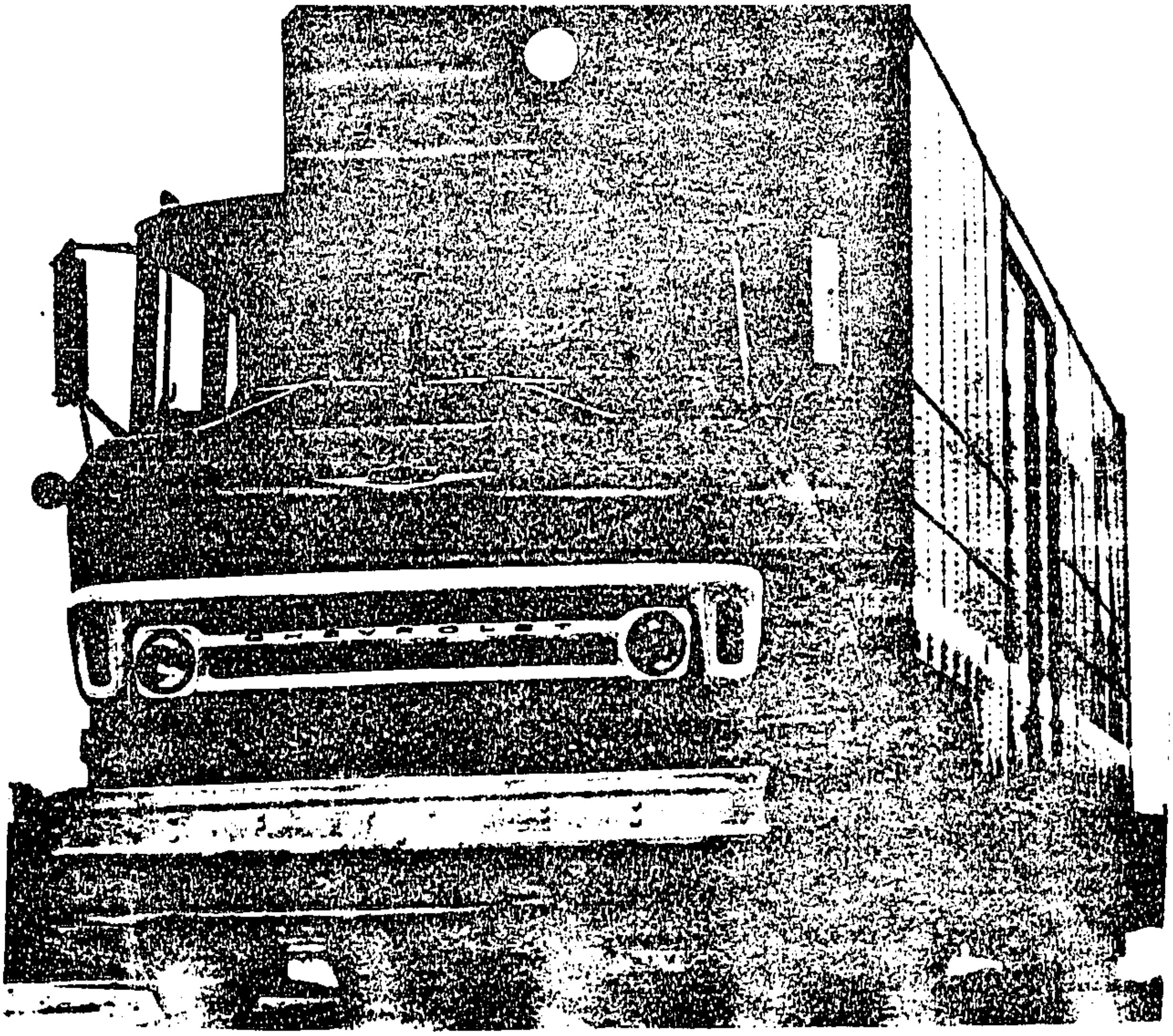

Figure 3-3, Low Deck Cab-Over-Engine.

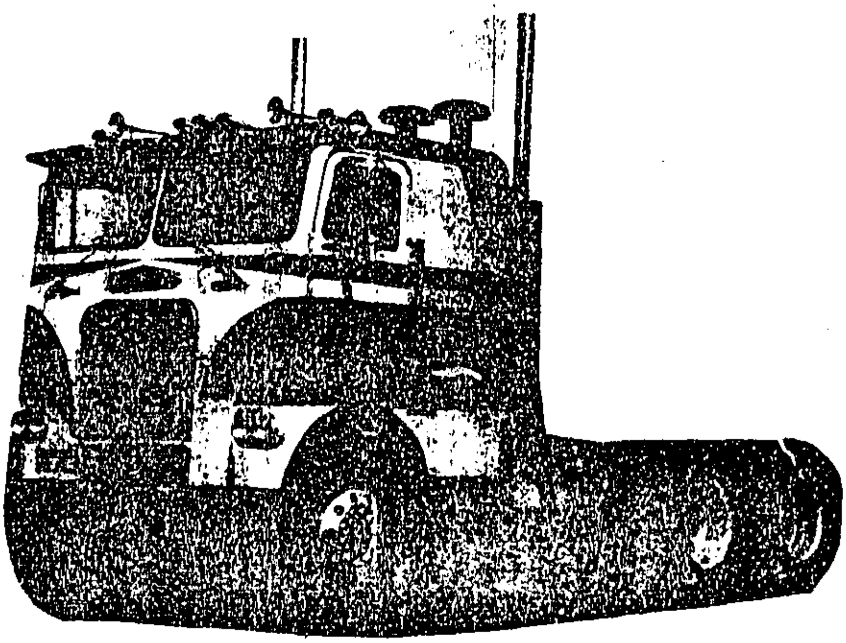

Figure 3-4, High Deck Cab-Over-Engine.

There are three truck design designations which reflect the major uses for trucks with GVWR greater than 10,000 pounds. A ruggedly built cab-chassis unit for mounting dump beds, concrete mixers, etc., is often referred to as a construction truck while a light cab-chassis unit for mounting van bodies, etc., is designated as a delivery truck. A truck-tractor for pulling trailers, etc., is called a line-haul truck.

The number of axles by which engine power is transmitted as traction at the road surface can also be used for truck designation. For trucks with two axles, one of which drives the truck (as in an automobile), the designation is 2 x 4; i.e., two out of the four wheels (dual tires count as one wheel) are driving. Similarly, a tandem axle, truck-tractor is designated as a 4 x 6 and an all-wheel drive truck is a 4 x 4 or a 6 x 6.

In terms of truck designation by the type of engine, trucks can be designated simply as having either a gasoline engine or a diesel engine. The horsepower rating of the engine can also be used for truck classification purposes.

Trucks can also be designated by the style of the truck or truck-tractor cab. The two main styles of cabs are the conventional cab (sometimes termed a "fixed" cab) style and the cab-over engine (COE) style. In a conventional cab, the driver sits behind the engine. Conventional cab styles may be either "short" (see Fig. 3-1) or "long" (see Fig. 3-2), depending on the length of the hood. In the COE style, the driver is positioned above and to the side of the engine. COE style may be either "low" (see Fig. 3-3) or "high" (see Fig. 3-4), depending on the distance of the deck, or floor, of the cab above the ground.

TRUCK CLASSIFICATION FOR PURPOSES OF NOISE REGULATION

The truck attributes most closely associated with truck noise level include the gross vehicle weight rating, the number of axles, and the size and type of the engine. All these attributes are somewhat related. For example, a truck with a large GVWR will tend to have more axles and will more likely be powered by a large diesel engine than a truck with small GVWR. GVWR is a prime candidate for defining regulated truck classification. As Table 3-2 indicates, the Motor Vehicle Manufacturers Association uses GVWR as a primary variable in reporting its production figures. In addition, most states register trucks according to GVWR.

A truck's GVWR depends on the sum of its axle weight ratings. Thus, classification by the number of axles may be redundant. Classification by engine size could again be redundant as the size of the engine selected for a given truck is, apparently, inherently dependent on its design GVWR.

The type of engine is another possible candidate for truck classification for noise regulation since gasoline and diesel engines differ somewhat in their noise characteristics (Reference 3). However, this engine noise level difference becomes less pronounced, as the engine component is considered in the totality of measured truck noise.

TRUCK CATEGORIES FOR PURPOSES OF REPORT DISCUSSION

Of newly manufactured trucks with a GVWR greater than 10,000 pounds but less than 26,000 pounds, almost 85% will be gasoline powered. Conversely, more than 96% of the trucks with GVWR greater than 26,000 pounds can be expected to be diesel powered.

Accordingly, in this document, trucks with a gross vehicle weight rating in excess of 10,000 pounds have been categorized as "medium duty" or "heavy duty" trucks as defined in Table 3.3. Also defined in Table 3.3 are truck GVWR groups within each of these GVWR categories.

TABLE 3-3

GVWR Truck Categories

GVWR Category	GVWR Group	Range of GVWR
Medium Duty Trucks (10,001-26,000 lbs)	1	10,001-14,000
	2	14,001-16,000
	3	16,001-19,500
	4	19,501-26,000
Heavy Duty Trucks (over 26,000 lbs)	5	26,001-33,000
	6	over 33,000

In addition to the above truck GVWR categorization, this document will also on occasion further categorize trucks by type of engine as either gasoline or diesel.

DISTRIBUTION OF TRUCKS BY CATEGORIES

A statistical analysis of the census data on the characteristics and uses of the truck population in the United States, which was collected and made available to EPA by the Bureau of the Census, provides an estimate of the total truck population in the United States in 1972. (For details, see Appendix O.) The total truck population with GVWR in excess of 10,000 pounds in 1972 was estimated to be 3,533,000 trucks. The distribution of these trucks by GVWR category and type of engine is shown in Table 3-4.

TABLE 3-4

TOTAL TRUCK POPULATION, 1972

GVWR Category	Gasoline Engine Number	Gasoline Engine Percent	Diesel Engine Number	Diesel Engine Percent	Total Trucks
Medium Duty	2,335,000	98	41,000	2	2,376,000
Heavy Duty	509,000	44	648,000	56	1,157,000
Totals	2,844,000	80	689,000	20	3,533,000

Source: A. T. Kearney Report to EPA, April 1974.

Table 3-5, a breakdown for diesel engine trucks by GVWR for selected years between 1966 and 1972, shows a trend toward fewer medium duty trucks being powered by diesel engines and a trend toward increased use of diesel engines for heavy duty trucks, particularly the larger GVWR group 6 trucks.

The distribution of new truck production in 1972, according to GVWR category and group as well as type of engine, is shown in Table 3-6. Over 90% of the new trucks produced are used in domestic truck transportation.

TABLE 3-5

PERCENT OF DIESEL TRUCKS TO TOTAL TRUCKS BY CATEGORIES FOR SELECTED YEARS, 1966-72

Year	Medium Duty Trucks					Heavy Duty Trucks		
	GVWR Group				Total	GVWR Group		Total
	1	2	3	4		5	6	
1966	0%	0%	1%	3%	4%	5%	19%	24%
1968	0	0	0	2	3	4	21	25
1970	0	0	0	3	3	4	28	32
1972	0	0	0	1	1	3	30	33

Source: MVMA 1973 Motor Truck Facts.

TABLE 3.6

NEW TRUCK PRODUCTION, 1972

GVWR Category	Gasoline Engine Number	Gasoline Engine Percent	Diesel Engine Number	Diesel Engine Percent	Total Trucks
Medium Duty	227,263	98	5,045	2	232,308
Heavy Duty	41,994	23	138,044	77	180,038
Totals	269,257	65	143,089	35	412,346
GVWR Group					
1	44,221	100	0	0	44,221
2	9,397	98	215	2	9,612
3	26,330	100	31	0	26,371
4	147,315	97	4,789	3	152,104
5	25,364	65	13,563	35	38,927
6	16,630	12	124,481	88	141,111
Totals	269,257	65	143,089	35	412,346

Source: A. T. Kearney Report to EPA, April 1974.

Medium duty trucks account for the larger share of new trucks with GVWR in excess of 10,000 pounds produced in 1972.

MAJOR TRUCK USERS

A listing of the major users of trucks to move goods is given in Table 3-10. As shown, the agricultural industry is the principal user of trucks and, in particular, the largest user of medium duty trucks. As also shown in Table 3-10, the largest user of heavy duty trucks is the truck-for-hire industry.

TRUCK MANUFACTURERS

The number of new trucks produced by the major truck manufacturers in 1972 are shown in Table 3-7. Four truck manufacturers, General Motors (including its Chevrolet Division), Ford, International Harvester and Dodge, produce almost 98% of all medium duty trucks and approximately 60% of the heavy duty trucks.

TABLE 3-7

NUMBER OF NEW TRUCKS BY MANUFACTURER, 1972

Truck Manufacturer	Medium Duty Trucks			Heavy Duty Trucks		
	Gasoline	Diesel	Total	Gasoline	Diesel	Total
Chevrolet	53,722	135	53,857	1,602	3,696	5,298
Diamond Reo	37	-	37	1,044	3,207	4,251
Dodge	45,042	278	45,320	3,623	1,480	5,103
FWD	4	8	12	301	606	907
Ford	63,544	3,010	66,554	13,952	18,824	32,776
GMC	25,568	446	26,014	8,126	16,017	24,143
IHC	39,064	1,165	40,229	12,230	29,311	41,541
Mack	0	0	0	25	26,331	26,356
White	0	3	3	753	21,854	22,607
Others	282	0	282	338	16,718	17,056
Totals	227,263	5,045	232,308	41,994	138,044	180,038

Source: A. T. Kearney Report to EPA, April 1974.

The financial characteristics of the parent companies of the major truck manufacturers is shown in Table 3-8. Of these parent companies, the five that are considered large, have sales and assets in excess of $1 billion; two have sales and assets between $500 million and $1 billion; and four smaller companies have less than $100 million in sales and assets.

In general, it can be expected that the larger parent companies would have the least difficulty financially in complying with the new truck noise regulations. Smaller companies, without equivalent in-house research and development programs, may have to rely on the noise reduction provided by the suppliers of truck components in order to comply with the noise regulations.

The suppliers of truck components which may be particularly affected by truck noise regulation are those producing engines, mufflers and fans. Most truck manufacturers rely heavily on two major diesel engine suppliers, Cummins and Detroit Diesel, as shown in Table 3-9. The Detroit Diesel Division of General Motors produces most Chevrolet and GMC diesel engines. Mack Truck uses an integrated approach to produce mated engines and transmissions.

TABLE 3-8

FINANCIAL CHARACTERISTICS OF TRUCK MANUFACTURER'S
PARENT COMPANY, 1972 ($ Millions)

Parent Company of Truck Manufacturer	Sales	Net Income	Assets	Net Worth	Comments
General Motors Corporation	$30,435	$2,163	$18,273	$11,683	Truck producing divisions are Chevrolet and GMC.
Ford Motor Company	20,194	870	11,634	5,961	For year ended 10/31/72.
Chrysler Corporation	9,759	221	5,497	2,489	Truck producing subsidiary is Dodge Trucks, Inc.
International Harvester Company	3,527	87	2,574	1,198	
The Signal Company (Mack)	1,481	41	1,328	653	Truck producing subsidiary is Mack. Including Brockway, a Division of Mack, had consolidated sales of $713 million and net income of $35 million.
White Motor Corporation	943	9	573	222	Truck producing divisions are Autocar, White, Freightliner and Western Star. Total truck sales of these groups were $611 million with earnings of $27 million in 1972.
Paccar, Inc.	595	30	268	170	Truck producing subsidiaries are Kenworth and Peterbilt. On and off-highway trucks produced by Peterbilt, Kenworth and Dart represents about 75% of sales.
Diamond Reo Trucks, Inc.	83	7	30	5	
Hendrickson Manufacturing Co.	44	Not Available	23	15	Sales include trucks, special truck equipment, and truck modifications.
FWD Corporation	28	.4	25	6	Sales primarily trucks, year end 9/30/72. FWD is a subsidiary of Oewen Corporation, and investment company.
Oshkosh Truck Corporation	22	.3	14	7	Sales primarily trucks.

Source: A. T. Kearney Report to EPA, April 1974

TABLE 3-9

SUPPLIERS OF DIESEL ENGINES USED BY TRUCK MANUFACTURERS, 1972

Truck Manufacturers	Allis-Chalmers	Caterpillar	Cummins	Detroit Diesel	GMC	IHC	Mack	Perkins	Scania Vabis	Total
Chevrolet	---	---	308	3,388	135	---	---	---	---	3,831
Diamond Reo	---	129	2,038	1,040	---	---	---	---	---	3,207
Dodge	---	---	1,046	434	---	---	---	278	---	1,758
FWD	---	1	165	448	---	---	---	---	---	614
Ford	---	9,336	4,759	7,739	---	---	---	---	---	21,834
GMC	---	---	1,255	14,599	609	---	---	---	---	16,463
IHC	---	747	11,830	14,475	---	2,742	---	628	---	30,476
Mack	22	331	2,612	1,584	---	---	21,121	---	661	26,331
White	44	779	15,513	5,501	---	---	---	---	---	21,857
Others	---	3,736	8,983	3,999	---	---	---	---	---	16,718
Totals	66	15,079	48,509	53,207	744	2,742	21,121	960	661	143,089

Source: A. T. Kearney Report to EPA, April 1974.

TABLE 3-10

DISTRIBUTION OF TRUCKS BY MAJOR USERS, 1972

Major User of Trucks	Medium Duty	Heavy Duty	Total
Agriculture	32.5%	10.3%	26.3%
Wholesale and Retail Trade	19.8	18.3	19.4
Construction	11.1	19.1	13.4
For-Hire	6.3	30.6	13.4
Services	9.5	2.5	7.5
Personal Transportation	9.0	1.0	6.7
Manufacturing	3.6	8.5	5.0
Utilities	3.4	1.9	2.9
Forestry and Lumbering	1.7	3.6	2.3
Mining	.6	1.9	1.0
All Other	3.0	2.3	2.1

Source: Developed from Truck Inventory and Use Survey, 1972 Census of Transportation.

REFERENCES FOR SECTION 3

1. A. T. Kearney & Company, A. T. Kearney Draft Report to U.S. Environmental Protection Agency, April 1974.

2. U. S. Environmental Protection Agency, "Background Document to Proposed Interstate Motor Carrier Regulation," November 1973.

3. Bolt, Beranek and Newman, Inc., BBN Report No. 2710, "The Technology and Cost of Quieting Medium and Heavy Trucks," January 1974.

SECTION FOUR

INFORMATION BASE

SOURCES USED FOR DEVELOPING INFORMATION

The information presented in this document was developed from (1) studies performed by staff personnel of the Standards and Regulations Division, Office of Noise Abatement and Control (ONAC), U. S. Environmental Protection Agency; (2) studies performed under contract to ONAC; (3) submissions by other Federal agencies; (4) submissions by the private sector; and (5) the open literature.

The studies dealing with considerations of public health and welfare were prepared by ONAC personnel. The data used are based largely on previous EPA reports (References 1, 2, 3, 4 and 5) and resulted from intensive analysis of existing information, such as the proceedings of an international conference on noise as a public health problem (Reference 6). The methodology developed assesses the statistical effects of various possible regulatory standards on the noise reduction achievable and the change in the equivalent number of people impacted by vehicle noise in urban areas of the United States. Numerous truck-community scenarios were also developed to evaluate the situational impact of truck noise on people in particular work and home situations.

Studies of noise control technology, the cost of compliance with such technology, if and when applied, and the economic impact on the truck manufacturers and associated truck component industries were largely the result of data acquired by firms under contract to EPA. The technology to reduce truck noise from current levels is presented in reports prepared by Bolt Beranek and Newman, Inc. (Reference 7) and by Wyle Laboratories (Reference 8). These reports also provide their estimates of the costs associated with the technology applications they cite. An economic impact analysis is discussed in a report prepared by A. T. Kearney (Reference 9). This report uses cost data as an impact for projections on such quantities as changes in truck sales and truck operating costs.

The National Bureau of Standards, working under an Interagency Agreement with EPA, provided assistance in the review (Reference 10) of truck noise test procedures. Statistical use was made of the truck resource information provided by the Bureau of the Census of the Department of Commerce (Reference 11). The Department of Transportation provided reports resulting from the Quiet Truck Program (Reference 12).

Information was also provided by the public sector in response to the Advance Notice of Proposed Rule Making (ANPRM) for new medium and heavy duty trucks published in the FEDERAL REGISTER on February 27, 1974 (39 FR 7955). The responses (Reference 13) received from industry, State and local governments, and other interested parties, are recorded in EPA Docket No. ONAC 74-2, which is available for inspection at the U. S. EPA Headquarters, 401 M Street, S. W., Washington, D.C. 20460.

Additional sources of pertinent information, particularly published articles from journals and the like, are also included in the references shown at the end of each section of this document.

BASELINE NEW TRUCK NOISE LEVELS

The baseline noise levels, for considering alternative regulatory options in the development of the new truck noise regulation, are those noise levels generated by current production trucks. This section discusses these baseline noise levels for different truck categories as well as the test procedure used to determine the noise levels indicated.

TEST PROCEDURE USED

The most widely used test in the United States for measuring noise levels for trucks with a GVWR in excess of 10,000 pounds is that established by the Society of Automotive Engineers (SAE) for determining the "Exterior Sound Level for Heavy Trucks and Buses" and is commonly referred to as the SAE J366 test. In April 1973 the test was revised, making it an SAE Standard (J366b) rather than an SAE Recommended Practice. The majority of the truck noise level data in this document was measured using the SAE J366a recommended practice test procedure. No significant changes in the test procedure were made in this SAE J366b revision. Accordingly, the previous new truck noise level data based on J366a are used herein as the baseline noise levels for current production trucks. A brief description of the SAE J366b test procedure follows, with a detailed description of the test included in Section 9.

The test site for performing the SAE J366b exterior truck noise level test is illustrated in Figure 4-1. A microphone is located 50 feet from the truck path. The truck approaches the acceleration point with the engine operating at about two thirds of maximum rated or governed engine speed. At the acceleration point, the accelerator is fully depressed and the truck accelerates, reaching the maximum rated or governed RPM within the end zone of the acceleration lane. Several runs are performed in different directions and the average A-weighted sound level of the two highest readings within 2 dB of each other corresponding to the noisiest side of the vehicle are

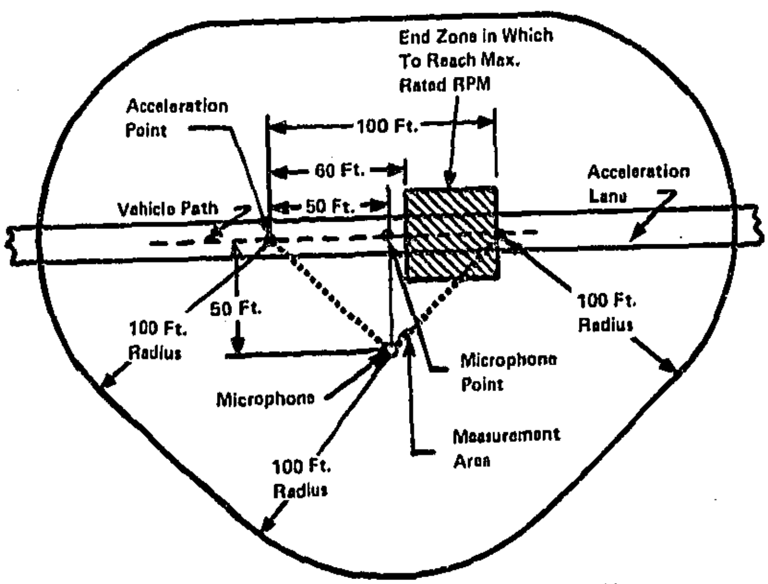

Figure 4-1 Test Site for SAE J366b.

reported. During the test, the truck never exceeds 35 mph. Since tires are relatively quiet at low speed, the J366 test results are primarily an indicator of propulsion noise, including noise from the cooling fan, intake air, engine, exhaust, transmission, and rear axle.

A histogram of the noise levels of new diesel trucks, measured

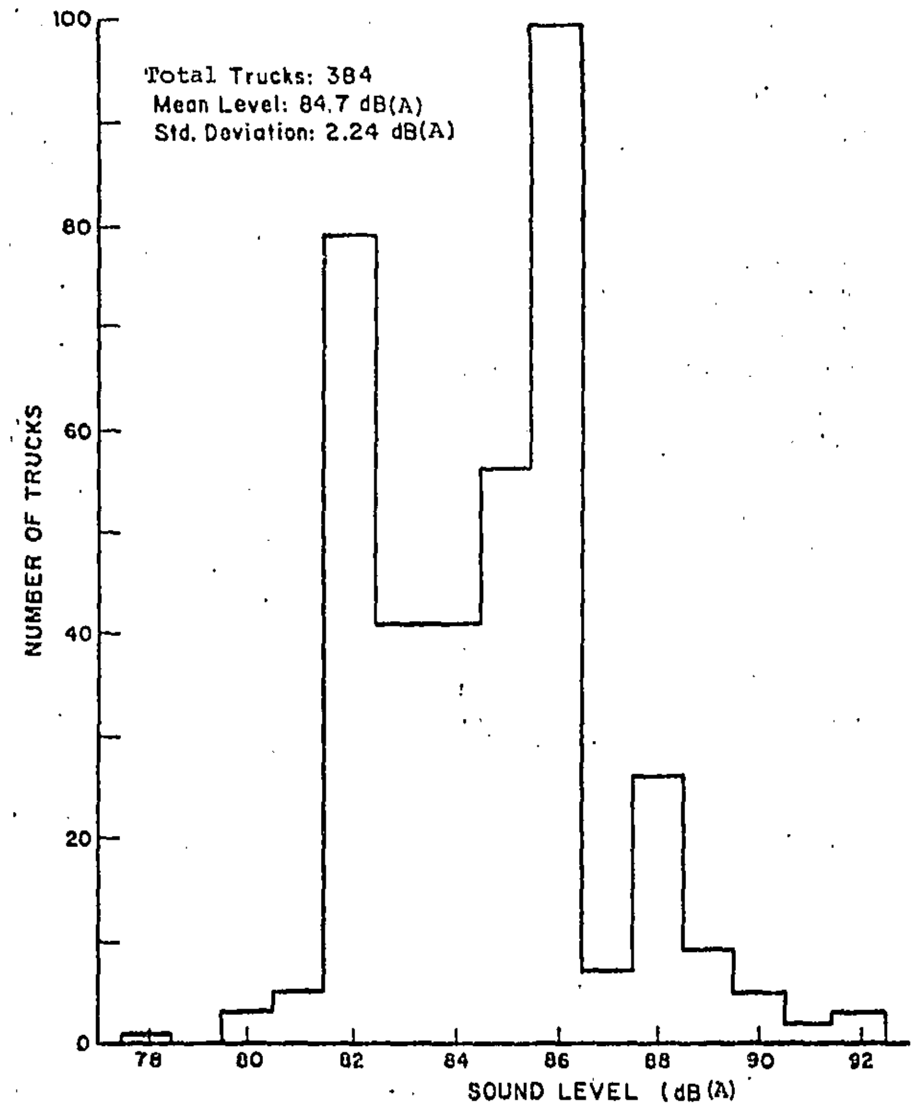

Figure 4-3 Histogram of New Diesel Truck Noise Levels.

Source: BBN Report No. 2710, January 1974.

according to the SAE J366 test procedure, is shown in Figure 4-1. For the total of 384 diesel trucks measured, the mean noise level was 84.7 dB(A) with a standard deviation of 2.24 dB(A). The trucks measured included trucks from the eight truck manufacturers which produced approximately 85% of the new diesel trucks sold in 1971. Not included in this total are experimental trucks such as those developed under the Quiet Truck Program of the Department of Transportation or those trucks developed by various truck manufacturers without government sponsorship.

Data on the noise levels of new trucks with gasoline engines are presented in the histogram shown in Figure 4-2. For the total of 18 trucks measured, the mean level was 83.5 dB(A) with a standard deviation of 2.35 dB(A). The difference between the mean noise level of gasoline and diesel powered new trucks is 1.2 dB(A).

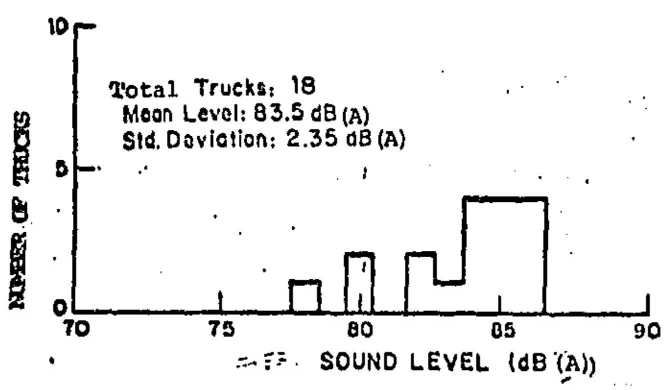

Figure 4-2 Noise Level Histograms of Gasoline-Powered Trucks.
Source: BBN Report No. 2710, January 1974.

A cumulative distribution of the new diesel truck noise levels is shown in Figure 4-4. Approximately 1% of newly manufactured 1973 trucks produce 80 dB(A) or less, 30% produce under 83 dB(A), and 86% produce less than 86 dB(A). Nevertheless, several new trucks did produce noise levels in excess of 90 dB(A).

Histograms of the noise levels measured for new gasoline-powered medium and heavy duty trucks are shown in Figure 4-5. The mean noise level for medium duty trucks appears to be less than 2 dB(A) lower than the mean noise level for heavy duty, gasoline powered new trucks.

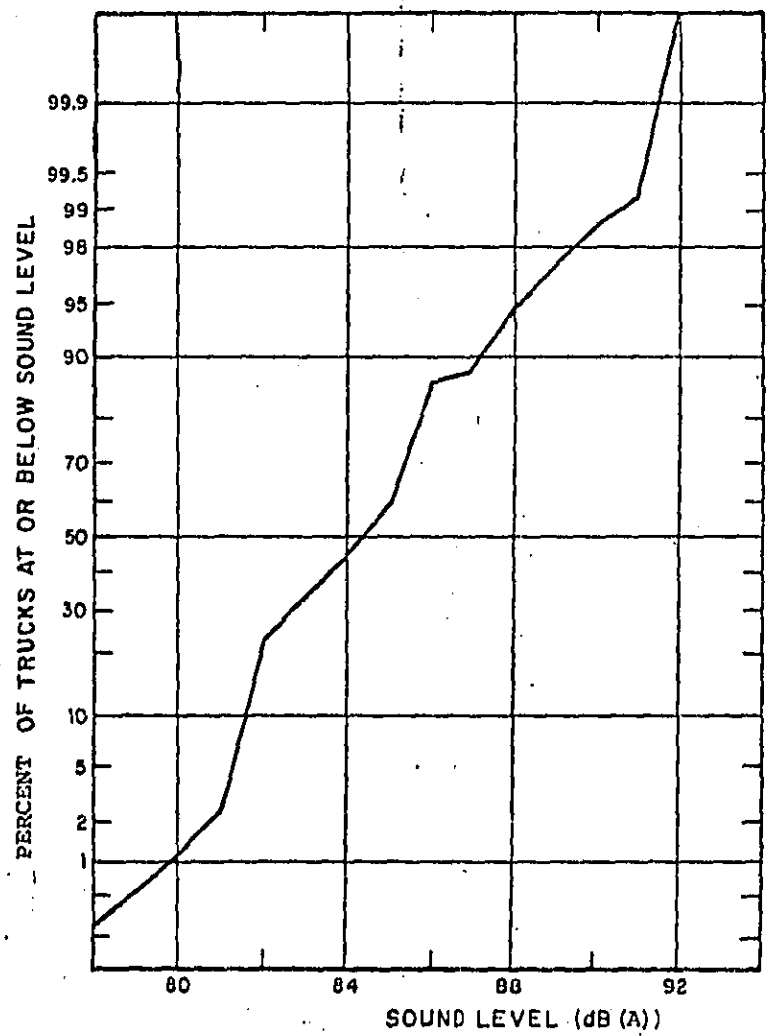

Figure 4-4 Cumulative Distribution of New Diesel Truck Noise Levels.

Source: BBN Report No. 2710, January 1974.

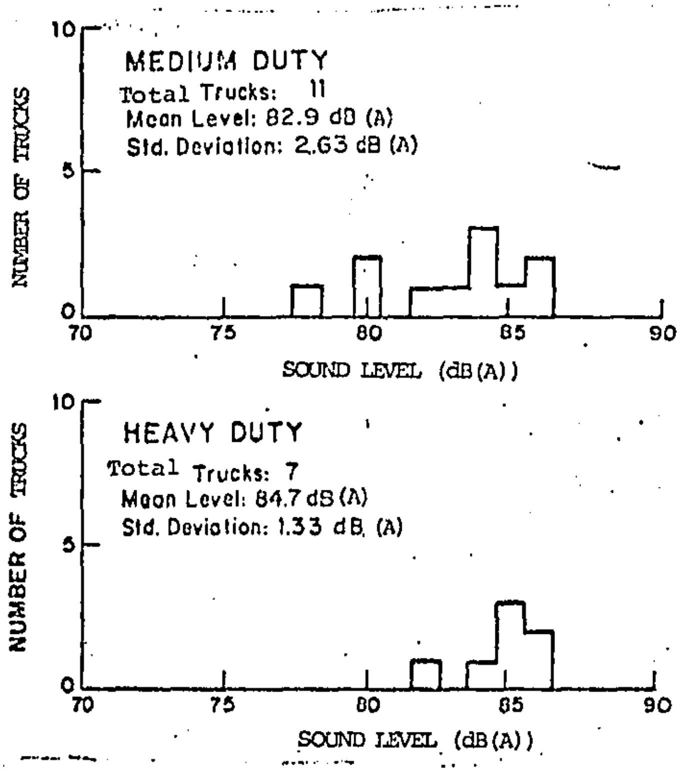

Figure 4-5 Noise Level Histograms of Gasoline-Powered Medium and Heavy Duty New Trucks.

Source: BBN Report No. 2710, January 1974

The preceding paragraphs discuss noise levels produced by new trucks when operating under low speed, high acceleration conditions. In the following paragraphs the noise generated by trucks travelling at relatively high speed is examined. This information was extracted from a draft of the "Background Document for Interstate Motor Carrier Noise Emission Regulations." It constitutes the basis for regulatory level of 90 dBA which has been proposed for interstate motor carriers. The data will also be utilized in the process of construcing a high speed regulatory level for new trucks.

In the surveys presented in this section, an effort was made to maintain standard conditions at almost all sites. Suitable instrumentation was used; sound level meters met the requirements of ANSI SI. 4-1971, American National Standard Specification for Sound Level Meters. Microphone calibration was performed by an appropriate procedure and at prescribed intervals. An anemometer was used to determine wind velocity, and microphones were equipped with suitable wind screens.

Restrictions were made to prevent measurements during unfavorable weather conditions (e.g., wind and precipitation). The standard site for pass-by measurements was an open space free of sound reflecting objects such as barriers, walls, hills, parked vehicles, and signs. The nearest reflector to the microphone or vehicle was more than 80 feet away. The road surface was paved, and the ground between the roadside and the microphone was covered by short grass in most cases.

The standard site for the stationary runup test included space requirements that were the same as for pass-by measurements, and the surface between the microphone and vehicle was paved. Microphones for stationary and pass-by measurements were located 50 feet from the centerline of the vehicle or lane of travel, 4 feet off the ground, and oriented as per manufacturer's instructions. Variations from the standard measurement sites and microphone locations were allowed if the measurements were suitably adjusted to be equivalent to measurements made via the standard methods. Exact procedures for the tests are included in the appendix.

Truck noise surveys have been conducted in California in 1965 (52), and 1971 (53), in the State of Washington in 1972 (54), and in New Jersey in 1972 (55). In 1973, EPA contractors conducted additional truck noise surveys of 6,875 trucks operating at speeds over 35 MPH in the states of California, Colorado, Illinois, Kentucky, Maryland, New Jersey, New York, Pennsylvania, and Texas, and of 2,583 trucks operating under acceleration conditions at speeds under 35 MPH in the states of California, Colorado, Florida, Maryland, Missouri, Texas, and Virginia.

In almost all cases, measurements were made at a distance of 50 ft from the center of the first (outer) lane of travel, using A-weighting and fast response on the sound level meter. In the 1973 surveys, the type of truck and number of axles were recorded in order to permit detailed analyses of the noise level distributions for various types of trucks.

In addition, a study of noise levels of 60 trucks produced during a stationary run-up test was carried out by EPA in Virginia in February, 1974.

Figure 4.6 shows cumulative probability distributions for the peak passby noise levels measured at 50 ft under high-speed freeway conditions in the surveys conducted prior to 1973. The data shown are for heavy trucks: 5,838 diesel trucks in California in 1965 (56), 172 combination trucks in California in 1971 (57), 531 trucks with 3 or more axles in Washington in 1972 (58); and 1,000 trucks with 3 or more axles in New Jersey in 1972 (59). The data are in close agreement: typically, 50% of the trucks were observed to exceed 87 to 88 dB(A) and 20% were observed to exceed 90 dB(A).

Figure 4.7 shows that under high-speed freeway conditions, buses are about 2 dB quieter than heavy trucks. Approximately 50% exceed 85 dB(A), and 6% exceed 90 dB(A). These data were obtained in New Jersey in 1973.

Table 4.1 shows the mean noise levels and percentages of all trucks with six or more wheels that were observed to exceed 90.0 dB(A) under high-speed freeway conditions in ten states. These data were all obtained in 1973, except for the Washington state data, which were obtained in 1972. The arithmetic mean of the percentage of trucks exceeding 90.0 dB(A) is 23.1%. When the data is weighted by the sample size obtained in each state, this percentage drops to 22.6%. When the data are weighted by the number of registered trucks above 10,000 lb GVWR/GCWR, the percentage drops to 21.0%.

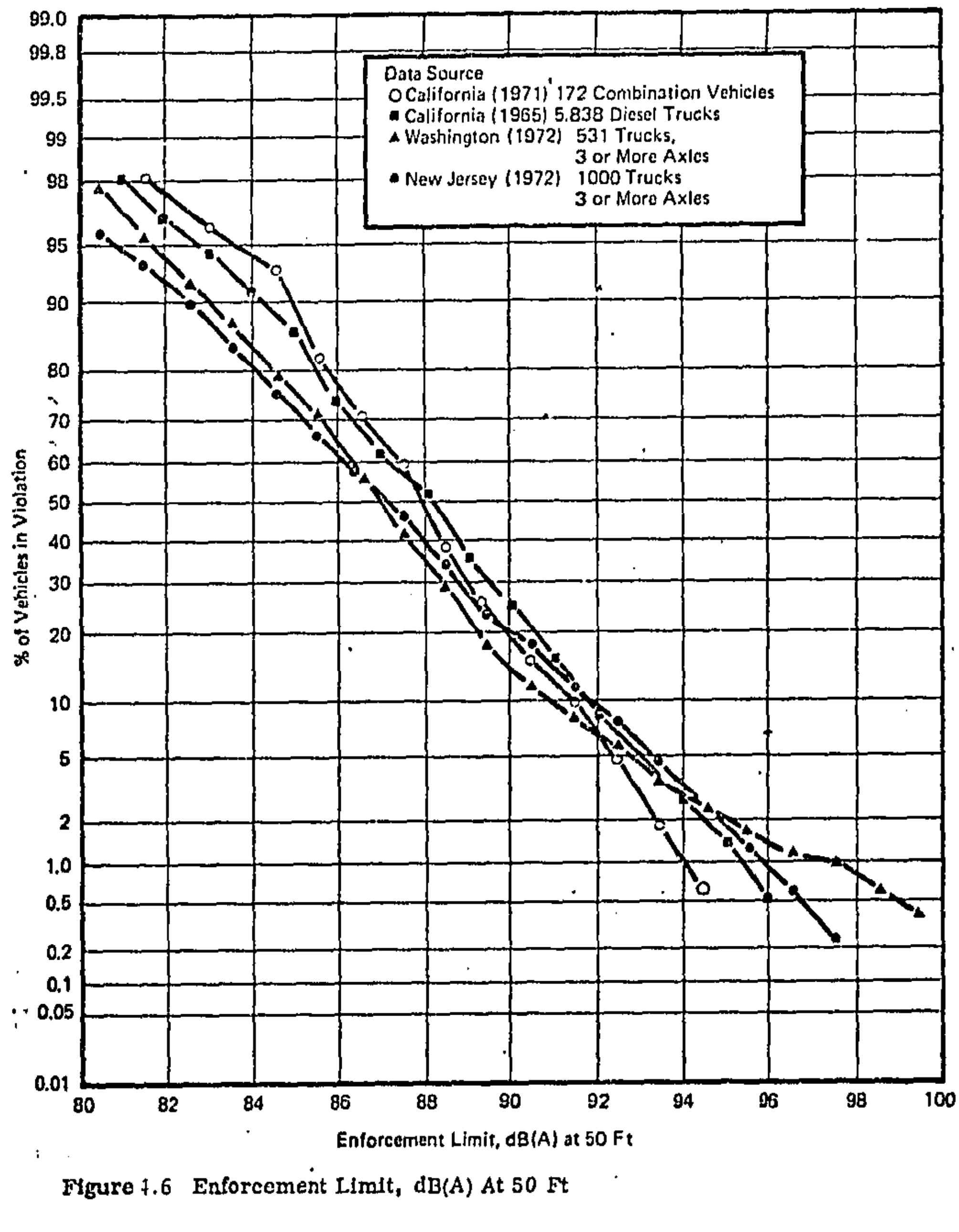

Figure 4.6 Enforcement Limit, dB(A) At 50 Ft

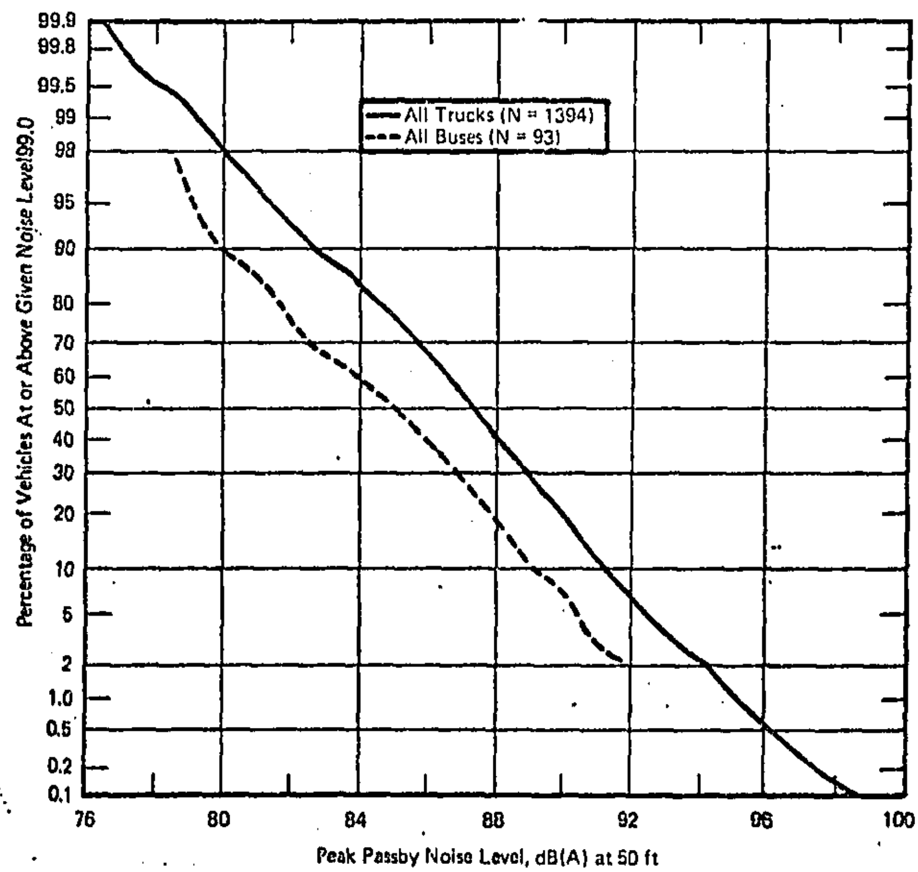

Figure 4.7 Cumulative Distribution Of Peak Passby Noise Levels For All Trucks And All Buses At Speeds Over 35 MPH

Table 4-1

ALL TRUCKS ABOVE 10,000 LBS GVWR OR GCWR

State	Source	Mean Noise Level	Mean Speed	% Above 90.0 dB(A)
CA	W.L.	85.4dB(A) (a)	-	5.0%
CO	BBN	84.6	51.7mph	10.0
IL	BBN	89.1	57.2	42.0
KY	BBN	88.8	61.3	40.0
MD	Md.DOT	88.1	-	30.0
NJ	BBN	87.2	56.5	20.0
NY	BBN	88.8	60.0	43.0
PA	W.L.	86.2 (a)	-	13.0
TX	BBN	83.7	56.1	12.5
WA	WA-72	86.6 (a)	-	16.0

mean percentage exceeding 90 dB(A) = 23.1%.

(a) median

Table 4-3 shows the same results by type of truck for the nine states in which data were obtained in 1973. The mean percentages of trucks exceeding 90.0 dB(A) ranges from 1.9% of 2-axle trucks to 36.1% of 5-axle trucks.

A crucial distinction must now be made. The fact that approximately 23% of all trucks observed in these surveys exceeded 90.0 dB(A) does not mean that 23% of all registered trucks above 10,000 lb GVWR/GCWR will exceed this level. This is because larger trucks operate many more miles per vehicle per year than smaller trucks do and accordingly show up more frequently in surveys than their actual numbers would indicate. For example, 2-axle trucks average 10,600 vehicle miles per year, while 5-axle trucks average 63,000 vehicle miles per year (60).

Using data from the 1972 Census of Transportation - Truck Inventory and Use Survey the following breakdown was obtained for the population of registered trucks above 10,000 lb GVWR/GCWR.

TABLE 4-2

TRUCK POPULATION OVER 10,000 lbs

2-axle straight truck	71.7%
3-axle straight truck	10.6%
3-axle combination truck	2.4%
4-axle combination truck	5.3%
5-axle combination truck	8.1%
Not reported or other	1.9%
	100.0%

Table 4-4 shows that when these percentages are multiplied by the mean percentages of each type exceeding 90.0 dB(A) from Table 4-3, a total of about 7% of all registered trucks above 10,000 lb GVWR/GCWR exceed 90.0 dB(A) at freeway speeds.

Table 4-3

2 AXLE STRAIGHT TRUCK ABOVE 10,000 LBS GVWR

State	Source	Mean Noise Level	Mean Speed	% Above 90.0 dB(A)
CA	W.L.	81.0dB(A) (a)	-	1.2%
CO	BBN	80.4	50.9mph	1.9
IL	BBN	83.1	55.7	1.0
KY	BBN	82.9	57.7	1.0
MD	Md. DOT	83.9	-	3.5
NJ	BBN	82.3	55.7	0.6
NY	BBN	85.1	59.4	6.0
PA	W.L.	81.2 (a)	-	0.9
TX	BBN	78.6	54.6	0.6
mean percentage exceeding given noise level:				1.9%

3 AXLE STRAIGHT TRUCK

State	Source	Mean Noise Level	Mean Speed	% Above 90.0 dB(A)
CA	W.L.	85.2 (a) (b)	-	8.0
CO	BBN	84.1	47.7	1.2
IL	BBN	85.8	54.5	9.0
KY	BBN	87.7	59.9	*
MD	Md. DOT	87.5	-	*
NJ	BBN	84.7	57.4	*
NY	W.L.	88.0 (a) (b)	-	26.0
PA	W.L.	84.5 (a) (b)	-	2.0
TX	BBN	84.8	50.6	*
mean percentage exceeding given noise level:				9.3%

(a) median

(b) all 3 axle trucks

* insufficient data

Table 4-3 (Continued)

3 AXLE COMBINATION TRUCK

State	Source	Mean Noise Level	Mean Speed	% Above 90.0 dB(A)
CA	W.L.	85.2 (a) (b)	-	8.0%
CO	BBN	83.8	51.9	*
IL	BBN	86.0	55.7	*
KY	BBN	87.8	59.0	*
MD	Md. DOT	86.6	-	17.0
NJ	BBN	85.7	57.2	1.0
NY	W.L.	88.0 (a) (b)	-	26.0
PA	W.L.	84.5 (a) (b)	-	2.0
TX	BBN	83.0	56.5	*
mean percentage exceeding given noise level:				10.8%

4 AXLE COMBINATION TRUCK

State	Source	Mean Noise Level	Mean Speed	% Above 90.0 dB(A)
CA	W.L.	84.2 (a)	-	3.0
CO	BBN	84.8	49.0	9.0
IL	BBN	87.1	55.4	22.0
KY	BBN	88.0	61.0	24.0
MD	Md. DOT	87.9	-	26.0
NJ	BBN	86.7	57.7	11.0
NY	BBN	88.8	58.8	26.0
PA	W.L.	85.7 (a)	-	9.0
TX	BBN	83.9	56.4	4.5
mean percentage exceeding given noise level:				15.0%

(a) median

(b) all 3 axle trucks

* insufficient data

Table 4-3 (Continued)

5 AXLE COMBINATION TRUCK

State	Source	Mean Noise Level	Mean Speed	% Above 90.0 dB(A)
CA	W.L.	85.9 (a)	-	7.0%
CO	BBN	87.0	53.7	18.0
IL	BBN	90.2	57.7	51.0
KY	BBN	90.6	62.6	56.0
MD	Md. DOT	89.7	-	42.0
NJ	BBN	88.3	58.7	32.0
NY	BBN	91.2	61.6	74.0
PA	W.L.	87.6 (a)	-	22.0
TX	BBN	87.5	57.9	23.0
mean percentage exceeding given noise level:				36.1%

(a) median

Table 4-4

TRUCKS EXCEEDING 90.0 dBA AT SPEEDS OVER 35 MPH

	% of all trucks above 10,000 lbs (a)	% of type exceeding 90.0 dB(A)	% of all trucks above 10,000 lbs affected (a)
2 axle straight truck	71.7%	1.9%	1.4%
3 axle straight truck	10.6	9.3	1.0
3 axle combination	2.4	10.8	0.3
4 axle combination	5.3	15.0	0.8
5 axle combination	8.1	36.1	2.9
All other (b)	1.9	36.1 (c)	0.7
	100.7%		7.1%

(a) Estimates are for all trucks over 10,000 pounds GVWR or GCWR, including trucks not involved in interstate commerce.

(b) "All other" includes straight truck with trailer, combinations with 6 or more axles, and combinations not specified in the 1972 Census of Transportation survey.

(c) No data available. Percentage exceeding noise level is assumed to be the same as for 5 axle combinations.

It is useful to note that truck noise which is predominantly tire noise may be estimated by the emperical formula given on Page 5-15. In particular the effect of a velocity change from speed mph to mph corresponds to a decrease in noise level ( ) of 40 LOG_{10} ( ) dB(A). When ( ) is 65 mph and ( ) is 50 mph the noise level reduction is 4.6 dB(A). Thus trucks travelling at 65 mph and which generate a noise level of 90 dB(A) would produce 85.4 (approximately 86 dB(A)) at 50 mph. This is of significance in comparing noise levels measured in the high speed test described in this document.

REFERENCES FOR SECTION 4

1. Noise Control Act of 1972, Public Law 92-574, 92 Congress, H. R. 11021, October 1972.

2. "Report to the President and Congress on Noise," EPA Report NRC 500. 1, December 1971.

3. "Public Health and Welfare Criteria for Noise," EPA Report 550/9-73-002, July 1973.

4. "Impact Characterization of Noise Including Implications of Identifying and Achieving Levels of Cumulative Noise Exposure," EPA Report NTID 73.4, July 1973.

5. "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety," EPA Report 550/9-74-004, March 1974.

6. "Proceedings of the International Conference on Noise as a Public Health Problem," EPA Report 550/9-73-008, May 1973.

7. "The Technology and Cost of Quieting Medium and Heavy Trucks," BBN Report No. 2710, January 1974.

8. "Cost Effectiveness Study of Major Sources of Noise: Vol I - Medium and Heavy Trucks," Wyle Laboratories Report No. WR 73-10, October 1972.

9. "A Study to Determine the Economic Impact of Noise Emission Standards in the Medium and Heavy Duty Truck Industry," A. T. Kearney Report (Draft), April 1974.

10. "Measurement Methodology and Supporting Documentation for Medium and Heavy Trucks," U. S. National Bureau of Standards, April 1974.

11. "1972 Truck Inventory and Use Survey" (Magnetic Tape), U.S. Department of Commerce, Bureau of the Census, 1972.

12. "Quiet Truck Program," U.S. Department of Transportation, 1972.

13. Response to Advanced Notice of Proposed Rule Making: Noise Emission Standards for New Products - New Medium and Heavy Duty Trucks, EPA Docket No. ONAC 74-2, April 1974.

SECTION 5

NOISE ABATEMENT TECHNOLOGY

COMPONENT NOISE CONTROL

Of the truck components that contribute to total truck noise levels, the most significant are the engine, fan, intake, exhaust, and tires. The relative importance of each of these sources varies according to the type of truck operation. This section describes noise abatement techniques for reducing the component source levels.

Engine

Internal combustion engines convert the chemical energy of fuel to mechanical energy through the controlled combustion of fuels in a combustion of fuels in a cylinder. The motion of engine components and the sudden increase in cylinder pressure occurring during combustion excites the engine structure, causing vibration of the external surfaces and attendant sound radiation. The magnitude of the radiated noise depends primarily on engine type and design, not on engine size or power.

Gasoline-fueled engines tend to be quieter than diesel-fueled engines. The reason for this is that in present production diesel engines the combustion forces are greater, especially in the mid to high frequencies where resonant structural modes are present in the engine.

Figure 5-1 shows engine noise source levels at 50 feet as a function of engine horsepower. Figure 5-1 is a histogram of these source levels. The three gasoline-fueled engines are in the 75 to 77 dB(A) range, and the diesel fueled engines have source levels ranging from 76 to 85 dB(A), with groupings at 76 to 77, 79 to 81, and 85 dB(A).

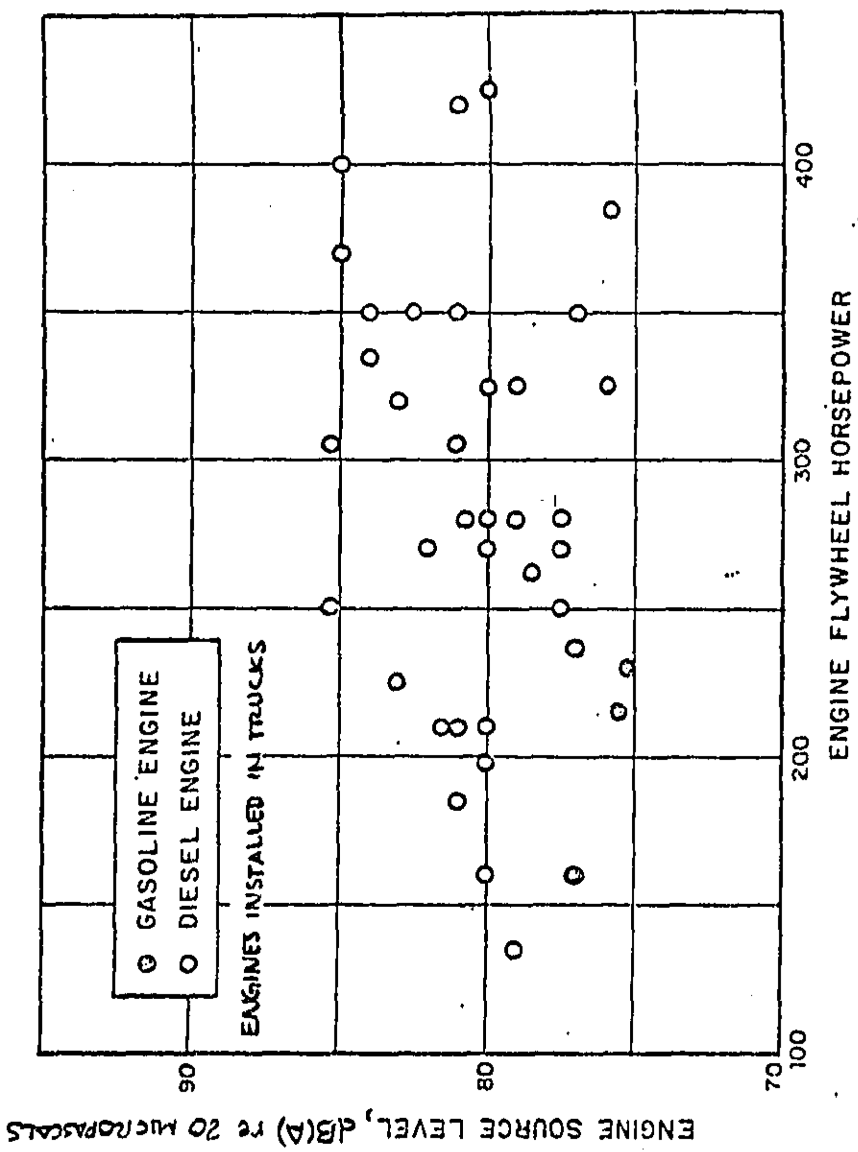

Figure 5-1, Engine Noise as a Function of Horsepower.

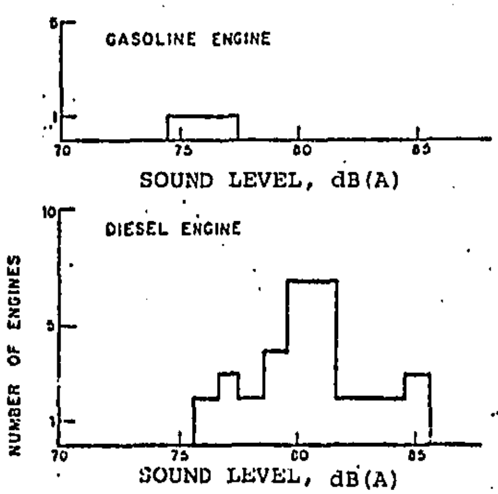

Figure 5-2 Histograms of Heavy Truck Engine Structure Noise (Engine in Truck).

Possible noise control treatments include modifications to the engine itself and modifications to control the path by which engine structural noise is radiated to the exterior. The choice of method will depend on the degree of noise reduction required, cost, lead time, and any associated penalties in performance.

Reduction of combustion-related noise would be particularly desirable for diesel engines. However, reducing this noise by reducing combustion power would also entail a reduction in engine output power. An alternative approach is to smooth out the rapid rise in pressure (Reference 1). One method of doing this is to control the fuel delivery rate, but with present production tolerances in the injection system this would be difficult. Another method is to use a turbocharger on 4-stroke cycle engines. Turbocharging increases peak cylinder pressures while decreasing the rate of pressure rise. Still another technique is to redesign the combustion chamber and injector spray pattern (Reference 1). At present, all these solutions are being tested by the major engine manufacturers. One major manufacturer is phasing all naturally aspirated engines out of production and replacing them with turbocharged models.

Control of machinery-related forces (e.g., oscillating pistons slapping the cylinder walls; see Reference 3) in present engines is aimed primarily at changing or reducing the structural response of the engine. Investigators are experimenting with better ways to support the piston in the cylinder and are trying to obtain better balance and closer tolerances in production engines. This technique, in combination with turbocharging, was used by one manufacturer to reduce the overall noise of a diesel-powered truck to 75 dB(A).

Several engine manufacturers are presently marketing quieting packages that attenuate engine structural noise by altering its transmission path. Depending on the particular quieting package and truck configuration, engine noise reduction ranges from 0 to 4 dB(A), with most packages providing about 2 to 3 dB(A) reduction. The packages generally consist of covers for the sides of the engine block and oil pan, vibration isolation of the valve covers or air intake manifolds and crossovers and, possibly, damping treatment on sheet metal covers (Reference 4). Thien (Reference 5) reports that close-fitting covers which extend over the entire engine structure provide about 15 to 20 dB(A) reduction in engine noise. Discussions with one major engine manufacturer indicated that such packages could reduce the overall truck noise by 10 to 15 dB(A). However, the engine manufacturers also indicated that these packages are not presently acceptable for production utilization because problems with cooling and service access have not yet been resolved.

To obtain the lowest possible overall truck noise level, most engine manufacturers appear to prefer an enclosure built into the truck cab rather than fitted onto the engine. Three truck manufacturers (International Harvester, White, Freightliner) under contract to the U.S. Department of Transportation (DOT) have investigated enclosure designs for cab-over engine trucks. The enclosures involved a tunnel configuration with the cooling fan at the enclosure entrance. Air flows through the enclosure and around the engine via acoustically lined ducts. All three manufacturers have built prototype vehicles generating less that 80 dB(A). The Freightliner truck has an overall noise level of 72 dB(A) (Reference 6). This truck uses a large frontal area radiator to reduce cooling fan requirements; the large engine tunnel formed by the underside of the cab gives the cooling air room to flow past the engine. Thus, full or partial engine enclosures built into the cab structure are technologically feasible. These enclosures will be necessary to reduce the overall noise of trucks equipped with standard diesel engines to low levels (75 dB(A) and below). Some current production trucks without enclosures can be quieted to 80 dB(A). This reduction, however, is dependent upon engine type.

Fan

Truck cooling fans have been designed with primary emphasis on purchase price rather than on aerodynamic efficiency or noise abatement. Accordingly, most fans are made of stamped sheet metal blades riveted to a hub that is turned by means of a belt and pulley arrangement connected to the engine. The fans tend to be small and operate at high speeds, which leads to high noise levels, since fan noise generation is proportional to fan speed. The fan cross section is not aerodynamically shaped, and the blade pitch angle does not vary with radius as it should if it is to properly develop uniform flow through all portions of the radiator. In order to minimize tractor length, it appears that manufacturers tend to squeeze the fan between the engine and radiator. Under favorable conditions, the fan would move air axially; in the usually cramped engine compartment, the flow is mostly radial, with a nonuniform velocity distribution.

Noise data for various truck fans are shown in Figures 5-3 and 5-4 as a function of engine flywheel horsepower. The brackets on the five points in the 300 to 400 hp region designate limits of uncertainty resulting from 0.5 dB(A) levels of uncertainty in the measurements used to estimate the fan noise levels. Fan noise on gasoline-powered trucks tends to be higher than on diesel-powered trucks because the greater heat rejection of gasoline engines requires more cooling air flow. Neither cab type nor engine power appear to have a significant effect of diesel-powered truck fan noise.

The control of fan noise must be viewed in terms of total cooling system design. Some noise reduction can be achieved by modifying the radiator, the shutters, the fan shroud, and, of course, the fan itself. Data presently available to ONAC are inadquate to quantify the exact relations between radiator size, heat transfer coefficient, and fan noise.

Radiator design is closely related to fan performance and noise. Radiators designed with low airflow requirements allow the use of slower turning and, thus, quieter fans. The amount of noise reduction achievable through modifications to the radiator depends on the initial design, but even well-designed cooling systems can often be quieted by 2 to 3dB(A) through modifications to radiator design (Reference 7).

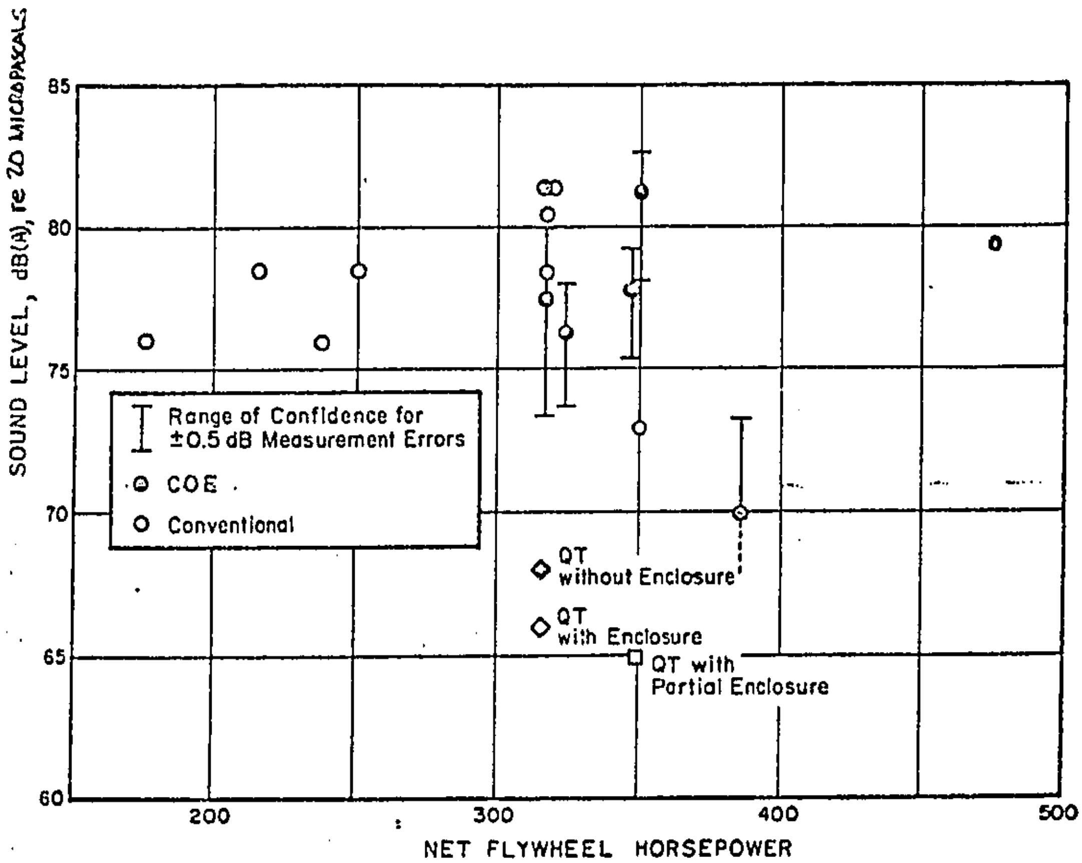

Figure 5-3 Diesel Truck Fan Noise Levels as a Function of Engine Horsepower.

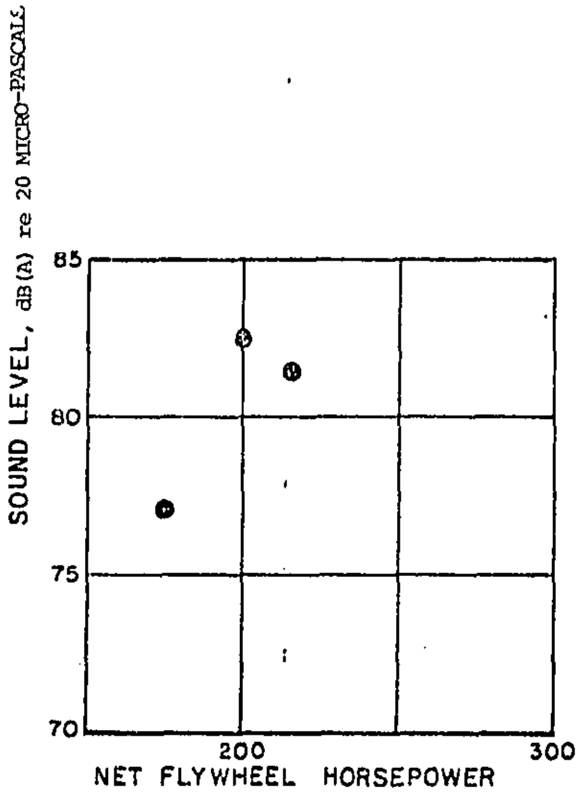

Figure 5-4 Gasoline-Fueled Truck Fan Noise Levels as a Function of Engine Horsepower.

Thermostatically controlled shutters are used on many trucks to regulate air flow through the radiator. The primary purpose of the shutters is to prevent cold water from overcooling the engine on very cold days. Shutters significantly influence fan noise. When the shutters are closed and air flow to the fan is substantially reduced, the fan blades stall and generate more noise.

Shrader (Reference 7) reports a 5 dB(A) increase in fan noise as a result of closed shutters. One manufacturer reported approximately a 2 to 3 dB(A) increase in total truck noise for his engine line of models when shutters were closed. Several manufacturers feel that shutters could be replaced by thermostats and bypass tubing.

The fan shroud, which ducts air from the radiator to the fan, is important in maximizing fan effectiveness and preventing recirculation of hot air back through the radiator. Shrouds that do not channel this air smoothly into the fan can lead to stalled blade tips with an attendant increase in noise. Shrader (Reference 7) claims that improved shroud designs can produce a 3 to 5 dB(A) reduction in fan noise levels.

The fan itself can often be changed to reduce noise. One of the most effective changes is to increase fan diameter and decrease fan speed. A 2- to 3-inch increase in fan diameter typically allows a 3 to 5 dB(A) reduction in noise for a constant volume flow rate. The extent to which fan diameter may be increased is limited by the configuration of the radiator and essential structural members of the truck.

The Cab Over Engine (COE) tractor is particularly suitable for a large, slow fan. Because of the large, blunt front on the COE, the forward motion of the truck tends to develop a high pressure rise in front of the radiator that supplements the flow created by the fan. Using this type of cab and a large radiator with a frontal area of 2,000 square inches, Freightliner achieved a fan noise level of 66 dB(A) (Reference 8). The fan, which is thermostatically controlled, operates for about only 1% of the time. For the remainder of the time, the forward motion of the truck is able to force sufficient cooling air through the radiator.

The data in Figures 5.3 and 5.4 indicate that most fans generate less than 80 dB(A). Those that are noisier can be replaced by a slightly different fan model and fan/engine speed ratio. Reduction of fan noise to 75 dB(A) may require somewhat larger radiator cores and larger, slower fans. Levels can be reduced to 65 dB(A) with larger radiator cores, larger and slower fans, careful design of fan shrouds, and a thermostatically controlled fan clutch that is phased with a shutter thermostat to prevent fan operation while the shutters are closed.

Intake

Air intake systems supply truck engines with the continuous flow of clean air needed for fuel combustion. These systems can range in size and complexity from a simple air filter mounted on top of a carbureter to an external air filter with ducts leading to the engine and a cab-mounted snorkel unit. Noise is generated by unsteady flow of air into engine cylinders. Supercharged engines with Rootes blowers also exhibit tones associated with the blade-passage frequency of the blowers. Turbochargers tend to smooth flow irregularities associated with cylinder charging.

Two DOT reports on exhaust systems (References 8, 9) include studies of air intake systems on five diesel engines. The sound levels are listed in Table 5-1. The DOT report also list the air intake source levels when additional air filters are installed on these engines. Source levels that have been measured for air intake systems on gasoline-fueled trucks are all less than 69 to 72 dB(A) at 50 feet.

Intake systems may be readily quieted by air filters. Hunt, et. al. (1973) and DOT (1973) (References 8 and 9) report that the intake systems they examined could in all cases be quieted to source levels below 75 dB(A) and in some case to below 65 dB(A). It is expected that no performance change in air intake systems will be needed to achieve overall truck levels of 83 or 80 dB(A). To achieve overall truck levels of 75 dB(A), for example, it may be necessary to add silencers to some engines.

TABLE 5-1

AIR INTAKE SOURCE LEVELS

Engine Type	hp	Air Intake Source Level at 50 Feet [dB(A)]
Naturally aspirated, 4-stroke	250	82
Turbocharged, 4-stroke	350	70
Rootes Blower, 2-stroke	238	82
Turbocharged, 4-stroke	238	83

Exhaust

Exhaust outlet noise emanates from the exhaust system terminus and is generated by the pressure pulses of exhaust gases from the engine. Shell-related exhaust noise consists of radiation from the external surfaces of the pipes and mufflers of the exhaust system. It is generated by two mechanisms, the transmission and subsequent radiation of engine vibration to the exhaust system and the transmission of internal sound to the exterior of the pipe.

Hunt et al. (Reference 9) found that the source levels of unmuffled outlet noise for diesel engines can range from 82 to 105 dB(A) at 50 feet. Exhaust shell noise is low enough that very few trucks require modifications to this source to reach overall levels of 83 dB(A). However, some modification is required to achieve overall levels of 80 dB(A) and lower.

Noise control techniques for exhaust noise consist of muffling exhaust outlet noise, using double-wall construction on pipes and mufflers to reduce radiation from exhaust line elements and incorporating vibration-isolated clamps connecting the exhaust pipe to the engine to reduce the engine vibration source of shell noise.

In selecting a muffler, the work the engine must expend on pushing exhaust gases out the exhaust port, with resulting degradation of overall engine performance, should be considered.

Manufacturers are able to choose from among a wide variety of mufflers, some of which provide low noise levels at no more cost or higher back pressure than noisier mufflers. Mufflers are available to reduce the exhaust source levels of 6 cylinder, in-line turbocharged diesel engines, naturally aspirated 4-stroke diesel engines, and turbocharged 4-stroke V engines to 75 dB(A) with no apparent cost increase.

The unmuffled source levels of popular 2-stroke engines are at least 10 dB(A) higher than for other engines. Although apparently no mufflers presently manufactured can reduce the source level of these engines, say, to 75 dB(A), the available technology could enable manufacturers to design such a muffler system, or combine present designs into a dual configuration.

The anticipated method of reducing exhaust noise on 12-cylinder, 2-stroke diesel engines to overall levels of 83 or 80 dB(A) is to use dual or series mufflers.

With the addition of turbochargers to diesel engines, which reduce the unmuffled exhaust noise, noise reductions on the order of 5 to 10 dB(A) have been reported. Thus, turbocharging greatly increases the ease of obtaining overall truck noise level reductions.

Tire Noise

Truck tires generate noise by interacting with road surfaces. Numerous factors affect tire noise, including pavement surface, tire tread design, tire load, whether the pavement is wet or dry, and vehicle speed. In a recent study for the Highway Research Board, Rentz and Pope (Reference 10) compiled truck tire noise data from seven sources and developed the following regression equation for

A-weighted tire noise levels L at 50 feet:

$$L = B + 40 \log_{10} \left(\frac{V}{40}\right) + 10 \log_{10} \left(\frac{W}{4500}\right) + 10 \log_{10} (N)$$

Here B is a constant, the value of which depends on the tread pattern and state of wear, V is the vehicle velocity (in mph), W is the tire load (in lbs) and N is the number of axles on the truck. When this equation was used to predict tire noise associated with 47 loaded tractor-trailer combinations, noise levels were found to be within a mean error of 1.3 dB(A) and a standard deviation of 2.2 dB(A) compared with measured data.

There are at least two techniques that may be used to control tire noise: (1) substitute quiet tires noisy ones, and (2) design quiet tires from the start. When considering substitution, based on presently available tires, it would be desirable to consider equipping trucks entirely with ribbed tires. It should be noted, however, that cross-lug tires are typically used on the drive wheels of tractor-trailer trucks because of tractive requirements.

The design of tires that are significantly quieter than those now being manufactured requires a technology base that is not now existent. Some efforts have been applied to developing new technology; for example, tire manufacturers have found that by randomizing tread patterns, pure tones can be spread in the frequency spectrum with a concomitant reduction in community annoyance. However, fundamental noise-producing mechanisms have not been quantitatively assessed.

TOTAL TRUCK NOISE CONTROL

The component noise control measures described above may be combined in a variety of ways to meet specified limits for overall truck noise. (Tire noise control is not included in this discussion.) In general, the noise control strategy is determined by the source level of the noisiest and most difficult-to-control component, usually the engine. Gasoline-fueled and diesel-fueled trucks are discussed separately because of the difference in their engine source levels.

The combinations of source levels suggested in this section for achieving specified overall truck levels are intended to be representative of practical examples. In some cases, a manufacturer may prefer to have one source level higher and another lower than suggested. As a guarantee of the component levels, tolerances could be placed on each component. For example, to ensure an 81 dB(A) for the engine, the manufacturer would design the engine for a 79 dB(A) level with a 2 dB(A) tolerance. Likewise, the expected tolerances for the fan and the exhaust might be 2 dB(A). These tolerances must be subtracted from the maximum listed values. Assuming that the component tolerances represent the maximum variance in source levels, the variance in overall truck noise would be about 2 dB(A); i.e., the mean noise level for all trucks would be about 1 dB(A) less than the noise level limit.

Diesel-Fueled Trucks

Present production medium and heavy duty diesel trucks display the following ranges of measured source levels (in dB(A)):

Engine	Fan	Exhaust	Overall Truck Noise Level (excluding tires)
76-85	76-85	75-85	79-88

All manufacturers are currently able to reach an 86 dB(A) overall level with off-the-shelf hardware. They have apparently concentrated on quieting their noisiest production trucks first. Thus, trucks having engines with source levels of 80 to 85 dB(A) have quieter fans and exhaust systems than trucks with quieter engines.

Table 5-2 shows one combination of ource levels that will yield a production line truck that generates an overall noise level of less than 83 dB(A). More than 30% of trucks presently being produced already generate noise levels less than 83 dB(A). Of those trucks not meeting this level some will require few modifications, while others will require engine or underhood treatment. Nevertheless, all manufacturers could produce trucks that would achieve this level with all

TABLE 5.2

COMPONENT SOURCE LEVELS FOR AN 83 dB(A)

OVERALL TRUCK NOISE LEVEL

Component	Noise Level, dB(A)	
Engine	$\leq$ 81	
Exhaust	$\leq$ 75	$\leq$ 83
All others	$\leq$ 70	

engine types, using off-the-shelf hardware. This may require that such trucks, depending on the model, be fitted with quieter exhaust systems, quieter cooling fans, and/or engine noise control packages.

The primary design problem will likely be the cooling fan. Truck manufacturers may purchase quieter fans from vendors, but fan noise is influenced by the operating environment as much as by fan design. However, manufacturers may elect to use larger, slower fans with well-designed shrouds and replace radiator shutters with a bypass tubing to achieve greater noise reduction.

Component source levels which will yield trucks whose overall noise level is, for example, 80 dB(A), are shown in Table 5-3. Virtually all trucks produced today will require quieting attention to meet this level. Engine noise will be a prime target for quieting. The quieter diesel engines, which are used in about 23% of the trucks currently produced, will require covers or quieting kits to reduce their noise, while the noisier diesel engines, which are used in about 12% of present production trucks, will require a partial engine enclosure, entailing redesign of the cab, or redesign of the engine itself to reduce structural and combustion noise. Alternatively, truck manufacturers may elect to use one of the quieter engines already available.

To obtain an 80 dB(A) overall level, manufacturers will also have to quiet other components. They may be able to compensate for a slightly too noisy engine by lowering exhaust levels more.

Gasoline-Fueled Trucks

The source levels measured in gasoline trucks are [in dB(A)]:

Engine	Fan	Exhaust	Overall Truck Noise Level (Excluding Tires)
75-77	80-85	80	83-86

Table 5-4 shows a combination of component levels that will produce a truck with an overall noise level of 75 dB(A). To achieve this level, most trucks will require some type of engine enclosure built into the cab. In addition, other components will require treatment with the best available technology.

Table 5-5 lists a set of component source levels that will produce a truck with an overall noise level of 83 dB(A). Noise control to meet this level will consist primarily of quieting fan noise by using a larger, slower fan and incorporating a better exhaust system.

A list of component source levels that will permit a truck to meet an overall level of 80 dB(A) is given in Table 5.6. Manufacturers will have no significant problems in achieving engine and exhaust noise levels. They will have to improve the cooling system by using a larger, slower fan, possibly a thermostatic control to eliminate shutters or control their opening, and possibly a larger radiator.

Table 5-7 lists component source levels that will give an overall truck noise level of 75 dB(A). Manufacturers will probably be able to quiet engine noise by means of engine covers and quieting kits; e.g., under-hood cab treatment, side shields, and recirculation panels.

TABLE 5-3
COMPONENT SOURCE LEVEL COMBINATIONS FOR
AN 80 dB(A) OVERALL TRUCK NOISE LEVEL

Component	Noise Level, dB(A)	
Engine	$\leq$ 75	
Fan	$\leq$ 74	$\leq$ 80
Exhaust	$\leq$ 75	
All Others	$\leq$ 70	

TABLE 5-4
COMPONENTS SOURCE LEVELS FOR A 75 dB(A)
OVERALL TRUCK NOISE LEVEL

Component	Noise Level, dB(A)	
Engine	$\leq$ 70	
Fan	$\leq$ 65	
Exhaust	$\leq$ 68	$\leq$ 75
All Others	$\leq$ 70	

TABLE 5-5
POSSIBLE COMPONENT SOURCE LEVEL COMBINATIONS
FOR SPECIFIED OVERALL TRUCK NOISE LEVELS

83 dB(A)

Component	Noise Level, dB(A)	
Engine	$\leq$ 78	
Fan	$\leq$ 80	$\leq$ 83
Exhaust	$\leq$ 75	
All Others	$\leq$ 70	

TABLE 5-6
POSSIBLE COMPONENT SOURCE LEVEL COMBINATIONS FOR SPECIFIED OVERALL TRUCK NOISE LEVELS

80 dB(A)

Component	Noise Level, dB(A)	
Engine	$\leq$ 75	$\leq$ 80
Fan	$\leq$ 74	
Exhaust	$\leq$ 75	
All Others	$\leq$ 70	

TABLE 5.7
POSSIBLE COMPONENT SOURCE LEVEL COMBINATIONS FOR SPECIFIED OVERALL TRUCK NOISE LEVELS

75dB(A)

Component	Noise Level, dB(A)	
Engine	$\leq$ 70	$\leq$ 75
Fan	$\leq$ 65	
Exhaust	$\leq$ 68	
All Others	$\leq$ 70	

SECTION 6

HEALTH AND WELFARE

INTRODUCTION

Section 2(b) of the Noise Control Act of 1972 states: "The Congress declares that it is the policy of the United States to promote an environment for all Americans free from noise that jeopardizes their health or welfare...." Consistent with this policy and as part of the regulation development process, two analyses have been conducted to evaluate the effects of new truck noise on public health and welfare.

In one analysis, discussed here, the effects on the American population of new truck operating rules, together with the effects of three different levels of new production truck noise were assessed. This study is a statistical analysis that considers the impact of truck noise on the total national population.

In a second analysis, environmental situations defined by scenarios were evaluated to estimate truck noise levels that might allow human activities to be carried on at various activity sites without evocation of annoyance by intruding truck noise. These levels can then be compared with different new truck noise levels to assess the type of environmental situations resulting.

Both analyses use the same basic information. The principal difference is in the presentation of the results. The statistical model considers the change in the average day-night noise energy level, Ldn. The individual case model considers the maximum noise level intrusion due to single events of truck passby noise.

EFFECT OF NEW TRUCK NOISE LEVELS ON PUBLIC HEALTH AND WELFARE "IN THE LARGE"

Introduction

In this section the effects of differing new production truck noise levels on the health and welfare of the United States population are analyzed. The approach taken for this analysis is statistical in that an effort is made to determine the order of magnitude of the population that may be affected by the proposed action. Thus, there may exist some uncertainties with respect to individual cases or situations. However, such effects cannot be completely accounted for; thus the necessity to employ a statistical approach.

The phrase "public health and welfare effects," as used herein, includes personal comfort and well-being as well as the absence of clinical symptoms (e.g., hearing loss).

To perform the analysis presented in this section, a noise measure is utilized that condenses the information contained in the noise environment into a simple indicator of quantity and quality of noise which, in EPA's judgment, correlates well with the overall long-term effects of noise on the public health and welfare. This measure was developed as a result of the Noise Control Act of 1972, which required that EPA present information on noise levels that are "requisite to protect the public health and welfare with an adequate margin of safety."

In accordance with this directive, EPA has selected those noise measures believed most useful for describing environmental noise and its effect on people, independent of the source of the noise. That is, the noise produced, whether by motor vehicles, aircraft, or industrial facilities, is evaluated on the basis of a common measure of noise. Further, the magnitude of environmental noise, as described by this measure that EPA considers desirable from a long-term view of public health and welfare, has been selected for a variety of occupied space and land uses.

In the following sections, the measures to be used in evaluating environmental noise, the numerical values for those levels EPA will consider in assessing impact, and a general methodology for quantifying the noise impact of any noise-producing system being added to the environment, or the impact of a change in an existing noise-producing system are addressed. A specific application of this methodology to assess the effects of the proposed regulations on motor vehicle noise is also developed.

Definition of Leq and Ldn

Environmental noise is defined in the Noise Control Act of 1972 as the "intensity, duration, and the character of sounds from all sources." A measure for quantifying environmental noise must not only evaluate these factors, but must also correlate well with the various modes of response of humans to noise and be simple to measure (or estimate).

EPA has chosen the equivalent A-weighted sound level in decibels as its general measure for environmental noise (Reference 1). The general symbol for equivalent level is Leq, and its basic definition is:

$$L_{eq} = 10 \log_{10} \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \frac{p^2(t)\,dt}{p_o^2} \right] \qquad (6.1)$$

where t - t is the interval of time over which the levels are evaluated, p(t) is the time varying sound pressure of the noise, and p is a reference pressure, standardized at 20 micropascal. When expressed in terms of A-weighted sound level, LA, the equivalent A-weighted sound level, Leq, may be defined as:

$$L_{eq} = 10 \log_{10} \left[\frac{1}{t_2 - t_1} \int_{t1}^{t_2} 10^{\frac{L_A(t)}{10}} \, dt \right] \qquad (6.2)$$

There are two time intervals of interest in the use of Leq for impact assessment. The smallest interval of interest for vehicle noise on highways is one hour, often the "design hour" of a day. The primary interval of interest for residential and similar land uses is a 24-hour period, with a weighting applied to nighttime noise levels to account for the increased sensitivity of people associated with the decrease in backgroundnoiselevels at night. This 24-hour weighted equivalent level is called the Day-Night Equivalent Level, and is symbolized as Ldn. The basic definition of Ldn in terms of the A-weighted sound level is:

$$L_{dn} = 10 \log_{10} \left\{ \frac{1}{24} \left[\int_{0700}^{2200} 10^{\left(\frac{L_A(t)}{10}\right)} dt + \int_{2200}^{0700} 10^{\left(\frac{L_A(t)+10}{10}\right)} dt \right] \right\}$$

or,

$$L_{dn} = 10 \log_{10} \left\{ \frac{1}{24} \left[15 \times 10^{\left(\frac{L_d}{10}\right)} + 9 \times 10^{\left(\frac{L_n+10}{10}\right)} \right] \right\} \qquad (6.3)$$

where Ld is the equivalent level, obtained between 7 a.m. and

10 p.m. and Ln is the equivalent level obtained between 10 p.m. and 7 a.m. of the following day.

Assessment of Impact due to Environmental Noise

The underlying concept for noise impact assessment in this analysis is to express the change in expected impact, in terms of number of people involved, to the change expected in the noise environment. Three fundamental components are involved in the analysis: (1) definition of initial acoustical environment, (2) definition of final acoustical environment, (3) relationship between any specified noise environment and expected human impact.

The first two components of the assessment are entirely site or system specific, relating to either estimates or measurement of the environmental noise before and after the action being considered. The same approach is used, conceptually, whether one is examining one single house near one proposed road or all the houses near the entire national highway system. The methodology for estimating the noise environment will vary widely with the scope and type of problem, but the concept remains the same.

In contrast to the widely varying possible methodologies for estimating the noise environment in each case, the relationships to human response can be quantified by a single methodology for each site or noise producing system considered in terms of the number of people in occupied places exposed to noise of a specified magnitude. This is not to say that individuals have the same susceptibility to noise; they do not. Even groups of people may vary in response, depending on previous exposure, age, socio-economic status, political cohesiveness, and other social variables. In the aggregate, however, for residential locations the average response of groups of people is quite stably related to cumulative noise exposure as expressed in a measure such as Ldn. The response to be used is the general adverse reaction of people to noise. This response is a combination of such factors as speech interference, sleep interference, desire for a tranquil environment, and the ability to use telephones, radio, and television satisfactorily. The measure of this response is related to the percent of people in a population that would be expected to indicate a high annoyance to noise to a specified level of noise exposure.

For schools, offices, and similar spaces in which criteria for speech communication or risk of damage to hearing are of primary concern, the same averaging process can be used to estimate the potential response of people as a group, again ignoring the individual variations among people. In both instances, then, residential (or like) areas and nonresidential, how the average response of people varies with environmental noise exposure is considered.

A detailed discussion of the relationships between noise and human response is provided in several published EPA documents. For example, the different forms of response to noise such as hearing damage, speech or other activity interference, and annoyance are related to Leq and Ldn in the EPA Levels Document (Reference 1). For the purposes of this study, two sets of criteria have been adapted from these EPA documents. It will be considered that if the levels identified in the previous document are met, no impact exists.

The level of environmental noise identified as requisite to protect the public health and welfare with reference to speech communication indoors is a day-night sound level (Ldn) of 45 dB (Reference 1). A noise environment having this level should provide, on the average, 100% speech intelligibility for all types of speech material, and have a calculated articulation index of 1.0 (Reference 2).

The intelligibility for sentences (first presentation to listeners) drops to 90% when the level of the noise environment is increased by approximately 19 dB above the identified level, and to 50% when the level is increased by approximately 24 dB. The intelligibility for sentences (known to listeners) drops to 90% when the level is increased by approximately 22 dB above the identified level, and to 50% when the level is increased by approximately 26 dB (Reference 1). Thus, considering that normal conversation contains a mixture of both types of material, some new and some familiar, it is clear that when the level of environmental noise is increased by more than 20 dB above the identified level, the intelligibility of conversational speech deteriorates rapidly with each decibel of increase. For this reason, a level which is 20 dB above the identified level is considered to result in 100% impact on the people who are exposed. For environmental noise levels which are intermediate between 0 and 20 dB above the identified level, the impact is assumed to vary linearly with level; i.e., a 5 dB excess constitutes a 25% impact vary linearly with level; i.e., a 5 dB excess constitutes a 25% impact and a 10 dB excess constitutes a 50% impact.

A similar conclusion can be drawn from the community reaction and annoyance data containedin Appendix D of Reference 1. The community reaction data show that the expected reaction to an identifiable source of intruding noise changes from "none" to "vigorous" when the day-night sound level increases from 5 dB below the level existing without the presence of the intruding noise to 19.5 dB above the pre-intrusion level. Thus, 20 dB is a reasonable value to associate with a change from 0 to 100% impact. Such a change in level would increase the percentage of the population which is highly annoyed by 40% of the total exposed population (Reference 8).

For convenience of calculation, these percentages may be expressed as fractional impact (FI). An FI of 1 represents an impact of 100%, in accordance with the following formula:

$$FI = 0.05\,(L - L_c) \quad \text{for } L > L_c$$
$$FI = 0 \qquad \text{for } L \leq L_c \qquad (6.4)$$

where L is the appropriate Leq for the environmental noise and Lc is the appropriate identified criterion level. (Note that FI can exceed unity.)

The appropriate identified criterion level for use in calculating fractional impact is obtained from Table 4 of Reference 1. For the analysis of the impact of the noise of motor vehicles on people living in residential areas, the appropriate identified level is an Ldn of 55 dB, which exists outdoors. For other analyses concerned with office buildings and other types of spaces when indoor speech communication is the principal factor of concern, the appropriate identified criterion level is an Ldn of 45 dB (indoors), which is translated to an outdoor level by using a sound level reduction appropriate to the type of structure.

Data on the reduction of noise afforded by a range of residential structures are available (Reference 3). These data indicate that houses can be approximately categorized into "warm climate" and "cold climate" types. Additionally, data are available for typical open-window and closed-window conditions. These data indicate that the sound level reduction provided by buildings within a given community has a wide range due to differences in the use of materials, building techniques, and individual building plans. Nevertheless, for planning purposes, the typical reduction in sound level from outside to inside a house can be summarized as shown in Table 6-1. The approximate national average "window open" condition corresponds to an opening of 2 square feet and a room absorption of 300 sabins (typical average of bedrooms and living rooms). This window open condition has been assumed here in estimating conservative values of the sound levels inside dwelling units which result from outdoor noise.

The final notion to be considered is the manner in which the number of people affected by environmental noise is introduced into the analysis. The magnitude of total impact associated with a defined level of environmental noise may be assessed by multiplying the number of people exposed to that level of environmental noise by the fractional impact associated with this level of the environmental noise as follows:

$$Peq = (FI)\ P \tag{6.5}$$

where Peq is the magnitude of the impact on the population and is numerically equal to the equivalent number of people all of which would have a fractional impact equal to unity (100%) impacted). FI is the fractional impact for the defined level of environmental noise and P is the population affected by this level of environmental noise.

TABLE 6-1

SOUND LEVEL REDUCTION DUE TO HOUSES* IN WARM AND COLD CLIMATES, WITH WINDOWS OPEN AND CLOSED

(Reference 3)

	Windows Open	Windows Closed
Warm Climate	12 dB	24 dB
Cold Climate	17 dB	27 dB
Approximate National Average	15 dB	25 dB

*Attenuation of outdoor noise by exterior shell of the house.

Where knowledge of structure indicates a difference in noise reduction from these values, the criterion level may be altered accordingly.

When assessing the total impact of a given noise source or an assemblage of noise sources, the levels of environmental noise associated with the source(s) decrease as the distance between the source and receiver increase. In this case, the magnitude of the total impact may be computed by determining the number of people exposed at each level, and summing the resulting impact. The total impact is given by the following formula:

$$P_{eq} = \sum_{i} P_i \cdot FI_i \qquad (6.6)$$

where FI_i is the fractional impact associated with the i^{th} level and P_i is the population associated with i^{th} level.

The change in impact associated with an action leading to noise reduction, or change in population through a change in land use, may be assessed by comparing the magnitude of the impacts for the "before" and "after" conditions. One useful measure is the percent reduction in impact (Δ), which is calculated from the following expression:

$$\Delta = 100 \frac{(P_{eq}\text{ (before)} - P_{eq}\text{ (After)})}{P_{eq}\text{ (before)}} \qquad (6.7)$$

Note that the percentage change may be positive or negative depending upon whether the impact decreases (positive percentage reduction) or the impact increases (negative percentage reduction).

Thus, a 100 percent positive change in impact means that the environmental noise has been reduced such that none of the population is exposed to noise levels in excess of the identified levels.

In order to place this concept in perspective, an example is first considered. In the EPA study, "Population Distribution of the United States as a Function of Outdoor Noise Level" (Reference 9), an estimate is provided for the number of people in the United

States exposed to various levels of urban noise. The above concepts can be used to illustrate the current impact of this exposure, and then to assess the change in impact if all noise sources were reduced 5, 10, or 15 decibels. In the following computation, using the data taken from this study, Pi is defined as the population between successive 5 decibel increments of Ldn. This population is assigned an exposure Ldn midway between the appropriate successive Ldn levels. For this example, the identified criteria level is an Ldn of 55 dB measured outdoors.

The result, provided in Table 6.2, shows that a 5 dB noise reduction results in a 55% reduction in impact, a 10 dB noise reduction results in an 85% reduction in impact and a 15 dB noise reduction results in a 96% reduction in impact.

The impact assessment procedure may be summarized by the following steps:

1. Estimate the Leq or Ldn produced by the noise source system as a function of space over the area of interest.
2. Define sub-areas of equal Leq or Ldn, in increments of 5 decibels, for all land use areas.
3. Define the population, P_i, associated with each of the sub-areas of step 2.
4. Calculate the FI_i values for each Ldn_i and Leq_i, obtained in step 2.
5. Calculate $FI_i \times P_i$ for each sub-area in step 2.
6. Obtain the equivalent impacted population for the condition

existing before the change being evaluated,

$Peq_B = FI_i \times P_i$,

by summing the individual contributions of step 5.

7. Repeat steps 1-6 for the noise environment existing over the area of interest after the change being evaluated takes place, thus obtaining Peq_A. (Note that the sub-areas defined here will not in general be congruent with those of step 2 above.)

8. Obtain the percent reduction in impact from

$$\Delta = 100 \cdot \left(\frac{P_{eq_B} - P_{eq_A}}{P_{eq_B}} \right) . \tag{6.8}$$

<u>Application of Assessment Technique to New Truck Regulation</u>

The methodology presented in the previous section can be directly applied for assessing the effects of motor carrier operating rules, together with the effects on the United States population of different noise levels for new production trucks. The following information provides a quantitative comparison of the noise reduction and change in the equivalent number of people impacted by vehicle noise in the urban areas of the United States.

<u>Urban Traffic.</u> In performing this analysis, use has been made of the highway noise model presented in the Highway Research Board Design Guide (HRBDG). Furthermore, the following assumptions have been made for the urban traffic situation:

1. The baseline conditions for trucks will exist as of October 1974, as described in the noise emission standards for motor carriers in interstate commerce proposed by EPA under

Section 18 of the Noise Control Act (38 FR 20102 July 27, 1973). Carrier operating standards require that all medium and heavy duty trucks over 10,000 pounds gross vehicle weight rating (GVWR) not exceed the level of 86 dB(A) under any conditions of operation when traveling at speeds less than 35 mph. In the urban environment, since the average speed through urban streets is 27 mph (Reference 1), this baseline assumption is a suitable starting point for the determination of noise level changes resulting from a new truck regulation.

2. The vehicle mixture is assumed to be 1% heavy duty trucks, 6% medium duty trucks and 93% automobiles (Reference 8).
3. The population density in the vicinity of urban roads for noise impact assessment is that recently reported by EPA (Reference 9).
4. State and city noise regulations becoming effective during the 1975 model year will force a 4 dB reduction in the noise produced by new production automobiles. The 4 dB reduction predicted to occur for automobiles and the expected use of quiet tires are estimates based on current trends in local and Federal noise ordinances. At this time, it is not known if such events will actually occur.

Freeway Traffic

This analysis has been performed in terms of constant speed (55 mph) cruise on level ground, and has made use of actual noise reductions observed during cruise conditions. The data used are those presented in HRBDG volume 5, page 11, table 2. The actual net

TABLE 6-2

ESTIMATE OF THE IMPACT OF SUCCESSIVE REDUCTION OF ALL URBAN NOISE SOURCES IN 5-DECIBEL INCREMENTS

Current Conditions			L_{dn} Noise Reduction in Decibels							
			0		5		10		15	
L_{dn} dB	Population exposed to higher L_{dn}, millions	P_i millions	FI_i -	FI_iP_i millions	FI_i -	FI_iP_i millions	FI_i -	FI_iP_i millions	FI_i -	FI_iP_i millions
55	93.4	34.4	0.125	4.3	0	0	0	0	0	0
60	59.0	34.7	0.375	13.0	0.125	4.3	0	0	0	0
65	24.3	17.4	0.625	10.9	0.375	6.5	0.125	2.2	0	0
70	6.9	5.6	0.875	4.9	0.625	3.5	0.375	2.1	0.125	0.7
75	1.3	1.2	1.125	1.4	0.875	1.1	0.625	0.8	0.375	0.5
80	0.1	0.1	1.375	0.1	1.125	0.1	0.876	0.1	0.625	0.1
Total Equivalent People Impacted				34.6		15.5		5.2		1.3
Percent Reduction in Impact				0		55		85		96

noise reduction during SAE J366 test is greater than the net noise reduction during cruise due to the effect of tire noise at high speeds.

For this analysis, the following assumptions were made:

1. A tire noise level of 77 dB(A) when measured at a cruise speed of 55 mph and at a distance 50 feet away from the vehicle. An assumption was made that cross-rib tires could be forced out of use as a result of increasingly severe high speed noise standards being instituted by EPA under authorization of section 18 of the Noise Control Act. This assumption of the future extensive use of straight rib tires further supports the choice of a tire noise level of 77 dB(A) at high speeds.
2. The mixture of vehicles is 10% trucks and 90% automobiles (HRBDG).
3. There are 8,000 miles of freeways throughout the United States in urban areas (Federal Highway Administration 1972 Highway Needs).
4. Since there exist very little data concerning the population density around highways, the average population density around urban highways is assumed equal to that found in urban areas for the nation as a whole. The 1970 census data indicated that the average population density in urban areas for the nation as a whole is 4,950 people per square mile; thus, the number chosen forthe present analysis is 5,000 people/square mile. Furthermore, if the population distribution around highways is assumed homogenous, it is estimated that there are

40 million people (8,000 x 5,000) presently living within 1/2 mile of (each side) an urban freeway.

5. A basic highway is level and has six lanes of traffic. For the purpose of calculating attenuation of noise on the highway, it is assumed that the typical house is on a lot 100 feet long, 50 feet wide, and 70 feet from the nearest lane of the freeway.
6. Design hour is predicated on traffic flow of 7,200 vehicles per hour traveling at an average speed of 55 mph.
7. As of October 1975, Interstate Motor Carrier operating rules will permit noise levels from medium and heavy duty trucks to be no greater than 90 dB(A) at speeds greater than 35 mph, measured at 50 feet from the centerline of the vehicle path. The data points used from which further extrapolations may be made are at 83, 80 and 75 dB.
8. For purposes of health impact assessments three models have been developed with varying effective dates. These are:

Model 1 - New trucks of over 10,000 lb GVWR will be required not to exceed the following noise levels (in dB(A)) after October of the year indicated:

83	1976
80	1980
75	1982

and the U.S.E.P.A. Interstate Motor Carrier standards, as proposed, are in effect.

Model 2 - Same as Model 1 with the following dates:

83	1976
80	1977
75	1980

Model 3 - Same as Model 1, with effective dates used to separate gas engine and diesel engine powered trucks:

Gas	Diesel	
80	83	1976
80	83	1977
75	80	1980
75	75	1982

The following analysis considers operations under three conditions: urban freeways only, urban streets only, and the aggregate of the two. The analysis derives the change in Ldn, for each condition, for various years between 1974 and 1992, the number of people impacted at levels of Ldn of 55 and higher, and the change in impact for the various strategies.

The results of the analysis are summarized in the attached tables:

Table 6-3 - Change in Ldn for the baseline case and the three models as a function of time, relative to 1974 noise levels.

Table 6-4 - Number of equivalent noise impacted people for the baseline case and the three models as a function of time.

Table 6-5 - Percentage change in number of equivalent noise impacted people for the baseline case and the three models relative to 1974.

The impact estimates indicate that Models 1 and 3 have the same results, whereas Model 2 accelerates the reduction in impact by approximately 2 years. The percent reduction in impact from freeway traffic is slightly greater than that for urban streets (63 or 57%). The estimated percentage reduction for the combined impact of traffic on urban streets is 58%, reflecting that the preponderance of the expected impact is attributable to traffic on urban streets.

Further analysis indicates that the remaining estimated impact from traffic on urban streets in 1992 apportioned to truck sources is approximately as follows:

Medium duty trucks	37%
Heavy duty trucks	6%

To achieve an additional significant reduction in impact requires further reduction of the levels for medium duty trucks and automobiles. For example, if both were reduced by an additional 6 dB, the above percentages would be decreased by a factor of 4 to 9.2% for medium duty trucks and 14.3% for automobiles. This change would reduce the day/night sound level resulting from traffic on urban streets by approximately 5.3 dB. This decrease in level would reduce the estimated equivalent number of people impacted after the regulation is fully effective from 15.9 million to 5 million, a reduction of over 86% from the 1974 baseline condition.

Table 6.3

Reduction in Day-Night Level in Decibels Relative to 1974 Values, as a Function of Years

Item	Year				
	1976	1980	1982	1990	1992
<u>Freeways</u>					
Operating rules and new autos only......................	2.4	2.4	2.4	2.4	2.4
Model 1....................	2.4	3.6	5.0	8.4	8.6
Model 2....................	2.4	4.4	6.2	8.6	8.6
Model 3....................	2.4	3.6	5.0	8.4	8.6
<u>Urban Streets</u>					
Operating rules and new autos only......................	0.7	1.2	1.4	2.0	2.0
Model 1....................	0.7	1.5	2.1	4.9	5.3
Model 2....................	0.7	1.8	2.5	5.0	5.5
Model 3....................	0.7	1.5	2.1	4.9	5.3

Table 6.4

Noise Impacted People
(In millions)

Item	Year					
	1974	1976	1980	1982	1990	1992
Operating rule and new autos only						
Freeway...............	2.7	2.1	2.1	2.1	2.1	2.1
Urban.................	34.6	31.5	29.4	28.4	26.0	26.0
Total...............	37.3	33.6	31.5	30.5	28.1	28.1
Model 1						
Freeway...............	2.7	2.1	1.8	1.6	1.1	1.0
Urban.................	34.6	31.5	28.0	25.6	15.9	14.9
Total...............	37.3	33.6	29.8	27.2	17.0	15.9
Model 2						
Freeway...............	2.7	2.1	1.7	1.4	1.0	1.0
Urban.................	34.6	31.5	27.0	23.2	14.9	13.8
Total...............	37.3	33.6	28.7	24.6	15.9	14.8
Model 3						
Freeway...............	2.7	2.1	1.8	1.6	1.1	1.0
Urban.................	34.6	31.5	28.0	25.6	15.9	14.9
Total...............	37.3	33.6	29.8	27.2	17.0	15.9

Table 6.5

Percent Reduction in Equivalent Noise Impacted Population Relative to 1974 Baseline

Item	Year				
	1976	1980	1982	1990	1992
<u>Freeway Only</u>					
Operating rules and new autos only.....................	22	22	22	22	22
Model 1....................	22	33	41	59	63
Model 2....................	22	37	48	63	63
Model 3....................	22	33	41	59	63
<u>Urban Streets Only</u>					
Operating rules and new autos only.....................	9	15	18	25	25
Model 1....................	9	19	26	54	57
Model 2....................	9	22	33	57	60
Model 3....................	9	19	26	54	57
<u>Total</u>					
Operating rules and new autos only..............	10	16	18	25	25
Model 1..................	10	20	27	54	57
Model 2..................	10	23	34	57	60
Model 3..................	10	17	27	59	57

EFFECT OF NEW TRUCK NOISE LEVELS ON PUBLIC HEALTH AND WELFARE "IN INDIVIDUAL CASES"

This section considers the public health and welfare in individual cases, the descriptions of the environmental situation models studied, a discussion of the basic equation derived for analysis purposes, and the presentation of the results obtained from analysis of the environmental situations described.

Description of Environmental Situations Studied

For the purpose of this model, an environmental situation was defined as follows: "An environmental situation is a common everyday activity at which a human being spends considerable time and in which intrusive noise of sufficient magnitude would evoke a feeling of annoyance." Since this definition of an environmental situation is broad in nature, human activities and sites where human activity occurs were selected to typify those environmental situations thought most prevalent.

The three broad categories of human activity selected were (1) normal conversation, (2) thought process and (3) asleep. For each activity category, additional definitions are made below to qualify the conditions and to set quantitative guidelines for the study. Definitions were selected with the intent to limit the number of environmental situations investigated but not to exclude nor compromise conditions highly germane to the model.

In the normal conversation category, the model was limited to the passby interference of trucknoise on normal conversation. Normal conversation was defined as an activity in which people could communicate at a comfortable voice level or hear television or radio sound at a volume setting that would be comfortable in the absence of intrusive noise. A level of 60 dB(A) was selected as an acceptable ambient speech level for normal conversation indoors or outdoors in the absence of intrusive noise. The 60 dB(A) level selected was based on (1) actual measurement, in a typical living room, during television listening at a comfortable volume setting and (2) analytical calculations of the acoustic energy in a typical living room due to speech sound power levels (Reference 4).

In the thought process category, the model was limited to the influence of noise on reading, writing or studying. A level of 45 dB(A) was selected as the acceptable ambient indoor level during the performance of any or all of these activities. The rationale for choice of the 45 dB(A) level is its common selection as that level which will permit uninterrupted thought activity due to intrusive noise in a quiet office (References 5 and 6). A second level, that of 51 dB(A), was selected as the outdoor ambient level to comfortably perform outdoor thinking. The rationale for this selection is based on the fact that outdoor ambient noise levels are typically higher than interior ambient noise levels (Reference 7).

In the asleep category, the model was limited to the passby influence of truck noise on sleeping. A level of 40 dB(A) was selected as that occurring in a typical urban bedroom. A level of 44 dB(A) was selected as that representative of a typical outdoor nighttime ambient level (Reference 7).

The five categories selected for sites where human activity enactment occurs were (1) an apartment interior, (2) a corner room interior of a frame house, (3) an office interior, (4) an outdoors residential location, and (5) an urban sidewalk location.

For the apartment interior site a room, with height to width to length dimensions of 8 ft to 15 ft to 20 ft, was selected as representative of a typical medium sized apartment. Further, it was assumed that the apartment contained a single window (closed and airtight) in a wall exposed to the exterior and subject to the incident intrusive noise. Other architectural-acoustic descriptions of the apartment interior site appear in Appendix B.

The frame house (corner room) interior site description was selected to duplicate most of the dimensions and acoustical characteristics of the apartment interior with the added condition that the room contained two adjacent walls with (closed and airtight) windows exposed to intrusive noise incident on the exterior windowed surfaces. Appendix B contains more architectural-acoustic description of the corner room in the frame house interior site.

The office interior site room size was maintained at the 8 ft x 15 ft x 20 ft dimensions of the apartment interior site, but was modelled to architectural-acoustic qualities thought representative of a typical office. Appendix B contains additional information to further define the architectural-acoustic description of the office interior site.

The outdoors residential site was defined as a generally open, free-field area void of obstructions that might cause sound reflections.

The urban sidewalk site, like the outdoors residential site, was defined as a free field. However, this is a special environmental situation in that it was assumed a person walking on a suburban sidewalk where the ambient level is 73 dB(A) would become annoyed, for whatever reason, if the ambient is appreciably raised. The 73 dB(A) level is that typical on an urban sidewalk (Reference 7).

Discussion of Equation Derived for Analysis

Having defined an environmental situation and several categories of human activities and activity sites, it is necessary to calculate the truck noise levels in dB(A) measured at 50 feet from the truck which, if permitted, would raise, for a particular human activity, the sound level at a selected activity site by a specified level above the acceptable ambient level assumed to have existed prior to the passage of the truck. To make these calculations, the typical environmental situation has been mathematically modeled using standard acoustic concepts. The derivation of the appropriate situational model equations, including the necessary assumptions, are presented in Appendix A.

$$\delta_o = \delta_r + 10 \log_{10}\left[\frac{(r_o)^2}{(r)^2} \frac{(1)}{(q)}\right] \qquad (6.8)$$

Equation (6.8), which is identical to Equation (A.33) in Appendix A, gives the noise level δ_o in dB(A) of a truck, measured at a distance r_o, whose passby will produce a noise level δ_r in dB(A) inside a particular room which is at a distance r from the specified truck operation. The transmission and absorption charactertics of the particular structure involved as well as the truck noise, which are all generally frequency dependent, are jointly incorporated into the parameter q given by

$$q = \sum_p q_p = \sum_p \frac{T_p}{A_p} \hat{J}_{op} \qquad (6.9)$$

Here, the summation subscript p identified the p th octave band, of interest to the study, while A_p and T_p represent, for the p th octave band, the interior absorption and structural transmittance, respectively, for the particular activity site. Also, $\hat{J}_{op}$ is the normalized A-weighted p^{th} octave band intensity component of the noise spectrum for the specified truck operation.

As an example of the use of Equation (6.8), suppose that it is desired to calculate the truck noise level in dB(A) measured at 50 feet which would preclude substantial annoyance associated with the disruption of a person's thought process during study inside the Apartment Interior activity site, as a result of low speed, high acceleration truck operation along a road 50 feet away from the Apartment.

It will be stipulated that an ambient noise level increase of 10 dB(A) above the acceptable ambient levels identified in this section will initiate a substantial degree of annoyance for all of the human activities defined. The 10 dB(A) ambient noise increase is derived from Reference 3, where it is indicated that an increase by this and even lesser amounts could cause annoyance. The 10 dB(A) might be considered as that amount of increase where substantial annoyance begins to occur. Thus, with this criteria, the noise level inside the room for the particular environmental situation being considered; i.e., thinking in an Apartment 50 feet from the road, is

$$\delta r = \text{acceptable ambient level} + 10 \text{ dB(A)}$$

$$\delta r = 45 + 10 = 55 \text{ dB(A)}$$

From the interior description of the Apartment site given in this section (and Appendix B), the sound absorption characteristics of the Apartment activity space can be determined. The steps necessary to calculate the total absorption for each octave band of interest for the Apartment activity site are summarized in Table C-1 of Appendix C. In Table C-1, values for the absorption coefficients, etc., for the various site components were obtained from the references cited in Appendix B. As shown in Table C-1, Column 6 provides octave band absorptions, in cm absorption units, for the octave bands listed in Column 1.

From the wall structure description of the Apartment site given in this section (and Appendix B), the transmission characteristics of the Apartment structure can be determined. The steps necessary to calculate the total transmittance for each octave band of interest for the Apartment structure are summarized in Table D-1 of Appendix D. In Table D-1, values for the transmission coefficients t were obtained from the relation

$$t = 10^{-\delta_t/10} \tag{6.10}$$

where δ_t is the transmission loss in decibels. Values for the various transmission losses were obtained as follows: for the windows, the best estimate of δ_t is that obtained from the "mass law" (Reference 10).

Thus, values of δ_t were obtained from the equation

$$\delta_t = 10 \log_{10}(1 + 1.366 \times 10^{-3} p^2 f^2) \qquad (6.11)$$

where p is the surface density, lbs/ft^2, of the window and f is the frequency in Hz. For the walls, values of δ_t were obtained from the reference cited in Appendix B.

The typical truck operation involved in this example environmental situation is that of the low-speed, high-acceleration truck operation that usually occurs when a truck at standstill begins movement. The noise spectrum associated with this common truck operation is shown in Figure E-1 of Appendix E. To facilitate its usage in the analysis, the truck noise spectrum of Figure E-1 was normalized to a total sound intensity of one watt/cm . Table F-1 of Appendix F summarizes the steps taken in this normalization process for the low speed, high acceleration truck operation noise spectrum.

The situational factors in Equation (6.9) can now be determined. The steps taken to obtain these situational factors for the environmental situation being presented are summarized in Table G-1 of Appendix G. From the data of column 5 of Table G.2, it is seen that the parameter can be calculated to be

$$q = \sum_p q_p = .000675 \qquad (6.12)$$

The noise level (δ_e), measured at a distance (r_e) of 50 feet, that the truck involved in this situational example can generate without producing a noise level (δ_A) of 65 dB(A) inside the Apartment located that the truck involved in this situational example can generate without producing a noise level (δ_r) of 65 dB(A) inside the Apartment located at a distance ($_r$) of 50 feet from the road without causing substantial annoyance to a person who is studying in the Apartment can thus be calculated from Equation (6.8). Using the above information and the value of q from Equation (6.12), it follows that

$$\delta_o = 55 + 10 \log_{10} \left\{ \left(\frac{50^2}{50^2}\right) \left(\frac{1}{.000675}\right) \right\} = 87 \text{ dB(A)} \qquad (6.13)$$

It should be emphasized that this allowable truck noise level for the environmental situation studied is for a one occurence single truck operation lasting over a relatively short time duration.

The procedure used in the above example to illustrate how the allowable truck noise level measured at 50 feet can be determined for a particular environmental situation is outlined in step format in Appendix H for use in calculating allowable truck noise levels in other environmental situations.

Results for Environmental Situations Studied

The procedure outlined in Appendix H was used to determine the truck noise levels at 50 feet which, if allowed, would cause substantial annoyance for each of a total of 113 environmental situations. The environmental situations studied included various combinations of activity sites, human activities, and distances from the road. The results for these environmental situations are presented in Tables 6.6 and 6.7 for low speed, high acceleration and constant high speed truck operation, respectively.

TABLE 6.6

LOW SPEED, HIGH ACCELERATION TRUCK OPERATION NOISE LEVELS AT 50 FEET TO PRECLUDE ANNOYANCE IN VARIOUS ENVIRONMENTAL SITUATIONS

Environmental Situation			Truck Noise at 50 Feet to Preclude Annoyance (dB(A))
Activity Site	Human Activity or Condition	Distance from Road Centerline (ft)	
Apartment Interior	Normal Conversation	200	114
Office Interior	Normal Conversation	200	111
Frame House Interior	Normal Conversation	200	110
Apartment Interior	Normal Conversation	100	108
Office Interior	Normal Conversation	100	105
Frame House Interior	Normal Conversation	100	104
Apartment Interior	Normal Conversation	50	102
Office Interior	Normal Conversation	50	99
Apartment Interior	Thought Process	200	99
Frame House Interior	Normal Conversation	50	99
Office Interior	Thought Process	200	96
Apartment Interior	Normal Conversation	25	96
Frame House Interior	Thought Process	200	95

TABLE 6.6 (CONTINUED)

LOW SPEED, HIGH ACCELERATION TRUCK OPERATION NOISE LEVELS AT 50 FEET TO PRECLUDE ANNOYANCE IN VARIOUS ENVIRONMENTAL SITUATIONS

Environmental Situation			Truck Noise at 50 Feet to Preclude Annoyance (dB(A))
Activity Site	Human Activity or Condition	Distance from Road Centerline (ft)	
Apartment Interior	Asleep	200	94
Frame House Interior	Normal Conversation	25	93
Office Interior	Normal Conversation	25	93
Apartment Interior	Thought Process	100	93
Office Interior	Thought Process	100	90
Frame House Interior	Asleep	200	90
Apartment Interior	Normal Conversation	12.5	90
Frame House Interior	Thought Process	100	89
Frame House Interior	Normal Conversation	12.5	88
Apartment Interior	Asleep	100	88
Office Interior	Normal Conversation	12.5	87
Apartment Interior	Thought Process	50	87
Frame House Interior	Asleep	100	84
Office Interior	Thought Process	50	84
Frame House Interior	Thought Process	50	84

TABLE 6.6 (CONTINUED)

LOW SPEED, HIGH ACCELERATION TRUCK OPERATION NOISE LEVELS AT 50 FEET TO PRECLUDE ANNOYANCE IN VARIOUS ENVIRONMENTAL SITUATIONS

Environmental Situation			Truck Noise at 50 Feet to Preclude Annoyance (dB(A))
Activity Site	Human Activity or Condition	Distance from Road Centerline (ft)	
Urban Sidewalk	Ambient Level	50	83
Outdoor Residential	Normal Conversation	200	82
Apartment Interior	Asleep	50	82
Apartment Interior	Thought Process	25	81
Frame House Interior	Asleep	50	79
Frame House Interior	Thought Process	25	78
Office Interior	Thought Process	25	78
Urban Sidewalk	Ambient Level	25	77
Outdoor Residential	Normal Conversation	100	76
Apartment Interior	Asleep	25	76
Apartment Interior	Thought Process	12.5	75
Frame House Interior	Asleep	25	73
Outdoor Residential	Thought Process	200	73
Frame House Interior	Thought Process	12.5	73
Office Interior	Thought Process	12.5	72

TABLE 6-6 (CONTINUED)

LOW SPEED, HIGH ACCELERATION TRUCK OPERATION NOISE LEVELS AT 50 FEET TO PRECLUDE ANNOYANCE IN VARIOUS ENVIRONMENTAL SITUATIONS

Environmental Situation			Truck Noise at 50 Feet to Preclude Annoyance (dB(A))
Activity Site	Human Activity or Condition	Distance from Road Centerline (ft)	
Urban Sidewalk	Ambient Level	12.5	71
Outdoor Residential	Normal Conversation	50	70
Apartment Interior	Asleep	12.5	70
Frame House Interior	Asleep	12.5	68
Outdoor Residential	Thought Process	100	67
Outdoor Residential	Asleep	200	66
Outdoor Residential	Normal Conversation	25	64
Outdoor Residential	Thought Process	50	61
Outdoor Residential	Asleep	100	60
Outdoor Residential	Normal Conversation	12.5	58
Outdoor Residential	Thought Process	25	55
Outdoor Residential	Asleep	50	54
Outdoor Residential	Thought Process	12.5	49
Outdoor Residential	Asleep	25	48
Outdoor Residential	Asleep	12.5	42

TABLE 6.7

CONSTANT HIGH-SPEED TRUCK OPERATION NOISE LEVELS AT 50 FEET TO PRECLUDE ANNOYANCE IN VARIOUS ENVIRONMENTAL SITUATIONS

Environmental Situation			Truck Noise at 50 Feet to Preclude Annoyance (dB(A))
Activity Site	Human Activity or Condition	Distance from Road Centerline (ft)	
Apartment Interior	Normal Conversation	200	117
Office Interior	Normal Conversation	200	115
Frame House Interior	Normal Conversation	200	114
Apartment Interior	Normal Conversation	100	111
Office Interior	Normal Conversation	100	109
Frame House Interior	Normal Conversation	100	108
Apartment Interior	Normal Conversation	50	105
Office Interior	Normal Conversation	50	103
Apartment Interior	Thought Process	200	102
Frame House Interior	Normal Conversation	50	102
Office Interior	Thought Process	200	100
Frame House Interior	Thought Process	200	99
Apartment Interior	Normal Conversation	25	99

TABLE 6.7 (CONTINUED)

CONSTANT HIGH-SPEED TRUCK OPERATION NOISE LEVELS AT 50 FEET TO PRECLUDE ANNOYANCE IN VARIOUS ENVIRONMENTAL SITUATIONS

Environmental Situation			Truck Noise at 50 Feet to Preclude Annoyance (dB(A))
Activity Site	Human Activity or Condition	Distance from Road Centerline (ft)	
Apartment Interior	Asleep	200	97
Office Interior	Normal Conversation	25	97
Frame House Interior	Normal Conversation	25	97
Apartment Interior	Thought Process	100	96
Frame House Interior	Asleep	200	94
Office Interior	Thought Process	100	94
Apartment Interior	Normal Conditions	12.5	93
Frame House Interior	Thought Process	100	93
Frame House Interior	Normal Conversation	125	92
Apartment Interior	Asleep	100	91
Office Interior	Normal Conversation	12.5	91
Apartment Interior	Thought Process	50	90
Office Interior	Thought Process	50	88
Frame House Interior	Asleep	100	88
Frame House Interior	Thought Process	50	87

TABLE 6-7 (CONTINUED)

CONSTANT HIGH-SPEED TRUCK OPERATION NOISE LEVELS AT 50 FEET TO PRECLUDE ANNOYANCE IN VARIOUS ENVIRONMENTAL SITUATIONS

Environmental Situation			Truck Noise at 50 Feet to Preclude Annoyance (dB(A))
Activity Site	Human Activity or Condition	Distance from Road Centerline (ft)	
Apartment Interior	Asleep	50	85
Apartment Interior	Thought Process	25	84
Frame House Interior	Asleep	50	82
Outdoor Residential	Normal Conversation	200	82
Office Interior	Thought Process	25	82
Frame House Interior	Thought Process	25	82
Apartment Interior	Asleep	25	79
Apartment Interior	Thought Process	12.5	78
Frame House Interior	Asleep	25	77
Frame House Interior	Thought Process	12.5	77
Outdoor Residential	Normal Conversation	100	76
Office Interior	Thought Process	12.5	76
Apartment Interior	Asleep	12.5	73

TABLE 6-7 (CONTINUED)

CONSTANT HIGH-SPEED TRUCK OPERATION NOISE LEVELS AT 50 FEET TO PRECLUDE ANNOYANCE IN VARIOUS ENVIRONMENTAL SITUATIONS

Environmental Situation			Truck Noise at 50 Feet to Preclude Annoyance (dB(A))
Activity Site	Human Activity or Condition	Distance from Road Centerline (ft)	
Outdoor Residential	Thought Process	200	73
Frame House Interior	Asleep	12.5	72
Outdoor Residential	Normal Conversation	50	70
Outdoor Residential	Thought Process	100	67
Outdoor Residential	Asleep	200	66
Outdoor Residential	Normal Conversation	25	64
Outdoor Residential	Thought Process	50	61
Outdoor Residential	Normal Conversation	12.5	58
Outdoor Residential	Thought Process	25	55
Outdoor Residential	Asleep	50	54
Outdoor Residential	Thought Process	12.5	49
Outdoor Residential	Asleep	25	48
Outdoor Residential	Asleep	12.5	42

As constructed, Tables 6-6 and 6-7 provide values of "Truck Noise" at 50 Feet to Preclude Annoyance" for the various environmental situations defined. The values of these noise level calculations were based on the quantitative guidelines defined priviously in this section (and Appendix B). The guidelines defined include the acceptable ambient noise levels for selected human activities at particular activity sites, the architectural-acoustic descriptions of the activity sites, and the ambient noise level increase criteria for substantial annoyance. Adjustment in any of all of these quantitative guidelines for the analysis procedure are easily made. The net adjustment is simply added algebraically to the values given in the column entitled "Truck Noise at 50 Feet to Preclude Annoyance." For example, if it is desired to replace the 10 dB(A) intrusion noise criterion with a 5 dB(A) criterion, the change is -5 dB(A). If, in addition, it is felt that a selected ambient level for a particular environmental situation is too low and that it ought to be increased by 7 dB(A), then the net adjustment is -5 +7 or +2 dB(A). Each entry in the above mentioned column is then decreased by 2 dB(A) to accommodate this situation.

REFERENCES FOR SECTION 6

1. "Information of Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety," EPA Report 550/9-74-004, March 1974.

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SECTION 7

ECONOMIC CONSEQUENCES OF NOISE CONTROL

INTRODUCTION

This section, using the three hypothetical models described earlier in this document, evaluates the several standards and respective effective dates in terms of costs, and, to a limited degree economic impact to determine the degree of disruption that might result among truck manufacturers and associated industries. The basis for the majority of data contained in this section is derived from two studies performed, under EPA sponsorship, for the purposes of this study (References 1 and 2).

Economic impact is of particular importance in assessing production lead time. A more detailed discussion of typical truck manufacturer lead times to implement design changes of the type envisioned to meet noise control requirements is given in Appendix N.

Model 1 postulates a new diesel engine truck noise level of 83 dB(A) effective in 1977. A two-year period to comply with this level would be followed with a level of 80 dB(A) effective for 1981 model year new trucks. A level of 75 dB(A) for 1982 model year trucks is further evaluated in this model.

Model 2 is the same as model 1. However, it looks at the costs associated with gasoline trucks. An 80 dB(A) level effective in 1978 and a 75 dB(A) level in 1981 were postulated.

TABLE 7-10 ESTIMATED RETAIL PRICE[1] INCREASES

Engine Family/ Engine Manufacturer	Model 1 83 dB(A)	Model 2 80 dB(A)	Model 3 75 dB(A)[1]	Estimated Market Share by Engine (percent)[4]
Gasoline Engines				
All Manufacturers	$ 0	$ 125	$ 300	65.00
Medium-duty Diesel Engines[2]				
Manufacturer:				
D	$125	$ 210	$1,250	2.2
E	100	300	1,250	0.77
G	125	275	1,250	0.17
Heavy-duty Diesel Engines[2]				
Manufacturer:[3]				
A	$200	$ 400	$1,350	0.9
A	150	350	1,250	12.0
B	425	1,000	1,300	6.0
B	325	800	1,500	6.0
C	100	400	1,250	0.47
C	0	125	525	4.8
D	0	150	1,250	1.5
F	125	325	1,250	.23
H	0	150	525	.02

Notes: [1]Cost is stated in terms of retail list price increases.

[2]Refers to severity of service rather than Gross Vehicle Weight (GVW).

[3]Multiple listings for individual manufacturers indicate major groupings of that maker's engines.

[4]Based on 1973 production.

Substitution of a quieter engine for a noisy one is possible within the medium duty and heavy duty classes (but not between classes). Substitution of gasoline engines for medium duty diesel engines is possible. Possible noise control measures and their individual estimated contributions to overall retail price increases are given in Appendix I, Tables A-1 and A-2. Additional insight into the relative impact of various noise control measures is provided by Table 7-1, which shows the relative market share (1973) of each family of medium and heavy duty engines installed in new trucks.

The price estimates in Table 7-1 assume an orderly change in manufacturing processes and adequate lead time. They do not include considerations of factory testing, prototype certification, or other compliance costs that may be imposed by regulatory actions; these are dealt with in "Cost of Compliance Testing," page 7-10. Figure 7-1 gives manufacturers' estimates of the increase in the retail cost of trucks when quieted to various illustrative levels as well as independent estimates from Table 7-1, which shows that:

1. Retail list price increases are generally lower for gasoline engine powered trucks than for diesel engine powered trucks.
2. At each illustrative noise level, there is a wide range in cost increases among diesel engine powered trucks.
3. Model 3 imposes a greater cost increment than either of the first two models, with the exception of engine manufacturer B.

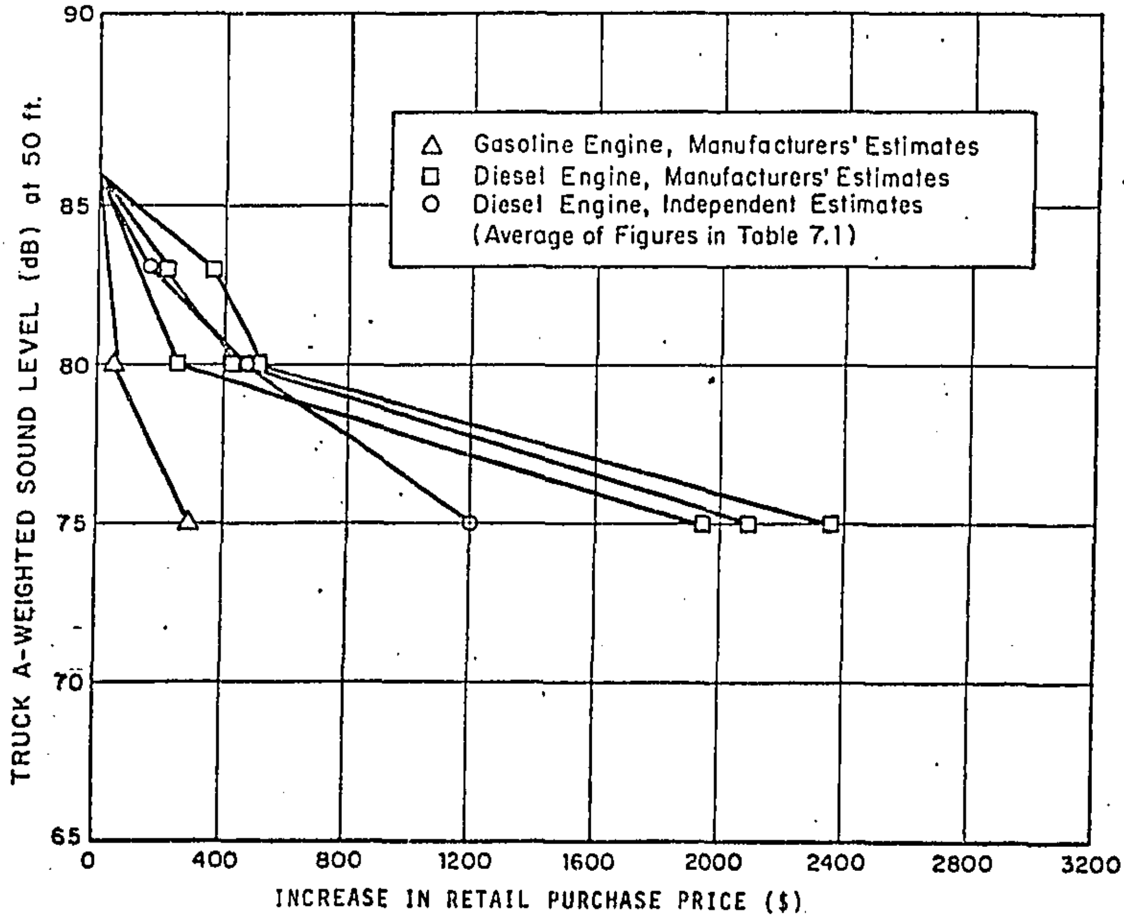

Figure 7.1. Increase in Retail Purchase Price for New Trucks for Various Illustrative Noise Levels Measured According to the SAE J366b Test Procedure.

Gasoline engine powered trucks tend to cost less to quiet than diesel engine trucks because they are generally quieter to begin with. The main reason for the price difference among diesel engines is that those produced by some manufacturers are inherently noisier than others and, therefore, require different noise control methods, as shown in Appendix I. The increase appearing in model 3 compliance costs occurs because at these modeled levels most, if not all, diesel trucks will require an engine enclosure. Based on current practice, such an enclosure would probably be built as an integral part of the truck cab structure. This enclosure will involve major retooling from current production machinery. The costs shown are believed to be "worst case" costs that could be directly ascribed to measures taken as a specific result of Federal noise standards. In fact, such retooling may be effective over time due to design, performance or safety requirements.

In addition to the engine other noise sources that may well have to change include the cooling and exhaust systems. Models 1 and 2 indicate that most manufacturers may have to make primary changes in the cooling system. These changes may include, for example, replacing current fans with larger, slower-turning fans that have carefully designed shrouding and that use a thermostatically controlled fan clutch phased with a shutter thermostat. A fan clutch would eliminate the need for shutters on trucks operating in all but the coldest environments, and would eliminate fan stall as a noise source. Model 3 reveals the likelihood that a high-technology fan system could be required. The costs of implementing these measures are detailed in Appendix A.

Model 1 shows that few diesel trucks will require exhaust system modifications. However, advanced exhaust systems, including mufflers with outer wrapping and vibration-isolated clamps for mounting the exhaust pipe to the engine, could be required to meet the standards hypothesized in model 2. For model 3, exposed exhaust pipes may require lagging (wrapping) to increase the transmission loss and isolate shell vibration. The cost of these treatments are listed in Appendix A.

Changes in Truck Operating Costs

Adding noise control devices to trucks has the effect of changing various physical characteristics: primarily the gross vehicle weight (GVW), the backpressure imposed on the engine by the muffling system, and the power required to run accessories such as the fan. Changes in these parameters will, in general, change the truck's fuel consumption per mile and, hence, the annual fuel costs incurred. This change in fuel costs and the incremental cost of maintaining the truck designed to meet more stringent noise levels than at present constitute the two elements of annual operating cost addressed here.

Other possible effects of equipment modifications to achieve noise abatement are reduction of the truck's maximum speed, resulting from decreased engine power available to drive the wheels, and reduction of the truck's maximum payload, resulting from an increase in tare (empty) weight. The second effect appears to be negligible when averaged over the entire truck fleet (Reference 1) and so is not developed further. This leaves the problem of reduced maximum speed, which may entail some cost to the operator since the truck would, in principle, be able to travel fewer revenue-miles per year. However, recently imposed reduced national speed limits make this a major issue. Moreover, although trucks.maybe designed to operate at a speed higher than legally allowable, obviously it must be presumed that they will remain within the legal limits; hence design speed as a bench mark may be of questionable validity.

The approach to the problem of speed reduction taken here is to assume that the purchaser of a new truck will specify an engine large enough to run the truck at the same top speed of which the unquieted version would be capable, i.e., present production. The cost of this extra horsepower, then, is reflected in the purchase price of the truck. The noise control treatments therefore induce a worst case indirect change in the owner's capital cost, in addition to the direct impact on capital cost referred to above.

The development of operating and indirect capital cost increases is contained in Appendix J. The results of that development are summarized here. Charges in operating expenses are shown in Table 7-2a.

Table 7-2a indicates that the horsepower savings associated with quiet fans result in a net cost savings for most trucks at most levels. Theoretically, such savings could be ascribed to the noise control effort. However, (1) it is possible that truck operators will simply use the fan power savings to increase speed; and (2) market forces may eventually dictate such a beneficial design modification, even without considerations of noise reduction. Therefore, the operating costs have been computed to exclude the fan horsepower savings to again develop a worst case scenario. The results are shown in Table 7-2b.

TABLE 7-2a
CHANGES IN ANNUAL COST (FUEL PLUS MAINTENANCE EXPENSES) CAUSED BY NOISE CONTROL TREATMENTS (INCLUDES FAN SAVINGS)

	Annual Cost Change		
	Model 1	Model 2	Model 3
Gasoline - medium	($ 53)	($ 96)	($ 84)
Gasoline - heavy	($120)	($238)	($210)
Diesel - medium	($ 63)	($ 63)	$ 51
Diesel - heavy	($224)	($ 66)	$116

Note: Parentheses denote net savings.

TABLE 7-2b.
CHANGES IN ANNUAL COST (FUEL PLUS MAINTENANCE EXPENSES) CAUSED BY NOISE CONTROL TREATMENTS (WITHOUT FAN SAVINGS)

	Annual Cost Increase		
	Model 1	Model 2	Model 3
Gasoline - medium	0	$ 9	$ 21
Gasoline - heavy	0	$ 19	$ 44
Diesel - medium	$ 9	$ 9	$123
Diesel - heavy	$19	$176	$359

The cost of extra horsepower needed to maintain the original level of service is shown in Table 7-3a. The fan savings result in a smaller required total engine output and, hence, a reduction in initial price. For the reasons listed in the preceding paragraph, however, these savings may not be realized. The indirect capital cost increase is therefore shown in Table 7-3b with fan savings excluded. The apparent cost of extra horsepower required by noise control treatments is small.

Cost of Compliance Testing

Another noise control cost will be the cost of testing production trucks to ensure end-product compliance. The cost thus incurred by the manufacturers will depend on various factors, such as the ease with which the necessary or required tests can be performed. The enforcement procedure described in Section 10 appears to involve only a nominal cost and no detailed cost analysis is therefore presented. Should an enforcement procedure significantly differ from that described in Section 10 further cost impact analysis will be necessary.

TABLE 73-a
CHANGES IN CAPITAL COST INDIRECTLY CAUSED
BY NOISE CONTROL TREATMENTS
(INCLUDES FAN SAVINGS)

	Capital Cost Change ( ) Denotes Net Savings		
	Model 1	Model 1	Model 3
Gasoline - medium	($ 30)	($ 60)	($ 58)
Gasoline - heavy	($ 98)	($210)	($204)
Diesel - medium	($ 96)	($ 96)	($ 85)
Diesel - heavy	($360)	($336)	($326)

TABLE 7-3b.
CHANGES IN CAPITAL COST INDIRECTLY CAUSED
NOISE CONTROL TREATMENTS
(WITHOUT FAN SAVINGS)

	Capital Cost Increase		
	Model 1	Model 2	Model 3
Gasoline - medium	0	0	$ 2
Gasoline - heavy	0	0	$ 6
Diesel - medium	0	0	$ 11
Diesel - heavy	0	$12	$ 35

COST IMPACTS

Impact on Truck Manufacturers

Market research among truck manufacturers indicates that cost increases on the order of those resulting from noise control retrofits (see Table 7-1) would likely be completely passed on to the consumer as equivalent price increases, with attendant normal markup added on. Future sales may potentially be affected by any future price increases or increases in truck operating costs. To account for both of these possible effects, a worst case equivalent price increase has been computed which consists of the actual price increase plus the net present value of the operating cost increase over the future life of the truck.* Table 7-4 gives the average equivalent price increases for each type of truck, both including and excluding fan savings (see "Changes in Truck Operating Costs," page

* The net present value was computed assuming a depreciation time of 10 years and an interest rate of 10%.

7-7). The figures in Table 7-4 were derived by computing the equivalent price increases explicitly for each major truck group and then taking an average, weighted according to each group's market share. The details of this computation are given in Appendix K. Where savings from reduced fan power outweigh other cost increases, the net gain in income could be assumed to be lost to the operator under worst case computations, competitive pressures forced a lowering of freight rates. A worst case "zero" is consequently entered for such cases.

	Representative Prices	
	Gasoline	Diesel
Medium	$ 5,746	$ 7,246
Heavy	11,434	25,213

The midpoint estimate of elasticity (y) of -0.7 is used.

$$dq/q = (-0.7) \cdot \frac{dp}{p}$$

where q is volume, dp is the change in equivalent price (Table 7-4), and p is the price shown above.

TABLE 7.4
EQUIVALENT PRICE INCREASES FOR QUIETED TRUCKS

	Model 1	Model 2	Model 3
		With Fan Savings	
Gasoline - medium	0	0	0
Gasoline - heavy	0	0	0
Diesel - medium	0	0	$1357
Diesel - heavy	0	0	$1506
		Without Fan Savings	
Gasoline - medium	0	$ 180	$ 431
Gasoline - heavy	0	$ 242	$ 576
Diesel - medium	$160	$ 319	$1,986
Diesel - heavy	$311	$1,581	$3,360

Source: Appendix K.

To estimate the impact of the equivalent price increases in Table 7-4 on possible future sales, an estimate of the price elasticity of demand for trucks was made. Rigorous estimates of this quantity are not currently available, but market research indicates a probable range of -0.5 to -0.9. The midpoint of this range, -0.7, was assumed as a working value. The percentage reduction in sales for a given price increase was then obtained by multiplying the percentage price increase by the elasticity. The percentage sales decreases corresponding to the price changes as shown in Table 7-4 are given in Table 7-5.

The differences among the three noise models used relates to the times at which the various noise levels in the models become effective. The three models are shown in Table 7-6.

TABLE 7-5

ESTIMATED PERCENTAGE REDUCTION IN ANNUAL VOLUME

	Model 1	Model 2	Model 3
		With Fan Savings	
Gasoline - medium	0	0	0
Gasoline - heavy	0	0	0
Diesel - medium	0	0	13.11%
Diesel - heavy	0	0	4.18%
		Without Fan Savings	
Gasoline - medium	0	2.20%	5.25%
Gasoline - heavy	0	1.48%	2.53%
Diesel - medium	1.54%	3.09%	18.31%
Diesel - heavy	0.86%	4.39%	9.33%

Based on "average" or "representative" truck prices (see A. T. Kearney, 1974).

TABLE 7-6

ALTERNATIVE NOISE REDUCTION SCHEDULES

	Model 1	Model 2		Model 3
	All Trucks	Gasoline	Diesel	All Trucks
Level 1 - 83 dB(A)	1977	1977	1977	1977
Level 2 - 80 dB(A)	1981	1978	1981	1978
Level 3 - 75 dB(A)	1983	1981	1983	1981

The absolute reduction in future sales is obtained by multiplying the percentages in Table 7-5 by the baseline volume forecast; i.e., projected future sales of unquieted trucks. The baseline projection is given in Table 7-7. Complete tables of future volumes for each of the three quieting options, with and without fan savings, are given in Appendix L.

So far, no judgment has been made as to whether fan savings should or should not be included in the sales forecasts. At this point, a hypothesis is made concerning the inclusion of fan savings in the impact analysis. Any design change which produces net cost savings in and of itself will ultimately be introduced as a result of market pressure. This applies to improved fans. The probable effect of new truck noise control regulations, however, may be to cause adoption of such design improvements earlier than would otherwise be the case. The noise control program can, therefore, claim credit for fan savings during the period prior to the time when market forces would otherwise result in introduction of the quiet fan. This period is assumed to be three years. The composite volume reduction forecasts are therefore constructed from the tables in Appendix L by including fan savings for the first three years under model 1 conditions (1977-1979 inclusive) and excluding fan savings thereafter (1980-2000). The composite volume forecasts are shown in Figures 7.2 through 7.5 for each truck category. In each figure, the baseline forecast and the revised forecasts are laid out for each of the three models. The figures show that from the models used the maximum differential impact occurs between 1980 and 1982, depending on the truck category. In general, model 1 shows more units being sold during this period than does Model 3; Model 2 is intermediate. In the case of heavy gasoline trucks, for example, 793 more units are sold in 1980 in model 1 than in models 2 and 3. For heavy diesels, models 1 and 2 result in 11,125 more units being sold than would be in model 3 in 1982.

To estimate the relative impact on truck manufacturers, the cumulative impact on dollar sales is computed for each model over the period 1977-1985, the period within which the models differ. The percent reduction in total dollar sales of all types of trucks over the period 1977-1983 is shown in Table 7.8. Model 3 produces the greatest impact while model 1 gives the least impact. The effect of quieting gasoline engines on a shorter-term schedule than diesel engines (model 3) shows a slightly greater adverse impact than if all trucks were quieted on a longer-term schedule.

TABLE 7-70

BASELINE FORECAST OF DOMESTIC TRUCK SALES BY ENGINE TYPE[1]
(THOUSANDS OF TRUCKS)

	Medium-Duty Trucks			Heavy-Duty Trucks			Total
	Gasoline	Diesel	Total	Gasoline	Diesel	Total	(All Trucks)
1976	203.9	3.1	207	40.4	164.6	205	412
1977	206.8	3.2	210	39.4	173.6	213	423
1978	209.8	3.2	213	38.1	184.9	223	436
1979	212.8	3.2	216	38.4	194.6	233	449
1980	215.7	3.3	219	38.6	204.4	243	462
1981	218.7	3.3	222	38.7	214.3	253	475
1982	221.6	3.4	225	38.8	225.2	264	489
1983	224.6	3.4	228	38.8	236.2	275	503
1984	228.5	3.5	232	38.7	248.3	287	519
1985	231.5	3.5	235	38.6	260.4	299	534
1986	234.4	3.6	238	38.4	273.6	312	550
1987	237.4	3.6	241	38.1	287.9	326	567
1988	241.3	3.7	245	37.7	302.3	340	585
1989	244.3	3.7	248	37.2	316.8	354	602
1990	248.2	3.8	252	36.6	333.4	370	622
1991	251.2	3.8	255	35.9	350.1	386	641
1992	255.1	3.9	259	35.0	367.0	402	661
1993	258.1	3.9	262	33.9	385.1	419	681
1994	262.0	4.0	266	32.8	404.2	437	703
1995	265.9	4.1	270	31.5	424.5	456	726
1996	269.9	4.1	270	32.8	443.2	476	750
1997	273.8	4.2	278	34.2	461.8	496	774
1998	276.8	4.2	281	35.7	481.3	517	798
1999	280.7	4.3	285	37.2	501.8	539	824
2000	284.7	4.3	289	38.8	523.2	562	851

[1] Source: A. T. Kearney, 1974. Forecasts for years 1976-1978 based on market research. Forecasts for years 1979-2000 based on following annual growth rates:

Gasoline - medium : 1.4
Gasoline - heavy : -0.3
Diesel - medium : 1.5
Diesel - heavy : 5.0

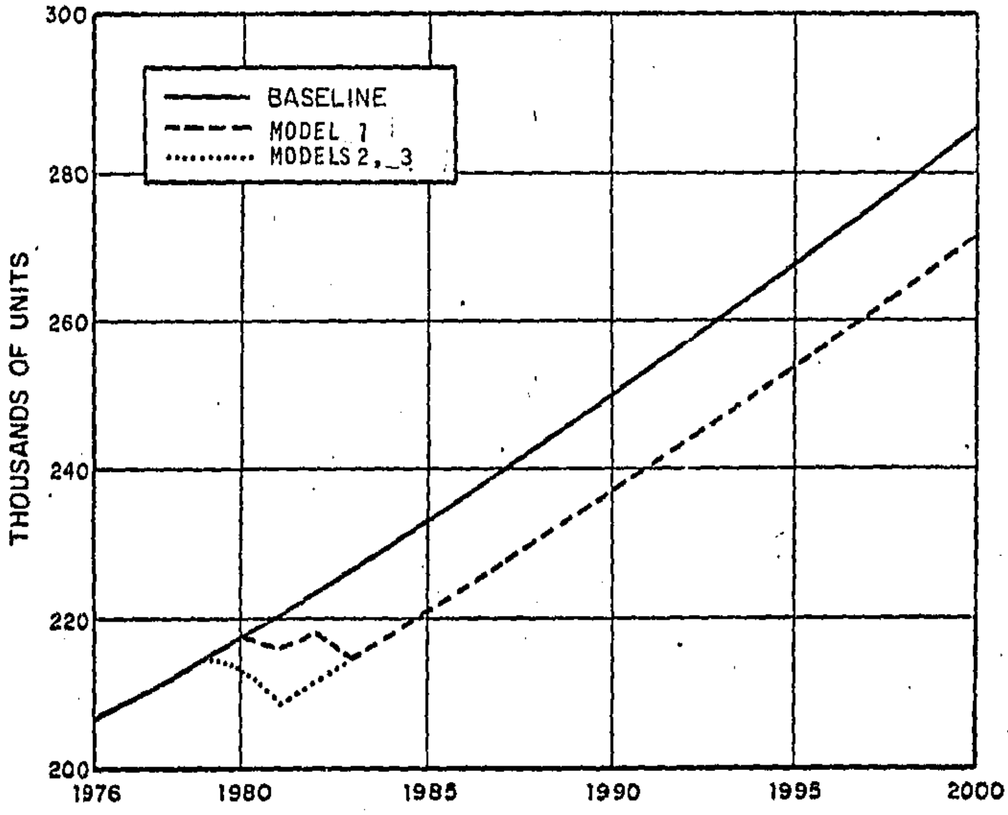

Figure 7-2. Volume Forecasts - Baseline and Quieted Gasoline-Medium

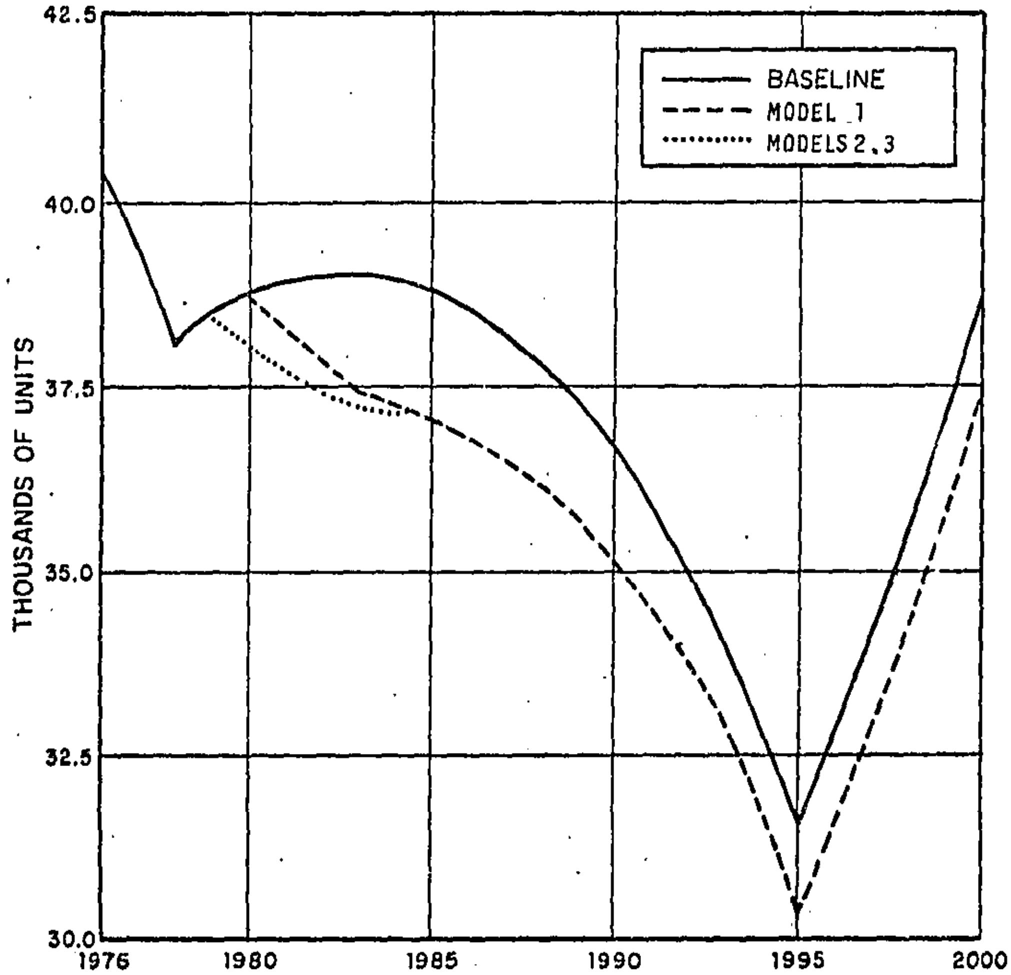

Figure 7-3 Volume Forecasts - Baseline and Quieted Gasoline-Heavy.

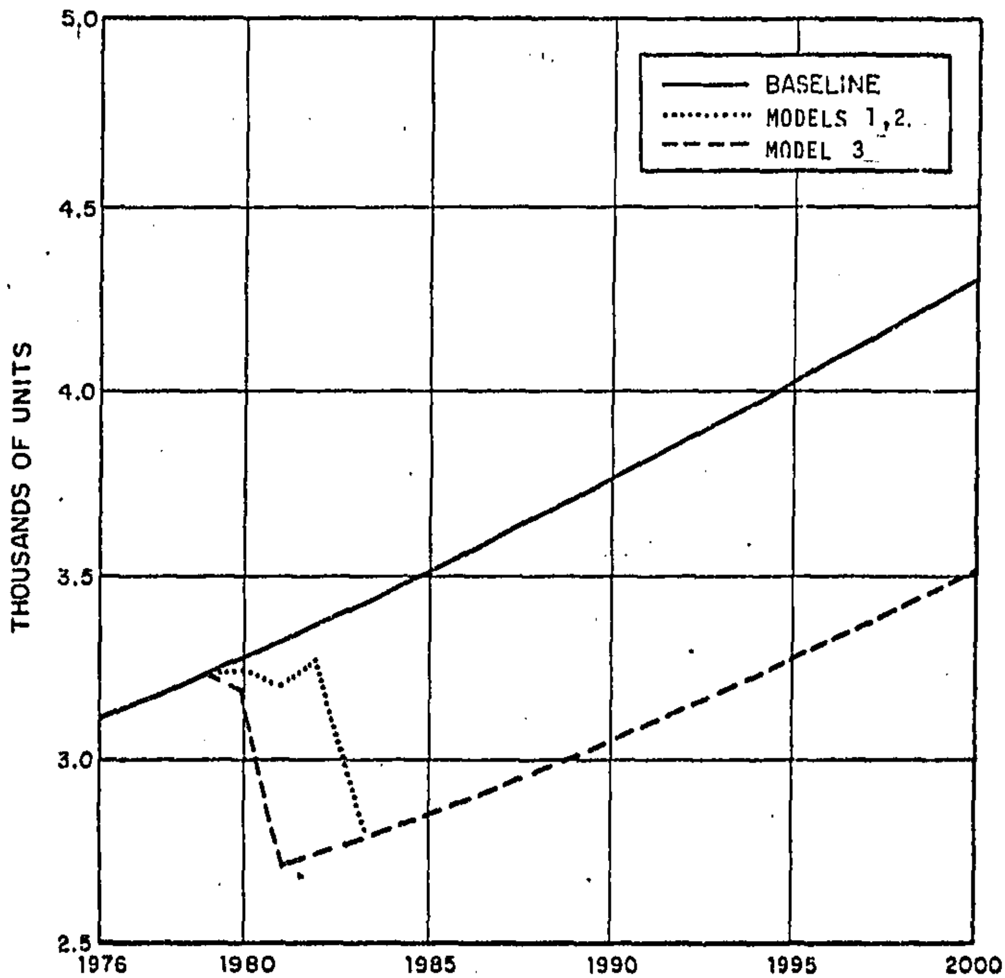

Figure 7-4 Volume Forecasts - Baseline and Quieted Diesel-Medium.

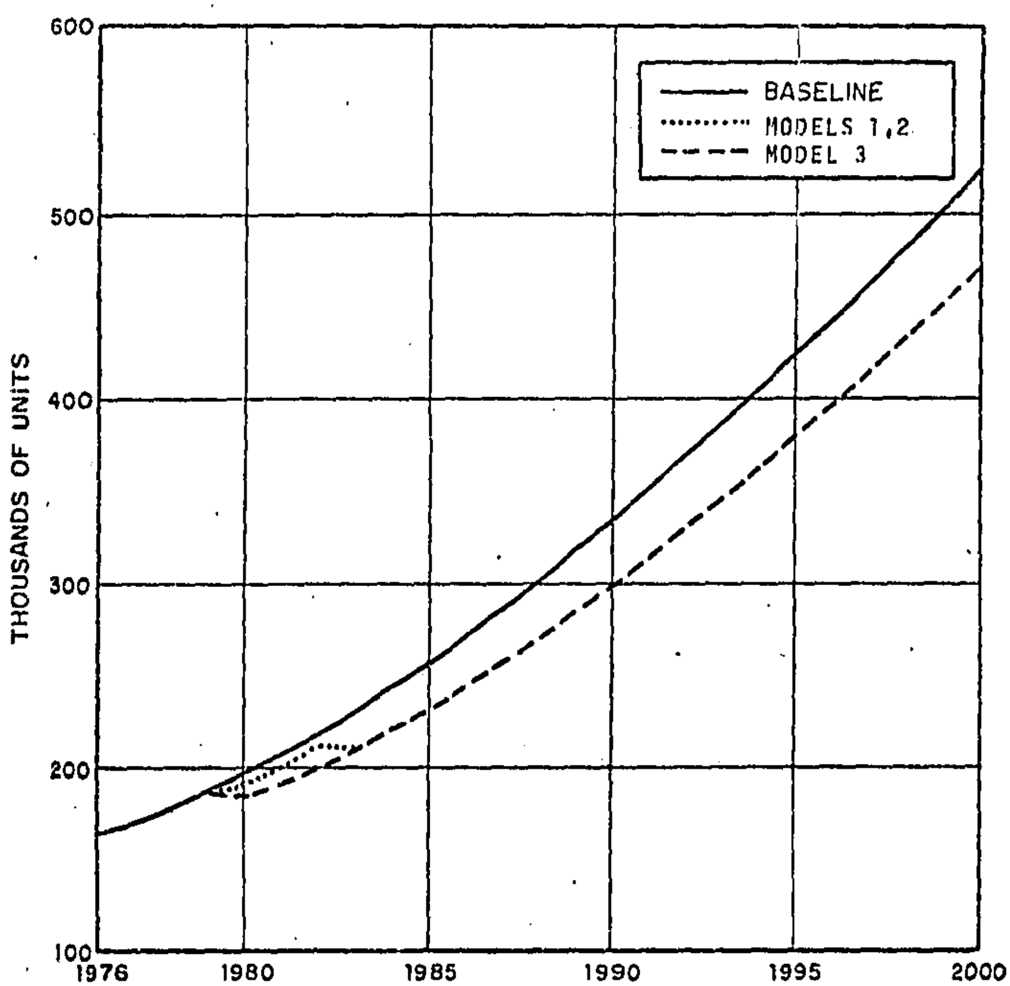

Figure 7-5 Volume Forecasts - Baseline and Quieted Diesel-Heavy

TABLE 7-8
CUMULATIVE COST IMPACT OF ALTERNATIVE QUIETING SCHEDULES

	Cumulative Baseline Sales* 1977-1983 ($ millions)	Cumulative Reduction In Sales due to Quieting Options 1977-1983 ($ millions)	Percent Reduction in Cumulative Sales, 1977-1983
Model 1	48,080	1,430	3.0
Model 2	48,080	1,560	3.2
Model 3	48,080	1,120	4.4

Source: Figures 7-2 through 7-4.

* Assumes the following average prices (A. T. Kearney 1974):

Gasoline - medium	$ 5,746
Gasoline - heavy	$ 11,434
Diesel - medium	$ 7,246
Diesel - heavy	$ 25,213

In addition to possible sales volume changes, other impacts on truck manufacturers could be a standardization of the product offering and changes in production operations, a reduction in the number of components and options offered by exhaust muffler systems, and cooling systems. Because these components currently have wide variations in noise levels, an anticipated effect of noise standards could be to eliminate many of them as variations in a given model family.

In models 1 and 2, the addition of acoustic treatments such as side panels, sheet metal supports, and fan modifications may require some modifications in fabrication and assembly operations.

Model 3 indicates that changes in production operations may occur because virtually all trucks would appear to require at least partial engine enclosures. Such enclosures could entail redesign of some cabs. The costs of these design and retooling actions may or may not be attributable wholly or in part to noise abatement standards, dependant on style or design changes that may be effected whether or not Federal noise standards are established. Estimates of increased engineering, design, and test costs for the total medium and heavy duty truck industry were, however, considered and are shown in Table 7-9. These expenditures could be expected to potentially result in employment increases of several hundred personnel.

TABLE 7-9
ESTIMATED TOTAL ENGINEERING, DESIGN, AND TEST INVESTMENT COSTS TO TRUCK MANUFACTURERS FOR NOISE CONTROL IN THE MEDIUM AND HEAVY DUTY TRUCK INDUSTRY

	Total Cost (Millions of Dollars)
Model 1	20
Model 2	40
Model 3	120

Source: Discussions with truck manufacturers.

Several of the larger manufacturer representatives expressed concern over what they consider to be potentially large development costs for noise levels such as those used in model 3. They state that if such development costs appear too high in relation to volume, the manufacturers could be expected to withdraw from the low-volume segments of the market and possibly eliminate those vehicle models which have low potential volume and require high development costs.

The overall impact from these moves on manufacturers' shares of the market would, however, on the whole, appear to be minor.

Because of the basically strong position of the truck manufacturing industry in the economy at this time, the potential volume changes that could occur as the result of Federal noise control regulations would in general appear to have little overall impact on most firms. The truck manufacturing industry has been growing at a rate of 7 to 8% per year (in current dollars) from 1966-1972. The value of shipments was estimated at $7.5 billion in 1972 and value added is estimated at $2.0 billion. These figures include light, medium, and heavy duty trucks. Imports were about 10-11% of 1973 domestic shipments and exports about 6-7%.

In 1973, truck manufacturing accounted for about 120,000 jobs in the U.S. Again, this represents employment in the production of all classes of trucks.

As a generalization, the major manufacturers are better able than small ones to adapt to the significant equipment changes that may be required as a result of certain noise standards. This ability reflects superior financial resources and a larger scale of operation which supports specialized personnel resources and organized research and development efforts that can be brought to bear on the adjustments required.

Table 7-10 indicates the market share of each manufacturer in the medium and heavy duty market.

Most truck manufacturers seem to anticipate few significant equipment modifications in truck manufacturing assembly operations if partial engine enclosures are not required to meet noise standards which may be imposed. Cost increases resulting from noise abatement hardware are expected to be passed on to customers. In addition, no change in pricing practices or dealer policy is anticipated; thus it could be anticipated that the customary markup will be added to such manufacturers' costs, resulting in the price increases postulated elsewhere in this study.

TABLE 7.10
MARKET SHARE OF MEDIUM AND HEAVY DUTY TRUCKS BY MANUFACTURER

Truck Manufacturer	%
Chevrolet	14.2
General Motors	11.7
Diamond Reo	1.1
Dodge	12.1
Ford	23.7
Duplex	.1
FWD	.2
International Harvester	20.2
Mack	6.3
White	5.9
Other	4.5

Impacts on Truck Users

Firms engaged in truck haulage will be affected by new truck noise control measures through changes in their capital costs and cost of operation. Using the estimated increases in purchase price and operating cost developed in the models used in Section 7, the effects

TABLE 7-11

MODELS OF POSSIBLE INCREASED CAPITAL COST (BASED ON YEAR IN WHICH VARIOUS STANDARDS COULD TAKE EFFECT)[1] ($ THOUSANDS)

	Model 1 - 1977		Model 2 - 1978		Model 3 - 1981	
	Per Truck[2]	Total[3]	Per Truck[2]	Total[3]	Per Truck[2]	Total[3]
Gasoline - medium	$ 0	$ 0	$125	$ 25,650	$ 300	$ 62,160
Gasoline - heavy	0	0	125	4,693	300	11,199
Diesel - medium	104	328	264	818	1,129	3,048
Diesel - heavy	195	33,560	487	86,092	1,119	217,422
Total		$33,888		$117,253		$293,829

[1]Excludes indirect capital cost savings due to fan treatments (see Section 7-2).

[2]Source: Figures from Table 7-1 averaged within each truck category.

[3]Numbers of trucks sold by category for each year obtained from Tables D-1 - D-4.

on the trucking industry have been projected in several ways. These include increases in annual capital outlays, annual costs of operation during the first year that various noise levels become effective, and annual costs of operation at such time as the entire fleet consists of quieted trucks.

Table 7.11 portrays the increased capital outlay (excluding the effects of fan savings) which the trucking industry could potentially be impacted by in the first full year in which various noise levels would hypothetically become effective.* This represents the change in purchase price for each truck category times that year's sales for that category. The largest effect is observed in model 3, for which $294 million extra could possibly be paid at retail for that year's trucks. Taking the 1981 projected unit sales from Tables D-1 through D-4 and the average unit prices from Table 7-8, the increase represents about 4.5% of the total new vehicle capital outlay for that year.

Table 7.12a and 7.12b show computations for the without- and with-fan savings cases, respectively, of the additional annual cost (including depreciation, interest, operating, and maintenance expenses) for the first full year during which various noise levels could become effective. The basis for these tables is presented in Appendix E. The models in Table 7.12a show that possible extra

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* In Tables 7-12, 7-13a, and 7-13b, only one initial year per noise level is considered; optional implementation schedules are not shown. The costs which would be shown if different schedules were used, however, are not substantially different from those given here.

annual costs associated with operating quiet trucks during the first year of each of the three models used increases from $11 million for model 1 to $168 million for model 2. Table 7.12b, on the other hand, shows that these costs are more than offset if one considers the savings due to the use of lower-powered fans.

The maximum annual cost resulting from noise abatement is reached when the truck population is 100% quieted. Cost estimates were made for both 1990 and 2000. Making these estimates required projection of truck population and average annual cost per unit by type (e.g., medium diesels, etc.) and noise level to the year 2000. The average annual cost was calculated in a manner similar to first-year costs as described in the previous paragraph, but with operating costs scaled to the trucks' annual average mileage rather than to first-year mileage. Population forecasts were obtained by using the model described in Section 8 and the volume forecasts presented in Appendix L.

Those volume estimates for the period 1976 to 1978 were based on extrapolations from sales forecasts provided by truck manufacturers. Heavy trucks are predicted to grow at an annual rate of 4.3% and medium trucks at 1.4%. These form the baseline estimates that were adjusted downward to reflect the quantity adjustment resulting from increased purchase and operating costs (which are the result of noise abatement). Since these estimates are simple extrapolations, change in technology, demand for transportation services, and other factors could result in the actual population in future years being larger or smaller than the predicted population.

TABLE 7-12a

MODELS OF POSSIBLE INCREASED ANNUAL COST
(EXCLUDES FAN SAVINGS) ($ MILLIONS)
(BASED ON YEAR IN WHICH VARIOUS STANDARDS COULD TAKE EFFECT)

	Model 1 - 1977		Model 2 - 1978		Model 3 - 1981	
	Per Truck[1]	Total[2]	Per Truck[1]	Total[2]	Per Truck[1]	Total[2]
Gasoline - medium	$ 0.	$ 0.	$ 46.00	$ 9.44	$108.40	$ 22.46
Gasoline - heavy	0.	0.	60.00	2.25	142.20	5.31
Diesel - medium	33.84	0.11	65.00	.20	404.02	1.09
Diesel - heavy	64.92	11.17	335.52	59.31	715.86	139.10
Total		$11.28		$71.20		$167.96

[1]Source: Appendix M.

[2]Truck volume for each year by truck category obtained from Appendix L, Tables D-1 through D-4.

TABLE 7-12b

MODELS OF POSSIBLE INCREASED ANNUAL COST (INCLUDES FAN SAVINGS) ($ MILLIONS) (BASED ON YEAR IN WHICH VARIOUS STANDARDS COULD TAKE EFFECT)

	Model 1 - 1977		Model 2 - 1978		Model 3 - 1981	
	Per Truck[2]	Total[3]	Per Truck[2]	Total[3]	Per Truck[2]	Total[3]
Gasoline - medium	($107.00)	($22.13)	($208.00)	($43.64)	($144.60)	($31.62)
Gasoline - heavy	(219.60)	(8.65)	(453.36)	(16.59)	(365.00)	(14.16)
Diesel - medium	(85.12)	(.27)	(56.36)	(.18)	135.82	.39
Diesel - heavy	(321.70)	(55.85)	(58.68)	(10.85)	1.66	.34
Total		($86.90)		($71.26)		($45.05)

[1]Parentheses denote net savings.

[2]Source: Appendix M.

[3]Truck volume for gasoline trucks in each of the models is the same as baseline volume (Table 7-7). Truck volume for diesel trucks obtained from Appendix D, Tables D-5 and D-6.

The two tables below give the possible annual total cost of quieting by type of truck as well as totals for all types for 1990 and 2000.

TABLE 7-13a
INCREASED TOTAL ANNUAL COSTS YEAR 1990
($ thousands)

Type	Model 1	Model 2	Model 3
Gasoline - medium	115,286	114,598	100,007
Diesel - medium	6,895	5,866	5,866
Gasoline - heavy	26,374	26,194	22,408
Diesel - heavy	1,034,875	914,968	911,366
Total for all types	1,183,430	1,061,626	1,039,647

TABLE 13b
INCREASED TOTAL ANNUAL COST YEAR 2000
($ thousands)

Type	Model 1	Model 2	Model 3
Gasoline - medium	147,482	147,431	145,970
Diesel - medium	8,637	8,523	8,523
Gasoline - heavy	28,633	28,633	28,080
Diesel - heavy	1,900,886	1,878,459	1,877,717
Total for all types	2,085,638	2,063,046	2,060,290

These cost estimates do not include any fuel savings which may be brought about by the use of fan clutches. The costs increase from 1990 to 2000, because the total population increases and the percent of quieted trucks increases. In 1990, for example, with the three models used, there are 699,000 unquieted trucks (all over 10 years old) and in 2000 there are 24,000 unquieted trucks (all over 10 years old).

These cost increases are large in the absolute, but are not necessarily a large percentage of the cost of operating a truck nor of the annual revenue earned by a truck. For example, a for-hire heavy diesel truck averaging 50,000 miles a year with an average payload of 10 tons at a freight rate of $0.17 per ton-mile will earn $85,000 per year. The $532 annual cost per truck of operating as shown in model 3 is thus about 0.6% of total revenues. In the case of private carriers, in which the trucks are owned by a firm whose chief income is from a source other than trucking, the cost increase can be spread over an even larger income base.

Changes in truck ratail prices and operating costs could conceivably affect freight rates and the quantity of trucking services* supplied by the trucking industry. The elasticity of the quantity of trucking services with respect to the price of trucks is estimated to be between -.31 and -.18. Thus, if noise abatement increases truck retail prices by $1,000 (about a 4% increase), this could result

* "Trucking services" is here defined as the number of trucks times the average lifetime mileage per truck.

in a reduction in trucking "services" of 0.76 to 1.24%. This does not represent the decrease in trucking activity in terms of annual ton-miles of freight or annual revenue; rather, it is the reduction in the stocks of trucks and the increase in the lifetime miles a truck is driven.

A 4% increase for new trucks could theoretically result in a reduction in the stock of trucks of from 0.8% to 2.84%. In addition, the lifetime mileage per truck will increase by from 0.16% to 1.56%.

The reduction in the annual volume of freight carried by a truck will depend upon the percentage change in freight rates and the elasticity of demand for freight service. The elasticity of demand for freight service is assumed to be between -0.5 and -0.3. Depending upon the degree of competition within the trucking industry, the extent of competition from other modes, and the regulatory policy of the ICC, some part of any possible increased cost of trucking services will be passed on to shippers. This, of course, applies only to common carriers. For contract haulers, the ICC does not regulate rates but competition will likely still determine the amount of the cost passed on. In addition, private truck fleets operated by firms producing products other than transportation services may easily pass cost increases through in the form of higher prices for their products. The ability of a firm to recover increased trucking costs depends upon the elasticity of demand for the product and the ratios of trucking costs to total costs. All otherthings being equal, the larger the proportion of trucking cost to total cost, the more likely it is that the firm will absorb part of the increased trucking costs.

Clearly, these impacts may be different for different geographical regions, since the same products produced in different regions have different magnitudes of transportation inputs.

The impact of noise standards and the resultant equipment modifications that may be necessary upon all classes of truck users (i.e., line haul, contract, and private) would appear likely to be very small from the information resulting from the three models used, since the cost of noise abatement represents an increase of less than 1% in the annual cost of owning and operating a large diesel truck. The impact may be somewhat greater for smaller trucks; however, smaller trucks are found primarily in private fleets, which is the user class that should experience smallest impact.

The relatively small size of the cost increases can lead to the conclusion that the impact on the trucking industry and on freight rates will be negligible. This conclusion is further reinforced when it is considered that, in the case of model 3, costs have been depicted as an upper bound, or worst case scenario. The one segment of the industry that may be altered is the owner-operator (contract) group. Owner-operators tend to be credit-limited (i.e., have poorer credit ratings), have less sophisticated accounting contracts, pay higher prices for fuel and parts, and have poorer maintenance programs than fleet operators. Given these disadvantages, an increase in the price of trucking services (i.e., higher prices for new trucks and/or increased fuel and maintenance costs) may impact directly and severely on marginal producers. Trucking industry marketing specialists estimate, however, that the majority of owner-operators will not be adversely affected by the worst case shown in model 3.

Impacts on Industries Associated with Truck Manufacturers

Changes in the design of trucks and in the number of trucks sold will affect industries that supply goods and services to truck manufacturers.

Engine Manufacturers. The major diesel-engine manufacturers are large, financially sound companies with strong technical capabilities. They will likely find it advantageous and/or necessary to invest resources in development programs aimed at reducing engine noise. The specific product changes that each engine manufacturer could need to make for each of the noise level models used in this study are shown in Table A-2.

Because sales volume changes due to the noise emission standards hypothesized in the three models are relatively small, no substantial change in employment, number of operative plants, market shares, and profitability would be expected. Noisier vehicle engines will tend to be eliminated in time, but the associated production facilities and equipment are transferable to other vehicle models having quieter engines.

One large manufacturer of diesel engines estimates that three years could be required to modify the engine for compliance with the standards used in this study's model 2. The manufacturer could be at a competitive disadvantage in the truck diesel engine market for several years should standards such as those described for model 2 be Federally adopted. One possible result of this disadvantage could be a shift in sales emphasis on the part of the manufacturer toward non-truck markets, with a consequent increase in the competition's share of the truck market. This situation is discussed in detail in Appendix F.

Muffler Manufacturers. A change in the product mix of muffler sales will likely occur, if the noise standards require more technically sophisticated and higher-priced designs.

It is unlikely that the changes in truck volume forecasted would have a significant impact on muffler manufacturers, assuming adequate lead time for production realignments. No changes in market shares would be expected, since no muffler manufacturer is considered to be in any better competitive position than any other in relation to the noise standards that were modeled. The major muffler manufacturers have apparently included in their forward planning the possible impact of the Federal noise emission standards on their business; raw material shortages and capacity constraints do not appear likely to result from the noise standards modeled. No disruptive effects on the industry are anticipated, because sales volume reductions would probably be small.

Fan Clutch Manufacturers. Fan clutches are an integral part of the various noise control equipment options and strategies outlined in this analysis. Not only can fan clutches reduce noise but also result in significant fuel savings. A review of the past market acceptance of fan clutches puts the potential benefits of fan clutches in perspective.

Historically, most truck owners have not installed fan clutches or have not been able to take advantage of the fuel savings if they were installed. Fan clutches have had several technical and reliability problems that hampered their use; these problems are now considered to be solved. Truck owners who have installed fan clutches have preferred to increase speed and payload rather than save fuel due to the lowered power requirements.

Currently, approximately 5% of heavy duty trucks are fitted with fan clutches. It could be expected that most, and possibly all, medium and heavy duty trucks would include fan clutches under models 2 or 3. As a rough approximation, employment in the fan clutch industry could increase by 1,500 to 2,000 if this implication were realized.

In short, significant growth in the fan clutch market would appear likely, provided that historic resistance to fan clutches is overcome. Federal noise emission standards could very well provide the impetus to accelerate widespread fan clutch acceptance.

Truck Distributors. Channels of distribution and truck distribution operations would not be expected to change materially as a result of the noise emission standards modeled because sales volume changes would be relatively small. Some accelerated buying immediately before and after noise regulations become effective may occur as customers try to avoid potential price increases. However, this effect is expected to be minimal since the price increases apparent from the hypothetical standards modeled would be small in comparison to total truck retail price. Lowered distributor sales volume would be offset by higher dollar sales volume for quieted trucks and a potentially slight increase in truck rental and leasing. However, rental and leasing costs for quieted trucks could be expected to rise based on costs associated with quieting.

Truck retail price increases, under model 3 conditions, appear to be less than 5% of current prices. Generally, the requirement to finance this increased cost could be met by end users. At the same time, marginal credit operators will be somewhat more marginal. However, this level of price change, particularly with lead times of several years to allow for appropriate planning, would seem to be within the range which could be accommodated in the normal course of business, and hence result in no disruptive effects in the economy in general or related industries in particular.

IMPACTS ON THE NATIONAL ECONOMY

Transportation and Trucking in the U.S. Economy.

The total transportation sector within the U. S. economy has doubled since World War II, while truck transport has increased about sixfold. During this period, truck transport has grown from 82 billion ton-miles to 470 billion ton-miles. Truck transport accounted for 18.7% of the total ton-miles in 1970 and 81.3% of the total revenue. These figures indicate that trucks haul those products for which relatively high rates per ton-mile are charged.

Trucks are generally faster and more flexible than other modes of transport. The line haul speeds for trucks range from 40 to 55 mph, which is faster than any other mode except air freight. In addition, trucks provide door-to-door service.

The greater speed of truck transport, together with smaller volume for truckload shipments than for carload shipments by rail gives the trucking industry a strong competitive position. Speed reduces inventory costs by allowing firms to hold smaller inventories. This applies more to products having high value per unit weight than to bulky low-valued products.

In addition to the advantages trucks have as a primary means of transport, they are also complementary to other modes. For example, rail or water shipments are often brought to and from terminal facilities by trucks.

<u>Impacts on Exports.</u>

As models one and two illustrate, the extent of product modifications, will probably consist basically of specifying quieted components from vendors. Domestic truck producers would be able to export both quieted and unquieted products to foreign countries, depending on local foreign noise regulations. U.S. manufacturers will be in an improved competitive position in foreign markets that require quiet trucks since they will have experience in the application of noise technology to their products.

A different situation exists under model 3 conditions, however, because redesign of some truck models may be necessary. In the case of redesigned models, domestic producers may have to ship trucks incorporating at least some noise control measures and associated costs, even though the foreign market competition and regulations may not require quieted trucks. On the other hand, foreign markets that require trucks to meet, say, the standards used in model 3 probably would not provide enough volume themselves to economically cause truck manufacturers to quiet their vehicles to that level without the impetus of U.S. regulaton. In such circumstances Federal noise regulation will make American companies competitive where they would otherwise not have been.

Study of information from truck manufacturers indicates that they expect no changes in export patterns due to Federal noise regulations.

Impacts on Imports.

Imports are not a large factor in the U.S. market for medium and heavy duty trucks. The general reputation of medium and heavy duty trucks of foreign manufacture isthat they do not have the quality to stand up to the tough line-haul conditions prevalent in the U.S. It seems unlikely that Federal noise regulations will alter the position of imports within the U.S. market.

However, the United States has the largest motor vehicle market in the world, which has attracted intense import competition. The heavy duty truck market appears to have good growth potential and may well attract import competition regardless of the noise standards.

It is, of course, possible that a foreign manufacturer may develop technology that could result in significant noise reduction from medium and heavy trucks. In such a case that technology could establish a new "available technology achievable at reasonable cost" base from which Federal regulations could be derived. This would potentially offer a unique and highly competitive advantage to foreign manufacturers and a new door to American markets unless such technology was competitively adopted by U.S. firms.

Impacts on Balance of Trade. Based on the foreign trade factors above, models 1, 2 and 3 indicate that no probable material impact on the balance of trade would be anticipated.

Summary

This economic study, based on the three hypothical models cited, indicates that the anticipated overall economic impact of the various modeled noise regulatory levels on the truck manufacturing industry, and industries dependent on trucks, would be expected to be low. The following summarizes the impacts postulated from each of the three models employed. Generally, the amount of cost increases and levels of change in the industry volume are estimated as low. As a result, disruptive impacts are not anticipated in most cases.

1. Model 1 - 1977. Cost changes and volume changes from baseline conditions are minor. Industry would be expected to continue its present growth pattern. No unemployment is anticipated, nor are any disruptive impacts.
2. Model 2 - 1981. No disruptive impacts are indicated if a six-year lead time is provided. The time is adequate to quiet "noisy" engines by using immediatley available technology. Additionally the development of lower-cost techniques would be possible and the economics of doing so might even indicate that such development would be likely. Volume changes and increased costs would not appear to have a significant impact

on industry activity. No unemployment or adverse impacts would be anticipated.

3. Model 2 - 1978. The three-year lead time has the potential for some limited market disruption as some vehicles could have to be removed from production due to inability to meet the standards. This may be attenuated overall, however, by increased production of other models.

4. Model 3 - 1983. Changes in volume and higher costs than for either models 1 or 2 could be anticipated. The eight-year period hypothesized as being available for planning and making adjustments for the growth of the industry over the period would apparently be sufficient to avoid disruptive impacts. The modest volume changes from the baseline forecasts and the continued growth of industry would indicate no disruptive impacts. No unemployment would be anticipated.

REFERENCES FOR SECTION 7

1. A. T. Kearney, Inc. "A Study to Determine the Economic Impact of Noise Emission Standards in the Medium and Heavy Duty Truck Industry," 1974.

2. Bender, E. K. and W. N. Patterson. "The Technology and Cost of Quieting Medium and Heavy Trucks," BBN Report No. 2710, 1974.

3. Fax, G. E. "Costs of Operating Quiet Trucks," BBN Tech Memo No. 190, 1974.

4. <u>Oil and Gas Journal</u> Petroleum Publishing Co., Tulsa, Okla., March 11, 1974.

5. U.S. Department of Commerce, Bureau of the Census, "1972 Truck Inventory and Use Survey" (magnetic tape), 1972.

SECTION 8

TRUCK ACOUSTIC ENERGY CHANGES AND LEAD TIME REQUIREMENTS

This section examines the effects of possible alternative new truck noise standards, using the three models described earlier, to endeavor to ascertain (1) the change in acoustic energy generated by the future truck population and (2) the projected lead times to achieve the varying modifications in production line truck design.

FUTURE CHANGES IN ACOUSTIC ENERGY LEVELS

The effects of possible alternative new truck noise standards as shown throughout the three models and depicted in Table 8-1 on the future acoustic energy generated by trucks with a GVWR in excess of 10,000 pounds are analyzed in this study. Taken into account are the distributions of trucks likely to be in use in future years, by gross vehicle weight rating, type of engine, age, and annual mileage. This makes it possible to estimate the possible change in the future acoustic energy from such trucks along typical highways.

TABLE 8.1
ALTERNATIVE PRODUCTION NOISE LIMITS, dB(A)

New Truck Model Year	Option 1 Gasoline	Option 1 Diesel	Option 2 Gasoline	Option 2 Diesel	Option 3 Gasoline	Option 3 Diesel
1977	83	83	83	83	83	83
1978	80	80	83	83	83	83
1979	80	80	80	83	83	83
1980	80	80	80	83	83	83
1981	75	75	75	80	80	80
1982	75	75	75	80	80	80
≥ 1983	75	75	75	75	75	75

Data utilized in development of the models used are premised on the following: that for any given calendar year, the truck generated acoustic energy along a typical highway will be the "mileage-weighted" summation of the product of (a) the acoustic energy produced by each category and model year of truck, (b) the number of such trucks registered, and (c) the annual mileage such trucks are driven. Annual mileage is explicitly considered because it affects the frequency with which a truck of a given category and age is encountered on the highway. For the purposes of these calculations, it is assumed that no truck noise control retrofit program is in effect, so that each truck produces the same noise level over its entire lifespan.

Thus, to assess the impact of alternative regulatory options on future changes in the acoustic energy generated by trucks, it will be necessary to know:

1. The mean peak noise level produced on the highway by truck model year for each category of truck
2. The total truck production by truck model year for each category of truck
3. The fraction of trucks still in use as a function of truck age for each category of truck
4. The average annual mileage as a function of truck age for each category of truck.

Each of these aspects, as it is related to calculation of the acoustic energy generated by trucks for any future calendar year, will be considered.

The mean peak noise levels, measured at 50 feet from the highway, which are projected to be produced in the future by various categories of trucks traveling at highway speeds are summarized in Table 8-2 as a function of the new truck noise levels considered in the three alternative models.

TABLE 8.2
MEAN PEAK NOISE LEVEL AT 50 FEET

	Regulated New Truck Noise Level	Highway Noise Levels: Medium Duty Gasoline	Medium Duty Diesel	Heavy Duty Gasoline	Heavy Duty Diesel
	None	84 dB(A)	87 dB(A)	87 dB(A)	89 dB(A)
Model 1	(83 dB(A))	84	84	84	84
Model 2	(80)	82	82	82	82
Model 3	(75)	79	79	79	79

The highway noise levels assumed for all unregulated trucks are mean noise levels computed from measurements obtained for EPA by contractors. Noise levels assumed for future regulated new trucks reflect the fact that, as propulsion noise of trucks is reduced by new truck noise regulation, tire noise will constitute an increasingly larger contribution to a truck's highway noise level.

The total new truck production projected for truck model years are summarized in Table 8-3. Total figures for 1961 through 1972 are actual production figures reported by the Motor Vehicle Manufacturers Association (MVMA), excluding buses and exported trucks, but including imported trucks from Canada (Reference 1).

The truck production figures for 1960 and before are weighted sums of previous production figures adjusted in accordance with the truck survival rate model described below to produce the estimated number of such trucks still in use as of 1972. Production figures for 1973 and beyond are based on estimates of truck production growth rates (Reference 2). For example, it is assumed that medium duty gasoline engine truck production will grow by 1.4% per year and that heavy duty diesel engine truck production will grow by 4.3% per year.

The fraction of trucks still in use as a function of truck age can be determined by generating a survival rate model for each category of trucks. Truck production data (Reference 2) and registration data (Reference 3) have been used to develop a truck survival rate curve for heavy duty diesel engine trucks. This survival rate curve is shown in Figure 8-1. For other categories of trucks, the Census truck registration data does not correspond well with the MVMA truck production data. For example, the MVMA reports that in 1971, 193,000 medium duty gasoline engine trucks were produced (excluding buses and exports but including imports from Canada). The 1972 Census data, however, show that 295,000 such trucks were registered. Thus 53% more trucks were registered than were produced. In view of the fact that all medium duty gasoline truck-tractors appear as heavy duty trucks in the Census data, it has been concluded that a substantial number of trucks with GVWR below 10,000 lbs are probably appearing as medium duty trucks in the Census data. Because of this type of inconsistency in the truck production versus registration data, the truck survival rate obtained for heavy duty diesel engine

TABLE 8-3

ANNUAL PRODUCTION OF TRUCKS (IN THOUSANDS)

Model Year	Medium Duty Gasoline	Medium Duty Diesel	Heavy Duty Gasoline	Heavy Duty Diesel
≤1960	1473	1	427	124
1961	177	1	34	24
1962	211	3	30	35
1963	222	4	39	43
1964	205	9	36	47
1965	228	9	41	63
1966	228	6	45	77
1967	189	5	39	64
1968	199	5	42	78
1969	219	3	41	96
1970	178	3	40	88
1971	193	3	38	98
1972	245	3	39	126
1973	198	3	40	133
1974	200	3	40	144
1975	202	3	40	155
1976	204	3	40	165
1977	207	3	39	174
1978	210	3	38	185
1979	213	3	38	195
1980	216	3	39	205
1981	219	3	39	214
1982	222	3	39	225
1983	225	3	39	236
1984	229	3	39	248
1985	232	4	39	260
1986	234	4	38	274
1987	237	4	38	288
1988	241	4	38	302
1989	244	4	37	317
1990	248	4	37	333
1991	251	4	36	350
1992	255	4	35	367
1993	258	4	34	385
1994	262	4	33	404
1995	266	4	32	425
1996	270	4	33	443
1997	274	4	34	462
1998	277	4	36	481
1999	281	4	37	502

trucks has been assumed to apply to all other categories of trucks as well.

The average annual mileage for various categories of trucks as a function of truck age were also obtained from projections based on the Truck Inventory and Use Survey Data. Table 8-4 shows the projected annual mileage per truck for each category being considered as a function of the age of the truck.

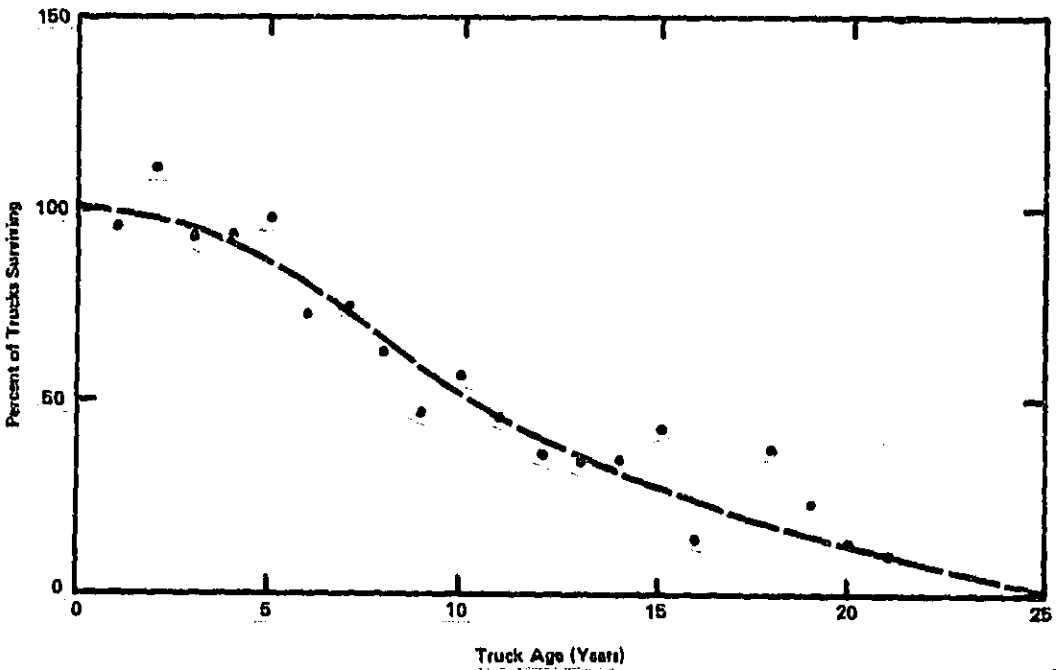

Figure 8-1 Percentage of Heavy Duty Diesel Trucks Surviving as a Function of Age.

Discussion of the Truck Inventory and Use Survey Data and the analysis used in obtaining the acoustic energy generated by trucks, the total and components of the truck population, the survival rate, and the annual mileage estimates for trucks may be found in Appendix O.

TABLE 8-4
ANNUAL MILEAGE PER TRUCK (IN THOUSANDS)

Age of Truck	Medium Duty Gasoline	Medium Duty Diesel	Heavy Duty Gasoline	Heavy Duty Diesel
1 Year	23	30	33	73
2	20	27	29	67
3	16	24	25	61
4	13	22	21	55
5	11	19	18	50
6	10	17	16	45
7	9	15	15	40
8	8	13	13	37
9	7	12	12	34
10	7	11	10	31
11	6	10	9	28
12	6	9	8	25
13	5	8	7	22
14	5	7	6	20
15	5	7	6	18
16	4	6	5	16
17	4	5	5	15
18	4	5	4	14
19	4	5	4	13
20	3	5	3	12
21	3	5	3	12
22	3	5	3	11
23	3	5	3	10
24	3	5	3	10
25	3	5	3	10

The results of this study of the projected changes in the acoustic energy generated by trucks with GVWR in excess of 10,000 lbs are shown in Figure 8-2. The acoustic energy level refers to the 1972 acoustic energy of such trucks. Note that for any new truck regulation, the increasing truck population produces an increase in

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acoustic energy level of approximately 1 dB every 5 years. On the other hand, with all of the three models employed for this study, the the acoustic energy level continues to decrease until approximately 1992. Actually, as older, noisier trucks are retired, the individual noise level of the average truck on the highway will continue to decrease until about the year 2000. However, the assumed growth rate in new truck production eventually outweighs the rate of older, noisier trucks being retired, causing the acoustic energy level to begin increasing again in about 1995. Finally, note that both models 2 and 3 indicate nearly identical results. This is because the dominant contribution to the acoustic energy level comes from heavy duty diesel engine trucks that are regulated similarly in both models 2 and 3. The maximum difference in acoustic energy level between models 1 and 3 is about 1 dB, which occurs around 1985.

In assessing the relative merits of alternative new truck noise levels in terms of the acoustic energy generated, it is important to observe how the truck population component for a given production period in years builds up and/or decays as a function of calendar year. Figures 8-3 through 8-5 show these results for new truck production in the context of the three models studied. It is also instructive to note the total truck-miles driven by the various truck population components as a function of calendar year. This relationship is shown in Figure 8-6 in the context of model 3. A comparison of Figure 8-6 with Figure 8-5 reveals that the total truck-miles contribution of a given truck population component decays more rapidly than its contribution to total truck population.

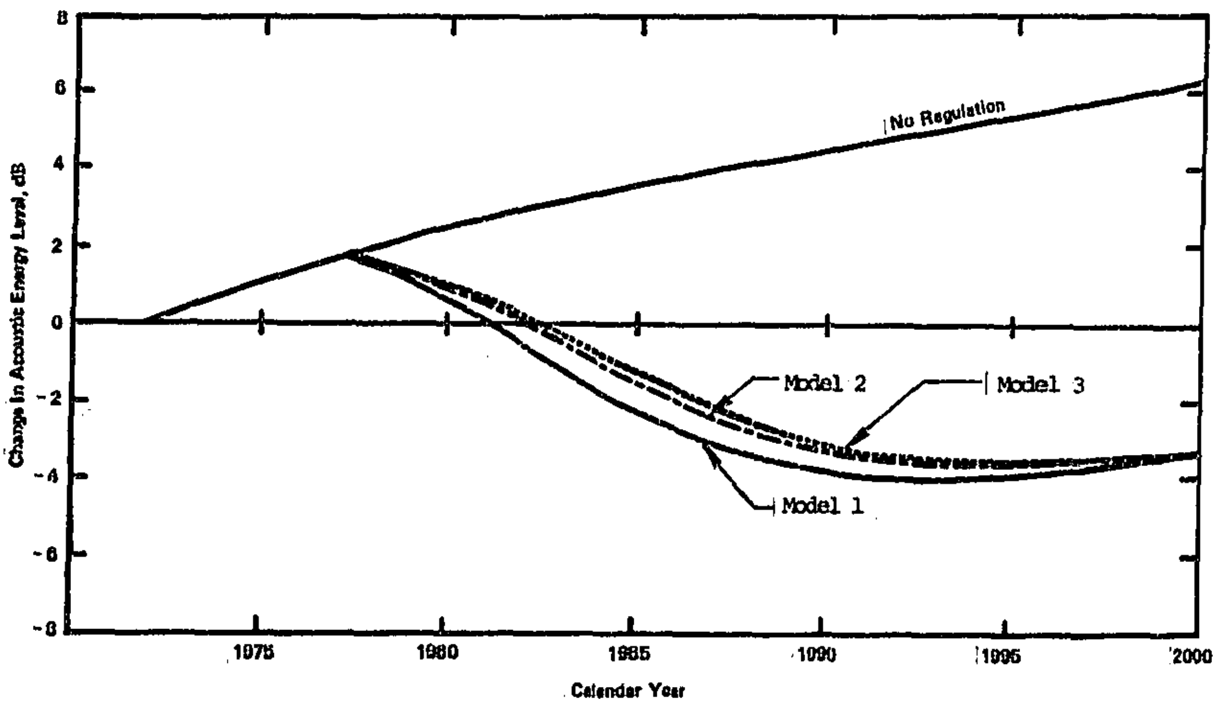

Figure 8-2 Changes in Mileage-Weighted Acoustic Energy Level.

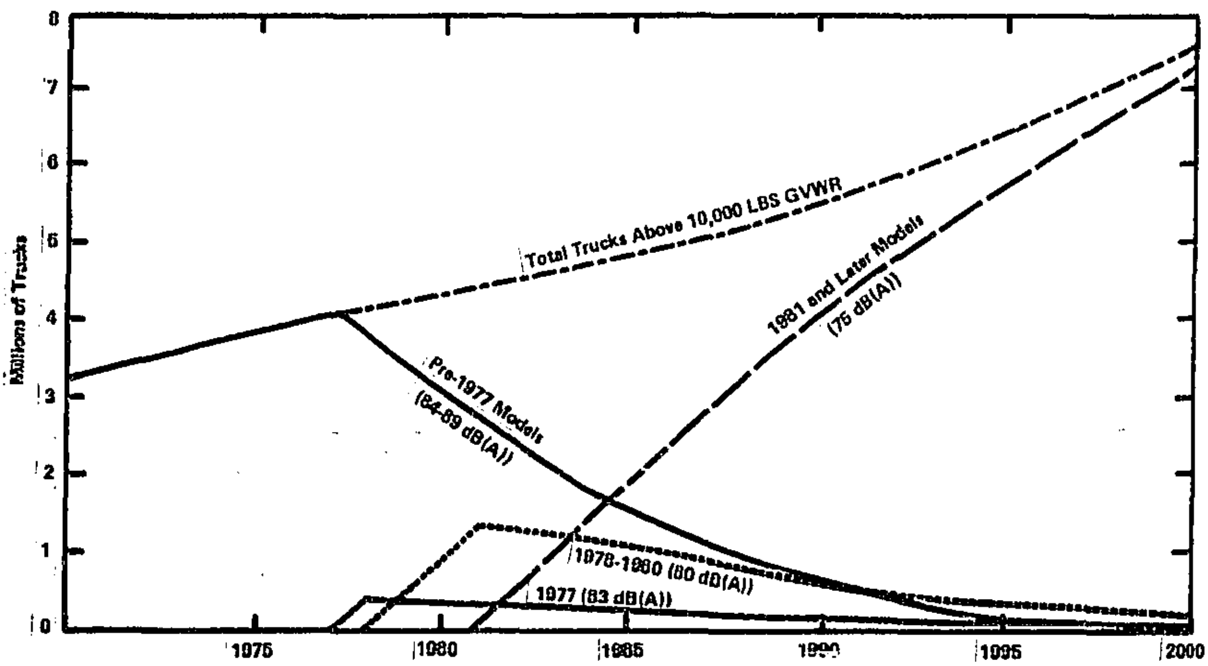

Figure 8-3 Truck Population Components by Truck Model Years - Model 1.

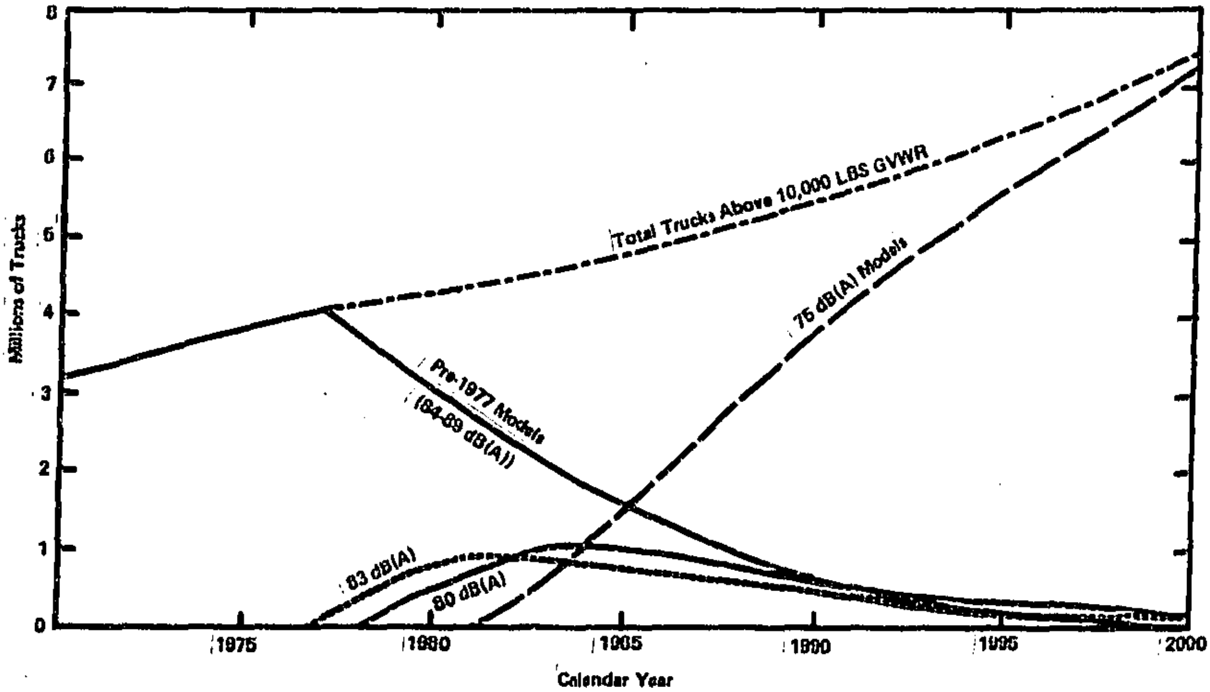

Figure 8-4 Truck Population Components by Truck Model Years - Model 2

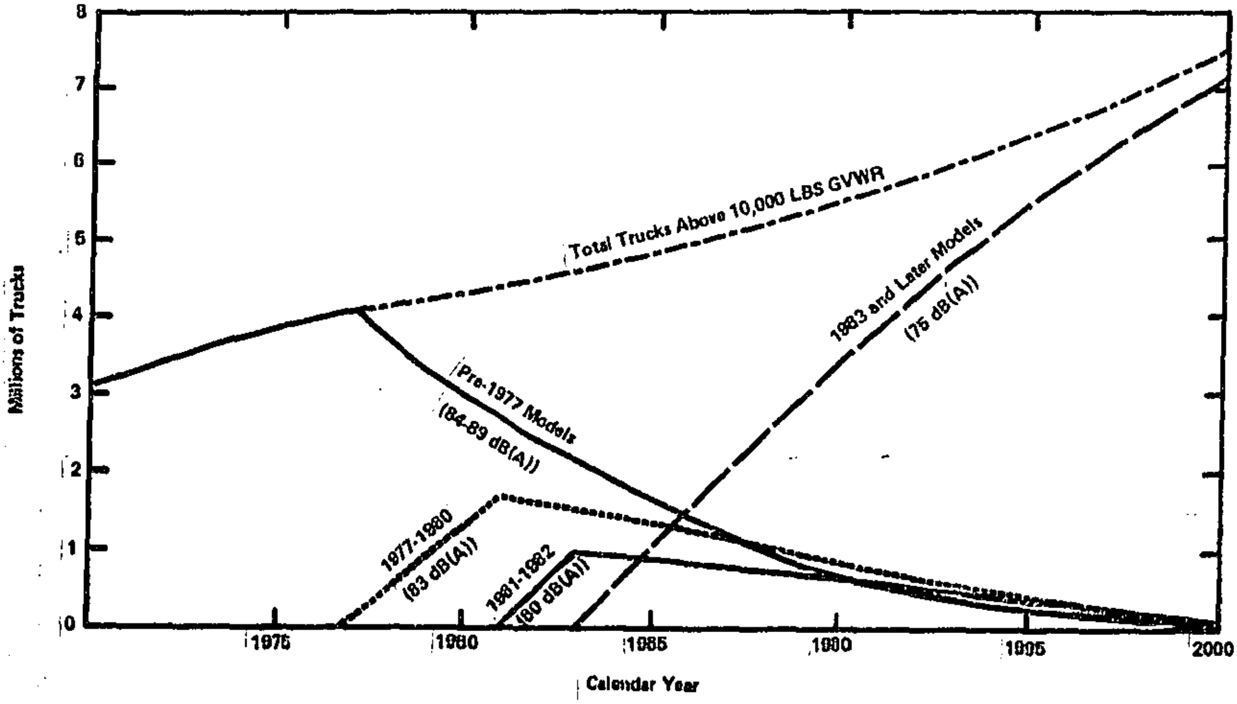

Figure 8-5 Truck Population Components by Truck Model Years - Model 3.

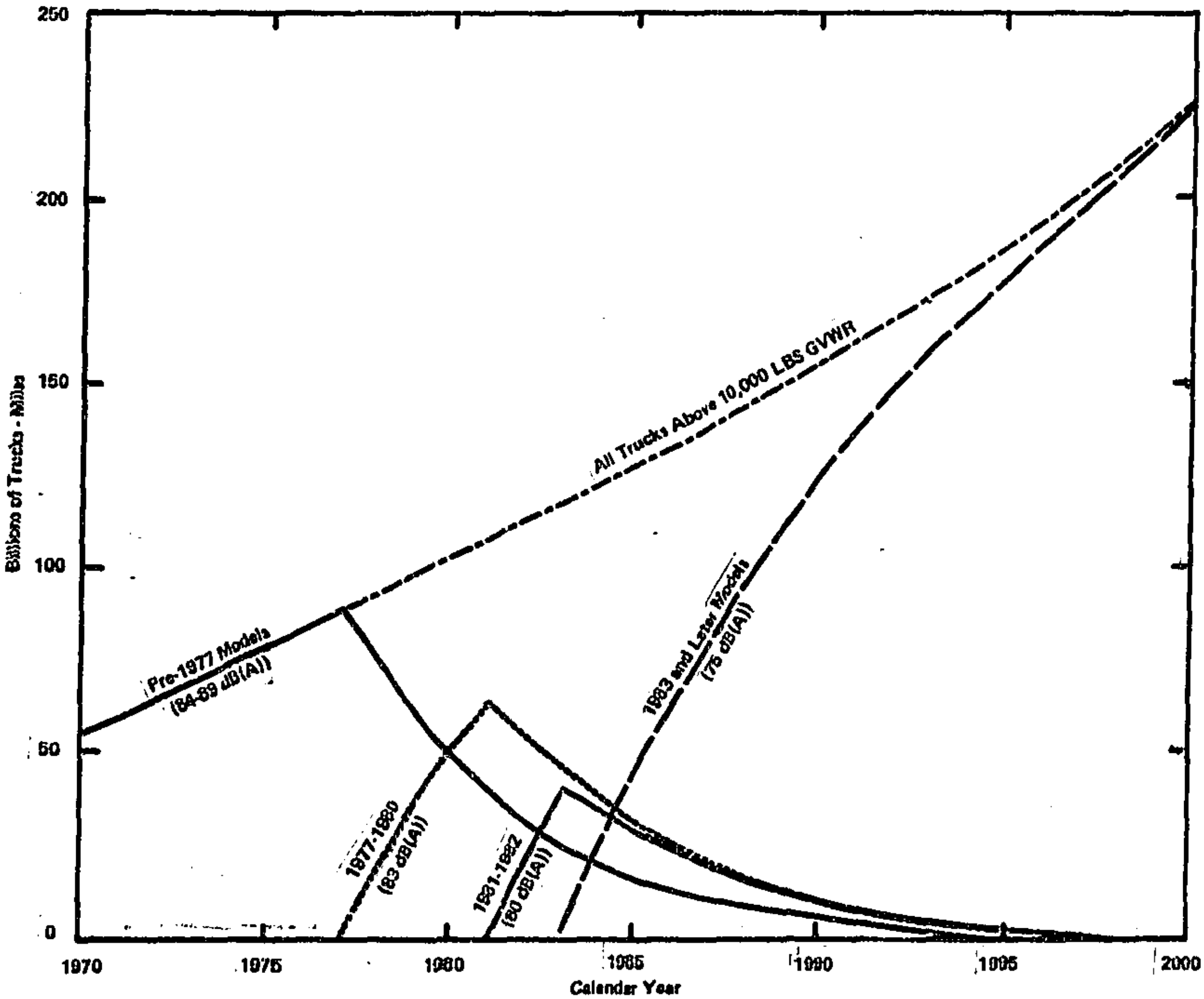

Figure 8-6 Breakdown of Total Truck-Miles by Truck Model Years - Model 3.

LEAD TIME REQUIREMENTS

The period between the introduction of a design goal for a product and the time the design goal is met is often termed "lead time." The actual length of time is directly related to the complexity and the resources available to implement the new designs. In general the sequence of events involved in modifying a new production truck is as follows. First, a design goal is usually selected on the basis of market or legislative pressure. The engineering groups responsible for the respective truck components then examine the design problem for possible solutions. Promising solutions are then either in a prototype version or modeled for testing and evaluation. Finally, one or more solutions are selected for complete product analysis and testing. This often includes a field test of durability.

The complexity of noise control design changes may be classified into two basic modes of engineering operations. For changes in the peripheral engine system (such as mufflers, air filters, cooling fans, and the like), noise control solutions would be implemented by modifying present production trucks; i.e., by specifying certain exhaust systems, air filters, fan configurations, and pulley sizes. Such modifications are made via an "engineering change order." For changes in the basic frame or cab configuration (such as partial enclosures or larger radiators), a complete design sequence could well be required, including some reliability testing.

The lead time required for either category of design changes varies with the complexity of the change and available staff, but some estimates may be made. It would appear that from 30 to 180 days are necessary for most manufacturersfor an engineering change order to be completed. The length of time required for a major new design varies for normal production and assembly planning from 1 to 4 years. In general, enclosing the engine could require cab modifications that could take as much as a yearfor each cabmodel offered. Discussions with manufacturers indicate that a 1-year lead time is adequate in terms of being nondisruptive of regular production, but that extensive overall truck redesign could require up to a full 4-year period. An example of a 4-year development cycle is given in Reference 4. Figure 8-7 has been reproduced from this reference. Concurrent development of similar noise control options could shorten the overall lead time for a complete product line.

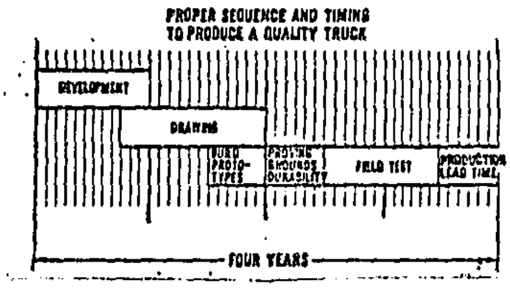

Figure 8-7 Estimated Lead Time for Redesigning a Truck.

Source: Reference 4.

An additional factor in lead time is engineering staff size and capability. All truck manufacturers have an engineering staff whose size is generally proportional to sales volume. Consequently, the larger companies have bigger staffs with more specialized capabilities, including staff specialized in noise control. The smaller companies may be dependent on their vendors for noise control to a greater degree than will the larger firms. Also, smaller companies will tend to rely on copying the noise control designs used by the more advanced companies or those described in the open literature. The increased lead time over large firms required by the smaller manufacturers is compensated for in part by the relatively fewer models they produce. Thus, while a large firm may have eight different cab designs to change, the small firm may have only three cab designs to change.

Varying lead times have been studied in terms of the noise levels for new trucks considered in the three models' scenarios. At each noise level, the complexity of the change and the capabilities required to achieve certain noise analyses and reductions are discussed.

More than 30% of present production trucks have noise levels less than 83 dB(A). Although this is a significant number of trucks reflecting some manufacturers' apparent efforts to comply with the State of California limit of 83 dB(A), which becomes effective in 1975, many models must be fitted with quieter exhaust systems, cooling fans, and engine noise control packages. All these modifications can be implemented by engineering change orders. The necessary engine exhaust systems appear to be available. Noise control packages are also apparently available at this time for those engines that would require them to meet the California standard.

The primary design problem will be to modify the cooling fan. All truck manufacturers purchase the fans from vendors; consequently, in an attempt to quiet fan noise, they will typically buy a "quiet" fan. However, fan noise is as much a function of a fan's environment as its design. At the present time, certain techniques are available that consistently reduce cooling fan noise; i.e., using larger diameter,, slower rotating fans with proper shrouding. In addition, the radiator shutters may require replacement by a bypass type of water temperature control, or be operated in conjunction with a thermostatically controlled fan such that the fan never operates with the shutters closed.

To incorporate the modifications that may be necessary to continue to produce essentially the same trucks now being produced, but all of which can satisfy an 83 dB(A) noise level, appears to be feasible within 1 to 2 years from the date of promulgation of an 83 db(A) standard. Most truck manufacturers indicate that nationwide compliance with an 83 dB(A) level could be achieved by the 1976 model year, with no significant disruptions in production. This was assuming that new truck noise regulations were promulgated in the fall of 1974. There are indications, however, that even without a Federal standard of 83 dB(A) in 1974, the majority of trucks produced in the 1976 model year will be able to meet that level.

Of the trucks measured for sound level, 1% are now at noise levels under 80 dB(A). Engine noise is a prime candidate in the quieting strategy for meeting this level, and certain currently popular diesel engines will likely require some sort of enclosure to meet it. Thus, the lead time necessary for a given truck to be produced which meets the 80 dB(A) level will vary depending on the engine. To accommodate these differences, truck lead times will be discussed in terms of gasoline engines, "quiet" diesel engines, and "noisy" diesel engines.

For gasoline engines, which power 65% of all new medium and heavy duty trucks, engine and exhaust noise do not appear to be significant problems and no major cab redesign is anticipated, other than possible modification of the radiator. Thus, gasoline engine new trucks could reasonably be assumed to be able to be quieted to meet an 80 dB(A) level in the same time span as for an 83 dB(A) level, that is, 1 to 2 years from the effective regulation date.

The quieter diesel engines, which are incoporated in about 23% of the trucks currently produced, could need noise control covers or kits to obtain the necessary reduction in engine noise. Such kits are not presently available for all these engines. Some development work could be required for this effort; however, it is not believed that this would be a major development program, but rather the adaptation of similar kits from one engine model line to another, or the development of acoustically treated covers and panels. Two to three years appear adequate for such comprehensive development, which would appear to encompass all models of vehicles now being produced. During this period it may also be necessary for some truck manufacturers to apply underhoodacoustic treatment. Similarly, some cooling system designs could require a modest refinement effort of from

2 to 3 years. Exhaust systems are now generally available to meet the 80-dB(A) level. All these measures can, therefore, be relatively easily accomplished to provide the necessary production capacity parts and installation within a maximum of 3 years of promulgation of a regulation requiring 80 dB(A).

The noisier diesel engines, which constitute about 12% of current truck production, will most likely require cab redesign in the form of a partial engine enclosure, or development of engine quieting techniques to reduce engine noise. This would be considered a major redesign and a design sequence similar to that illustrated in Figure 8-7 would be necessary. Cab redesign would probably include enlarging the cab tunnel or underhood area to accommodate sound-absorptive treatment and larger radiators. Accordingly, about 4 years could be needed to develop a new cab, keeping within a normal, that is non-disruptive, production planning and implementation cycle. Most manufacturers offer several truck models each of which could require individual major redesign. Unlike automobiles, such truck redesign is not normally done annually; however, by staggering design efforts at, say, one year intervals, three cabs could be redesigned in about 6 years with more efficient utilization of engineering staff than would be possible with parallel efforts and, consequently, even less cost impact than would reasonably be expected to result if a shorter period of time were required.

An alternative solution to truck redesign would be for the manufacturers of noisy engines either to quiet them with noise control covers or kits or with structural or combustion modifications. One major engine manufacturing company indicated that if quiet engines were required, it would provide them to its customers. Assuming that this company does have the ability to quiet its engines within a 3-year lead time, then major cab redesign would not be required and the lead time for trucks with these engines would be the same as for the quieter diesel engines; i.e., 3 years from the date of promulgation of and 80 dB(A) standard.

Freightliner currently is operating on the highway a 72 dB(A) prototype developed under the DOT Quiet Truck Program. Other manufacturers have built prototype test trucks with overall noise levels as low as 72 dB(A), but have not operated them extensively on the highway.

Quieting strategies and lead times which may be necessary for limiting truck noise to 75 dB(A) are again appropriately discussed according to whether new production trucks are powered by gasoline engines, quiet diesel engines, or noisy diesel engines. Some diesel engines (approximately 5% of the current total new truck production) are only slightly noisier than gasoline engines. Quieting techniques could be developed using present production line technology to reduce their engine source level to less than 70 dB(A). These engines could then be used to power trucks built without enclosures. It is believed that the nondisruptive lead time would be on the order of that for 80 dB(A) trucks, but, with added time allowed to develop the engine noise control covers and kits, mufflers, and fan systems. This assumes 2 years to refine certain mufflers to obtain a 68 dB(A) source level, a concurrent one-year period to develop engine noise control kits, and a two-year development time by manufacturers for the fan and all other systems. If a maximum total lead time for both large and small manufacturers of about six years was allowed, following promulgation of a 75-dB(A) standard, no significant disruptive effects would be anticipated within the truck manufacturing or parts industry. That is, small manufacturers could perform three successive model changes in six years and larger firms with additional resources could do some of the work concurrently.

Noisy diesel engines will in all likelihood require enclosures. Allowing two additional years for enclosure development beyond that required to meet 80 dB(A), the redesign of current production noisy trucks to meet a 75-B(A) level could take about 8 years. However, new developments in diesel engine technology, such as better covers for existing engines or improved structural design, could reduce this lead time considerably.

In summary, the lead times required by truck manufacturers to quiet their products are best classified by the engine used in the truck. The most difficult quieting problem, and consequently that contributing most to establishing the production lead time, is engine structural noise. Table 8-5 lists the estimated lead times required by all truck manufacturers to ensure that all trucks produced will meet the specified noise levels. Lead times are defined as starting from the date of promulgation of a standard.

TABLE 8-5

ESTIMATED LEAD TIMES FOR TRUCK PRODUCTION

Noise Level	Gasoline Engines	"Quiet" Diesel Engines	"Noisy" Diesel Engines
83 dB(A)	1-2 years	1-2 years	2 years
80 dB(A)	3 years	3 years	6 years
75 dB(A)	6 years	6 years	8 years

REFERENCES FOR SECTION 8

1. "1973 Motor Truck Facts," Motor Vehicle Manufacturers Association, 1973.

2. "A Study to Determine the Economic Impact of Noise Emission Standards in the Medium and Heavy Duty Truck Industry," A. T. Kearney Report (Draft), April 1974.

3. "1972 Truck Inventory and Use Summary" (Magnetic Tape), U. S. Department of Commerce, Bureau of the Census, 1972.

4. "Proceedings of the Conference on Motor Vehicle Noise," General Motors Corporation Report, June 1973.

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SECTION 9

MEASUREMENT METHODOLOGY

INTRODUCTION

The procedure for determining whether or not a new truck complies with a prescribed noise level involves two basic elements, namely: a method for performing a test on a selected truck and a method for selecting trucks. This section deals with the testing of selected trucks, while section 10 discusses a possible selection process.

Several tests currently in existence were considered by the E.P.A. as methods for testing new production trucks. The Society of Automotive Engineers test designated SAE-J366-b seems to be the only test available with a sufficient data base to permit its consideration as a test that could be utilized effectively in the near term without extensive further evaluation as to its efficacy. It is described in detail in the following paragraphs.

LOW-SPEED, HIGH ACCELERATION TEST

Introduction

This test establishes the procedure, environment, and instrumentation for determining the maximum exterior sound level for motor trucks, truck tractors, and buses, when they are operated under conditions of low speed (under 35 mph) and high acceleration.

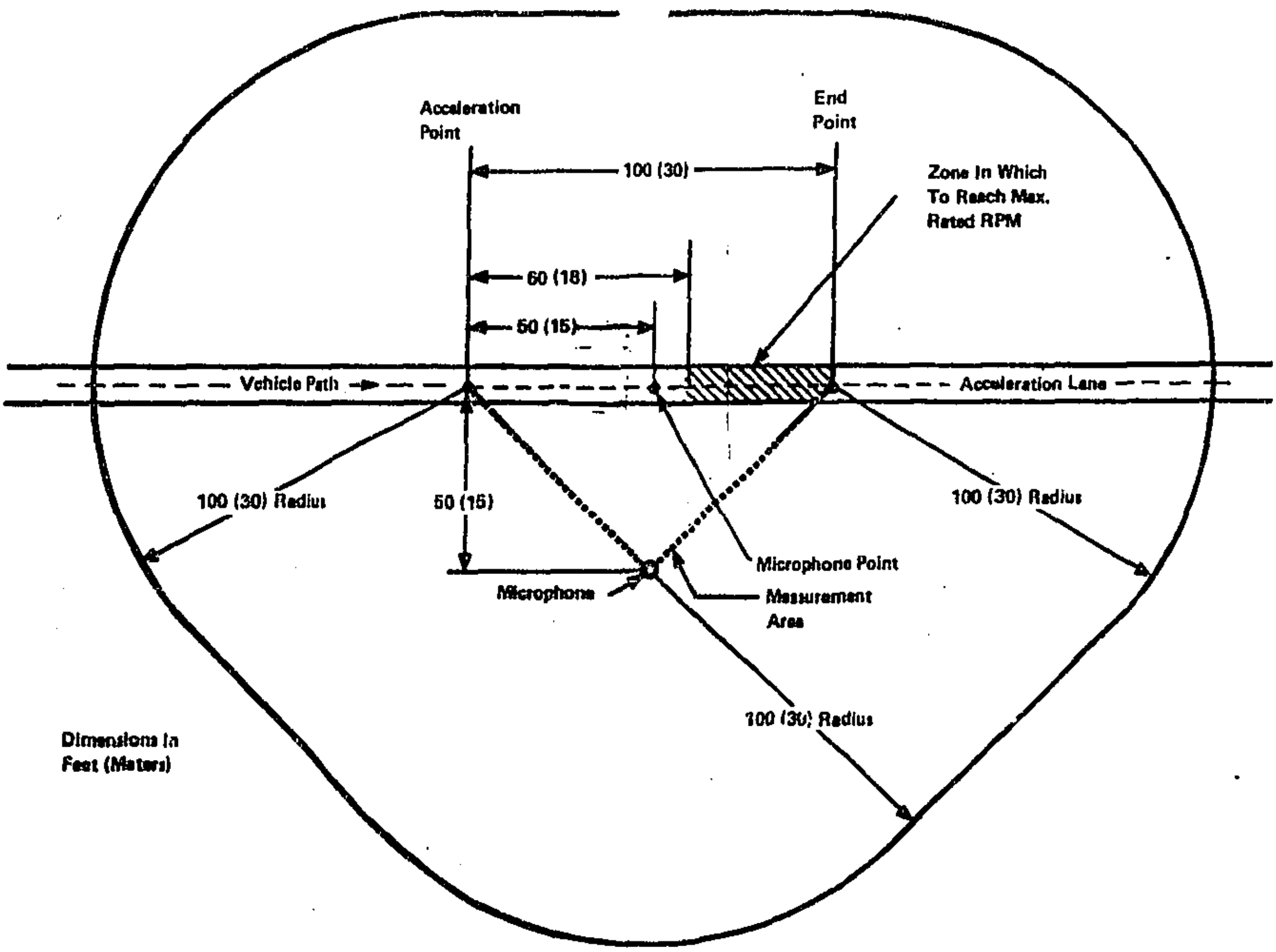
Instrumentation

The following instrumentation shall be used, where applicable, for the measurement required.

1. A sound level meter which meets the Type 1 requirements of ANSI S1.4-1971, Specification for Sound Level Meters.
2. As an alternative to making direct measurements using a sound level meter, a microphone or sound level meter shall be used with a magnetic tape recorder and/or a graphic level recorder or indicating meter, providing the system meets the requirements of SAE J184.
3. A sound level calibrator.
4. An engine-speed tachometer.

Test Sites

1. A suitable test site shall consist of a level open space free of large reflecting surfaces, such as parked vehicles, signboards, buildings, or hillsides, located within 100 ft (30 m) of either the vehicle path or the microphone. See Fig. 9-1.
2. The microphone shall be located 50 ft (15 m) from the centerline of the vehicle path and 4 ft (1.2 m) above the ground plane. The normal to the vehicle path from the microphone shall establish the microphone on the vehicle path.
3. An acceleration point shall be established on the vehicle path 50 ft (15 m) before the microphone point.
4. An end point shall be established on the vehicle path 100 ft (30 m) from the acceleration point and 50 ft (15 m) from the microphone point.



F... ..1 Minimum Undire... ... Test Site

5. The end zone is the last 40 ft (12 m) of vehicle prior to the end point.
6. The measurement area shall be the triangular area formed by the acceleration point, the end point, and the microphone location.
7. The reference point on the vehicle, to indicate when the vehicle is at any of the points on the vehicle path, shall be the front of the vehicle except as follows:
   a. If the horizontal distance from the front of the vehicle to the exhaust outlet is more than 200 in (5080 mm), tests shall be made using both the front and rear of the vehicle as reference points.
   b. If the engine is located rearward to the center of the chassis, the rear of the vehicle shall be used as the reference point.
8. During measurement, the surface of the ground within the measurement area shall be free from powdery snow, long grass, loose soil, and ashes.
9. Because bystanders have an appreciable influence on meter response when they are in the vicinity of the vehicle or microphone, not more than one person, other than the observer reading the meter, shall be within 50 ft (15 m) of the vehicle path or instrument, and that person shall be directly behind the observer reading the meter, on a line through the microphone and the observer.

10. The ambient sound level (including wind effects) coming from sources other than the vehicle being measured shall be at least 10 dB(A) lower than the level of the tested vehicle.
11. The vehicle path shall be relatively smooth, dry concrete or asphalt, free of extraneous material such as gravel.

Procedure

1. Vehicle operation - full throttle acceleration and closed throttle deceleration tests are to be used. A beginning engine speed and proper gear ratio must be determined for use during measurements.
2. Select the highest rear axle and/or transmission gear ("highest gear" is used in the usual sense; it is synonymous to the lowest numerical ratio and an initial vehicle speed such that at wide-open throttle the vehicle will accelerate from the acceleration point):
3. a. Starting at no more than two-thirds (66%) of maximum rated or of governed engine speed.
   b. Reaching maximum rated or governed engine speed within the end zone.
   c. Without exceeding 35 mph (56 km/h) before reaching the end point.
4. Should maximum rated or governed rpm be attained before reaching the end zone, decrease the approach rpm in 100 rpm increments until maximum rated or governed rpm is attained within the end zone.

5. Should maximum rated or governed rpm not be attained until beyond the end zone, select the next lower gear until maximum rated or governed rpm is attained within the end zone.

6. Should the lowest gear still result in reaching maximum rated or governed rpm beyond the permissible end zone, unload the vehicle and/or increase the approach rpm in 100 rpm increments until the maximum rated or governed rpm is reached within the end zone.

7. For the acceleration test, approach the acceleration point using the engine speed and gear ratio selected in paragraph 4.1.1 and at the acceleration point rapidly establish wide-open throttle. The vehicle reference shall be as indicated in paragraph 3.7. Acceleration shall continue until maximum rated or governed engine speed is reached.

8. Wheel slip which affects maximum sound level must be avoided.

9. For the deceleration test, approach the microphone point at maximum rated or governed engine speed in the gear selected for the acceleration test. At the microphone point, close the throttle and allow the vehicle to decelerate to one-half of maximum rated or of governed engine speed. The vehicle reference shall be as indicated in paragraph 9.3.7. If the vehicle is equipped with an exhaust brake, this deceleration test is to be repeated with the brake full on immediately following closing of the throttle.

Measurements

1. The meter shall be set for "fast" response and the A-weighted network used.

2. The meter shall be observed during the period while the vehicle is accelerating or decelerating. The applicable reading shall be the highest sound level obtained for the run. The observer shall rerun the test if unrelated peaks should occur due to extraneous ambient noises. Readings shall be taken on both sides of the vehicle.

3. The sound level for each side of the vehicle shall be the average of the two highest readings within 1 dB of each other. Report the sound level for the side of the vehicle with the highest readings.

General Comments

1. Measurements shall be made only when wind velocity is below 12 mph (19 km/hr).

2. Technically trained personnel shall select the equipment to be used for the test measurements and the tests shall be conducted only by persons trained in the techniques of sound measurement.

3. Proper usage of all test instrumentation is essential to obtain valid measurements. Operating manuals or other literature furnished by the instrument manufacturer shall be referred to and shall be the principal reference for both recommended operation of the instrument and precautions to be observed, except where they may be in conflict with the E.P.A. prescribed procedures, in which case the latter shall govern. Specific items to be considered are:

a. The effects of ambient weather conditions on the performance of the instruments (for example, temperature, humidity, and barometric pressure) should be taken into account.

b. Proper signal levels, terminating impedances, and cable lengths should be maintained on all multi-instrument measurement systems.

c. The effect of extension cabler and other components should be taken into account in the calibration procedure. Field calibration shall be made immediately before and after each test sequence. Internal calibration means is acceptable for field use, provided that external calibration is accomplished immediately before or after field use.

4. Vehicles being tested shall not be operated in a manner such that the break-in procedure specified by the manufacturer is violated.

References

Suggested reference material is as follows:

ANSI S1.1-1960, Acoustical Terminology

ANSI S1.2-1967, Physical Measurement of Sound

ANSI S1.4-1971, Specification for Sound Level Meters

Applications for copies of these documents should be addressed to the American National Standards Institute, Inc., 1430 Broadway, New York, New York 10018.

MODIFICATION TO SAE-J366b

The process of developing a suitable test for truck noise emission is a continuing one. The present SAE J366b is the third stage in the SAE effort, the first and second stages being labelled SAE J366 and SAE J366a. A fourth modification, suggested by the National Bureau of Standards, is described in reference (1). In the following sections some of the difficulties identified by the U.S.E.P.A. associated with SAE J366b are discussed, and considerations are presented which may be helpful in the generation of the next modification, or in the development of other future tests.

<u>Nature of the Source</u>

As the truck, under test, traverses the vehicle path (Fig. 9.2.3.1) it behaves as a variable acoustic source. For example, exhaust noise, engine surface radiated noise and cooling fan noise all vary with time during the test. This implies that during the test, the truck (regarded as an acoustic source) is changing its acoustic power output, its directivity pattern and its spectrum as a function of time and consequently also as a function of its position. A truck under test is a complicated acoustic source and the most optimum manner to characterize its acoustic behavior would appear to warrent further study.

<u>Modifications</u>

Several areas in the present SAE J366b standard which appear worthy of further study are:

Geometry: The total length of path available to the test vehicle is 100 feet. It may be that increasing this distance, as well as that allotted to the end zone, would reduce the number of trials required to achieve maximum engine rpm inside the presently defined end zone.

It is necessary to know where a vehicle is located when it is radiating sound during a test. This information is needed to properly combine and/or interpret sound level readings taken simultaneously at several microphones. In addition, a time base is needed to define simultaneity for multimicrophone data. For example, in the SAE J366b Standard a constant power source at the beginning of the end zone produces about a 2.8-dB higher sound level reading at the test microphone than the same source located at the far end of the end zone. Knowledge of truck position would minimize this type of discrepancy. Position/time measurements are also necessary to establish the directivity characteristics of the truck-radiated noise.

Microphones. The measurement of a moving variable source, such as a truck moving on a straight path, requires more than one microphone if significant results are to be obtained. For example, if it is assumed that the sound levels anywhere on a line parallel to and spaced 50 ft away from the line of travel of a truck is the significant quantity for truck noise measurement, then it is clear that a single fixed microphone will see only what the source radiates at a single angle at a single distance at a single instant of time. At that same instant of time the source directivity pattern may be such as to radiate a higher intensity of sound in some other direction than that of the microphone. Since the directivity pattern can be changed with time, the microphone may never have detected this higher intensity if it had occurred. A suitable ensemble of microphones would have detected it. Another case could occur in which the single microphone would not see a maximum directivity pattern; that is, if the maximum occurred in the angular range, 0 to 45 degrees is the angle measured from the line of travel to the maximum. This would be true for both the front and rear of the truck.

Of the 180 degrees of horizontal directivity pattern that exists on one side of a truck, the SAE J366b microphone looks at only 90. That is, only one half of the angular spread of the directivity pattern is examined. Trucks are not omnidirectional sources, as the data in references 2 and 3 show. The question of how best to deploy a multimicrophone test ensemble requires attention. This includes a study of the optimum number of microphones as well as their three-dimensional spatial distribution.

Test Site

At the test site, there are certain parameters not adequately covered in SAE J366b. These are:

1. The acoustical characteristics of the surface of the site. Acoustically "hard" surfaces such as concrete tend to absorb less acoustic energy than soft ones, such as dirt, grass cover, or fresh asphalt. Also, acoustic interference effects are different for these cases. It, therefore, is desirable to specify

the surface of the test site so that this source of error is eliminated.

2. There have been indications that, when the test site surface deviates from planarity, anomalous acoustical results are obtained. This question requires further study and a determination should be made of the degree of flatness necessary for accurate acoustic measurements.
3. The air temperature at the sites as well as the barometric pressure and humidity all affect the acoustic levels measured in any given test. An effort should be made to develop suitable correction procedures for these variations.
4. An additional effect is that of temperature gradient. The size of this effect is not presently known in truck noise emission tests. It could be important, especially at sites where the surface is asphalt. In the summer the hot asphalt surface could produce a substantial temperature gradient. The gradient tends to bend sound "rays" and could produce different readings at a test microphone than if there were no gradient.
5. Noise emission tests are presently conducted in the open air. This is satisfactory from an acoustic point of view. However, it makes the test schedule weather dependent. The usefulness of developing a practical weatherproof structure in which a passby test could be performed is suggested for consideration.
6. The instrumentation delineated in SAE J366b has been largely superseded by rapid advances in this field. It is consequently

dated so as to imply manual data collection and data processing. These techniques can be updated and automated by the use of digital computers. It should be possible to have the test result displayed within seconds after the truck has driven past the ensemble of test microphones.

HIGH SPEED SOUND EMISSION TEST PROCEDURES

This is a test procedure for measuring the sound level produced by tires intended primarily for highway use on motor trucks, truck tractors, trailers and semitrailers, and buses. The procedure provides for the measurement of the sound generated by tires, mounted on a motor vehicle at specified tire load and operated at 50 mph (80 km/h).

Specifications for the instrumentation, the test site, and the operation of the test vehicle are set forth to minimize the effects of extraneous sound sources and to define the basis of reported levels.

Instrumentation

The following instrumentation shall be used:

1. A sound level meter that satisfies the type 1 requirements of ANSI S1.4-1971, Specifications for Sound Level Meters; or
2. As an alternative to making direct measurements using a sound level meter, a microphone or sound level meter shall be used with a magnetic tape recorder and/or a graphic level recorder or indicating meter, providing the system meets the requirements of SAE J184, with "slow" response specified in place of "fast" response.

3. An acoustical calibrator for establishing the calibration of the sound level meter and associated instrumentation.

4. An anemometer.

Test Site

The test site must be located in a flat area free of reflecting surfaces (other than the ground), such as parked vehicles, trees, or buildings within 100 ft (30 m) of the measurement area.

The vehicle path shall be relatively smooth, semipolished, dry, portland concrete free of extraneous surface material.

The microphone shall be located 50 ft (15 m) from the centerline of the vehicle path at a height of 4 ft (1.2 m) above the ground plane. The normal to the vehicle path from the microphone shall establish the microphone point on the vehicle path. See Fig. 9-2.

The test zone extends 50 ft (15 m) on either side of the microphone point along the vehicle path. The measurement area is the triangular area formed by the point of entrance into the test zone, point of exit from the test zone, and the microphone.

The measurement area shall be surfaced with concrete, asphalt or similar hard material, and in any event shall be free of powdery snow, grass, loose soil, or ashes, or other sound-absorbing materials.

The ambient sound level (including wind effects) at the test site shall be at least 10 dB below the level of the test vehicle operated in accordance with the test procedure.

The wind speed in the measurement area shall be less than 12 mph (19 km/hr).

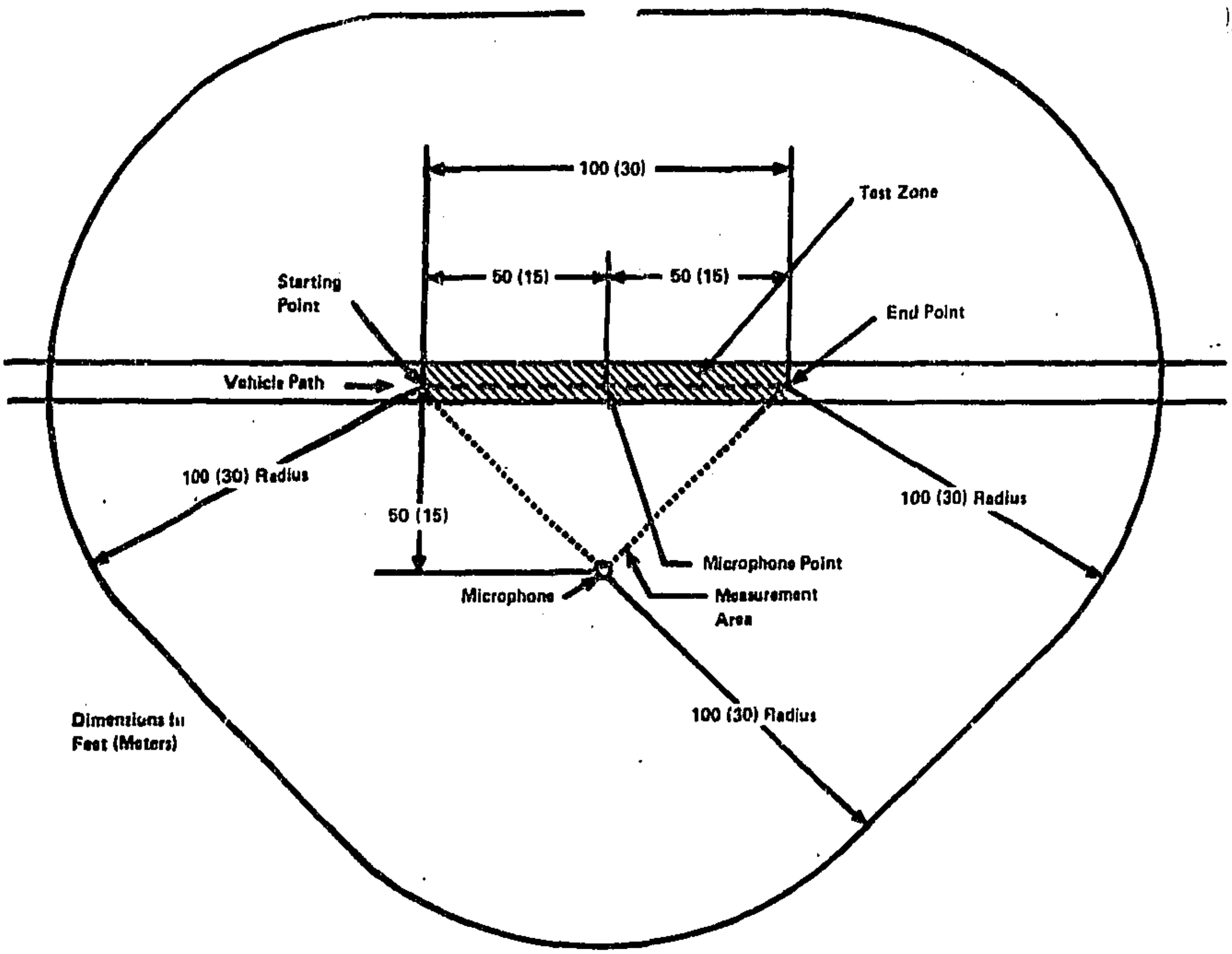


Figure 9-2 Test Site

Vehicle

The vehicle shall be a motor vehicle equipped with the set of tires it will have when it enters commerce, that is, when it is delivered to the first person who in good faith purchases the motor vehicle for purposes other than resale. The tire specifications must be recorded for each tire.

Tires

The tires shall be inflated to the maximum pressure and loaded to the maximum load specified by the Tire and Rim Association for continous operation at highway speeds exceeding 50 mph (80 km/h).

If local load limits will not permit a full rated load, the test may be conducted at the local limit with inflation pressure reduced to provide a tire deflection equal to the maximum load and inflation pressure, provided the load is not less than 75% of the maximum rated load. Because this may cause small differences in (sound) levels, such levels may not be reported absolute unless they are identified with the percent of load used. Sound levels obtained when the loading is (P) percent must be corrected by adding the quantity $10 \text{ Log}10 \left(\frac{100}{P}\right)$ to the measured values.

Procedure

The test vehicle shall be operated in such a manner (e.g., coasting) that the sound level due to the engine and other mechanical sources is minimized throughout the test zone. The vehicle speed at the microphone point shall be 50 mph (80 km/h).

The sound level meter shall be set for "slow" response and the A-weighting network. The observer shall record the highest level attained during each pass of the test vehicle, excluding readings where known acoustical interferences have occurred.

Alternatively, each pass of the test vehicle shall be recorded on magnetic tape and subsequently analyzed with a sound level meter and/or graphic level recorder.

There shall be at least three measurements. The number of measurements shall equal or exceed the range in decibels of the level obtained.

The sound level reported shall be the average of the two highest readings within 2 dB of each other.

General Comments

Measurements shall be made only when wind velocity is below 12 mph (19 km/hr).

Technically trained personnel shall select the equipment to be used for the test measurements and the tests shall be conducted only by persons trained in the techniques of sound measurements.

Proper usage of all test instrumentation is essential to obtain valid measurements. Operating manuals or other literature furnished by the instrument manufacturer shall be referred to and shall be the principal reference for both recommended operation of the instrument and precautions to be observed, except where they may be in conflict with the EPA prescribed procedures, in which case the latter shall govern. Specific items to be considered are:

1. Specifications for orientation of the microphone relative to the ground plane and the source of sound should be adhered to.

(Assume that the sound source is located at the microphone point.)

2. The effects of ambient weather conditions on the performance of the instruments (e.g., temperature, humidity, and barometric pressure) should be taken into account.

3. Proper signal levels, terminating impedances, and cable lengths should be maintained on all multi-instrument measurement systems.

4. The effect of extension cables and other components should be taken into account in the calibration procedure. Field calibration should be made immediately before and after each test sequence. Internal calibration means are acceptable for field use, provided that external calibration is accomplished immediately before or after field use.

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OTHER TEST PROCEDURES

In the course of preparing this document test procedures other than SAE J366b were considered. They included:

1. Stationary Run-Up (Idle - Maximum - Idle - IMI). In this test the engine is initially in an idle condition. It is rapidly accelerated by maintaining a wide open throttle and then decelerated by quickly closing the throttle. In this test, the engine's

own intertia provides the load.

b. Stationary-Run-Up (Steady State). In this test the truck wheels are required to drive a load. The engine is then accelerated to maximum rpm and maintained there for a short time. This type of test permits more time for conducting the test and it does not depend upon transient peak noise emission as in the IMI test. However, the development of a satisfactory loading procedure, which itself does not produce noise (which could interfere with the test), is a matter of some uncertainty. Several loading techniques have been suggested, such as coupling an inertia load to the wheels and at the same time jacking up the rear wheels. Another suggestion is to use the vehicle's own brake as a loading device. The use of dynamometer rollers, either free or loaded, has also been suggested.

The possibility of performing stationary run-up tests inside an enclosure, in order to make the procedure weatherproof, has also been considered.

3. In addition to stationary run-up-type tests there exists the possibility of developing a weatherproof passby test. This entails covering a suitable length of test track with a canopy that can adequately shield the track from the elements. At a certain portion of the track the heavy weather resistant canopy is replaced by a thin, tough plastic canopy. This thin canopy is light enough to exhibit a very small acoustic trans-

mission loss but is also strong enough to be reasonably weather resistant. The measuring microphones are placed outside the thin canopy at essentially the same positions they occupy in open air testing. They too are protected by coverings of the same thin, tough plastic.

The feasibility of developing this kind of test is by no means means assured. However, its ultimate utility and its initial apparent "do-ability" suggest that it should be considered further.

All of the above tests appear to have the capability of being developed into short (approximately 2 minute) tests and this aspect of the test development should be carefully considered.

SUMMARY

This section has presented:

1. The details of the SAE J366b noise emission test as a candidate for the standard test for new truck noise emission regulation
2. Some considerations for further development of SAE J366b
3. A brief discussion on other tests considered for use in the measurement of new truck noise

REFERENCES FOR SECTION 9

1. Leasure, W. A. and T. L. Quimby. "Measurement Methodology and Supporting Documentation for Medium and Heavy Duty Trucks," 2nd Draft Final Report, Nation Bureau of Standards, April 1974.

2. Ben H. Sharp, "Research on Highway Noise Measurement Sites," Wyle Laboratories Research Staff Report WCR 72-1, p. 99 - 105, March 1972.

3. J. W. Thompson, "An Engineering Approach to Diesel Truck Noise Reduction," SAE Preprint 730713, Portland, Ore. meeting, August 20-23, 1973.

SECTION 10

ENFORCEMENT

GENERAL

Enforcement of new product noise emission standards applicable to new medium and heavy duty trucks may be accomplished through certification or production verification testing of vehicle configurations, assembly line testing using continuous testing (sample testing or 100% testing), or selective enforcement auditing of production vehicles and in-use compliance programs. The predominant portion of any certification or production verification testing and assembly line vehicle testing can be carried out by the manufacturer and audited or confirmed by authorized government personnel as necessary.

Any test used for certification or production verification testing, and any test used for assembly line testing of production vehicles, should be the same test or else correlative so that compliance may be accurately determined. Measurement methodologies which appear applicable both for certification or production verification testing and any assembly line testing are the EPA Low Speed High Acceleration and the EPA High Speed Test.

CERTIFICATION

Certification is the testing of selected prototype products by a manufacturer or by the government in order to determine whether the products conform to a standard. Certification serves the purpose of verifying that a manufacturer has the technology in hand or "available" and, where required, it may be used to verify that the applied technology will last for some period of use.

Certification may involve the testing of every configuration of a manufactuturer's production to verify whether each conforms, or configurations may be grouped into categories with similar emission characteristics and only selected configurations tested. The configurations tested are then considered representative of the other untested configurations in a category.

The concept of certification has associated with it the issue of approval by the government after a manufacturer has demonstrated conformity through testing.

Because certification normally deals with a few prototype vehiles, it does not give any indication of the conformance of the manufacturer's product with standards. The ability of a manufacturer to apply the technology to a prototype model does not necessarily mean that actual production line vehicles will also conform. Verification that production models conform can be made only by actual testing of production models.

PRODUCTION VERIFICATION

Production verification is the testing of selected pilot line (first production) models by a manufacturer or by the government to verify whether a manufacturer has the technology in hand and is capable of applying the technology in a manufacturing process. The tested pilot line models (or first production models) must conform with the standard prior to any distribution into commerce of that model.

Production verification does not involve any formal governmental approval or issuance of certificates subsequent to manufacturer testing, nor is any extensive testing required of the government. Any regulations would require that prior to distribution into commerce of any manufactured configuration, as defined within the regulations, the configuration must undergo production verification. A vehicle model would be considered to have been production verified after the manufacturer has shown, based on the application of the noise measurement tests, that a configuration or configurations of that model conform to the standard. Production verification testing of all configurations produced by a manufacturer may not be required where a manufacturer can establish that the noise levels of some configurations within a model are consistently higher than others or are always representative of other configurations. In such a case, the higher emitter would be the only configuration requiring verification. After initial verification manufacturers must re-verify whenever they implement engineering changes to their products that are likely to adversely affect noise emissions. Additionally, further testing on some continuing or other periodic basis of production line products will still be necessary to ensure, with some confidence, that all products being manufactured conform to the standards prior to being distributed into commerce.

Production verification provides the government with confidence that production models will conform to the standards and limits the possibility that nonconforming vehicles will be distributed in commerce because initial testing is performed on pilot line or first production models. Because the possibility still exists that subsequent models may not conform, assembly line vehicle testing should be made a part of any enforcement strategy in order to determine whether production vehicles continue to conform to the standard.

ASSEMBLY LINE TESTING

Assembly line testing of production vehicles is a process by which vehicles, as they are completed on the assembly line, are tested to determine whether they conform to applicable standards. This determination as to whether production vehicles comply with the standard can be made by the use of either continuous 100% testing of newly assembled vehicles, or testing of representative samples of newly produced vehicles and drawing inferences with regard to the conformity with the standard of other newly assembled vehicles. In the case of the production of nominally identical vehicle configurations, which exhibit the same or similar noise emission characteristics through the application of the same or similar noise attentuation technology, the use of sample testing is a realistic way of determining compliance by other untested vehicles produced by a manufacturer.

Continuous 100% Testing

In the absence of a short, inexpensive test, 100% testing can be costly and time consuming and in most cases unnecessary in the absence of some justification to the contrary since sample testing can yield the desired result. At this time, 100% testing is not proposed as a primary enforcement tool; however, 100% testing may be required should a manufacturer be discovered producing nonconforming vehicles.

Sample Testing

Sample testing involves the testing of a percentage of vehicles on some continuous basis or the auditing of production line vehicles on some random basis or for cause. An auditing strategy would enable the government to determine if production vehicles meet promulgated emission standards and provide a deterrent to the distribution in commerce of nonconforming products. An auditing strategy involves the testing of a representative number of production vehicles in a random fashion. Because the number of vehicles tested under an auditing strategy is nominal, the cost and effort associated with implementation of such a strategy for a conforming manufacturer is only a fraction of the cost of a program involving continuous testing because fewer vehicles are involved.

Any sampling strategy adopted by the government would not necessarily impose a quality control or quality assurance scheme upon a manufacturer, but would merely audit the conformity of his products and provide a deterrent to the distribution in commerce of nonconforming products.

ENFORCEMENT ACTION

The prohibitions in the Act would be violated where the manufacturer fails to properly certify or verify the conformance of production vehicles, where it is determined on the basis of assembly line testing, or other information, that nonconforming production vehicles are knowingly being distributed into commerce, or where the manufacturer fails to comply with an Administrator's order specifying appropriate relief where nonconformity is determined.

SECTION 11

ENVIRONMENTAL EFFECTS

Whenever action is taken to control one form of environmental pollution, there are possible spinoff effects on other environmental or natural resource factors. In this section the single effects of truck noise control on air and water pollution, solid waste disposal, energy and natural resource consumption, and land use considerations will be evaluated.

It is useful to recall that the principal sources of truck power train noise are the fan, engine, and exhaust. Fan noise control involves the use of more efficient, large, slowly turning fans and fan clutches that disengage the fan entirely when fan cooling of the engine is not required. Engine noise reduction is achieved by means of damped and vibration-isolated engine components and enclosures. Exhaust noise is principally controlled through the use of more effective mufflers.

AIR

The major potential effect on air pollution from the noise control measures described above would be an increase in engine exhaust emissions as a result of an increase in exhaust system back pressure (Reference 1). Truck exhaust mufflers have been designed and tested that adequately reduce exhaust noise without exceeding engine manufacturers back pressure specifications. Accordingly, no increase in air pollution is to be expected from noise control related to exhaust mufflers. Air intake systems modifications, should they be necessary, are not expected to result in any change in vehicle performance or increase air emissions.

WATER AND SOLID WASTE

There are no significant impacts that would apparently result from truck noise control on either water quality or solid waste disposal.

ENERGY AND NATURAL RESOURCE CONSUMPTION

There are several ways in which noise control may affect energy consumption. The major factor is the use of fans that can be disengaged when not required. Fax (Reference 2) develops the following estimates of fuel savings in gallons per mile per unit of accessory horsepower not used.

	Truck Category	
Engine Type	Medium Duty	Heavy Duty
Gasoline	.0035	.0019
Diesel	.0019	.0010

Also, the following annual mileages by truck category apply:*

	Truck Category	
Engine Type	Medium Duty	Heavy Duty
Gasoline	10,000	18,000
Diesel	21,000	54,000

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* Data reduced from U.S. Bureau of Census, 1973.

Finally, the following number of trucks were in use in 1972 (see Sections 3 and 8).

Engine Type	Truck Category Medium Duty	Heavy Duty
Gasoline	2,335,000	509,000
Diesel	41,000	648,000

Combining the data in the above three tables, as well as the estimated savings of 6 hp for gasoline trucks and 15 hp for gasoline trucks and 15 hp for diesel trucks, shows that if all trucks were equipped with large thermostatically controlled fans, approximately one billion gallons of fuel would have been saved in 1972, more than that actually consumed.

A secondary energy effect might involve decreases in engine efficiency as a result of increased exhaust system back pressure. Since exhaust systems can generally be made to meet engine manufacturers back pressure specifications, any effect on fuel consumption in this area is expected to be minor. Further, there is no empirical evidence that acoustically effective mufflers necessarily create high back pressure.

Another potential secondary effect on fuel consumption is the increased truck rolling resistance attributable to the weight of noise control materials. The weight of noise-reducing materials varies from a few pounds for a thermostatic fan clutch or compliant engine mounts to potentially several hundred pounds for an engine enclosure. Even several hundred pounds, however, represents only a fraction of one percent of the total vehicle weight of medium and heavy trucks. Since only a small fraction of the energy generated by a truck engine is used to overcome rolling resistance (most is used to overcome aerodynamic drag), the effect of additional weight on energy and hence on fuel consumption is considered inconsequential.

Effects on the consumption of other natural resources are expected to be small. As indicated, no more than the addition of several hundred pounds per truck are likely to be required for noise treatment, under models 2 and 3 used earlier in this document. This is a small fraction of the roughly 25,000 to 30,000 lbs per tractor/trailer vehicle.

LAND USE

The expected effect of a Federal new truck regulation on land use could conceivably be favorable. For example, land bordering on highways and streets could become more desirable for residential and commercial use as the environmental noise from medium and heavy trucks is reduced. However, should the foregoing not be the case, it can certainly be stated that Federal regulations would not adversely affect land use.

REFERENCES FOR SECTION 11

1. Bender and Patterson, "The Technology and Costs of Quieting Medium and Heavy Trucks," BBN Report 2710, 1974.

2. Fax, G. E., "Costs of Operating Quiet Trucks," BBN Tech Memo 190, 1974.

APPENDIX A: DERIVATION OF BASIC SITUATIONAL MODEL EQUATIONS

In Section 6, Tables 6-6 and 6-7 presented the calculated truck noise levels (in dB(A) measured at 50 ft from the truck), which, if permitted, would raise the sound level at a particular site 10 dB(A) above the appropriate ambient level assumed to have existed prior to the passage of the truck. These calculations are based on the standard acoustic concepts presented below.

A truck is regarded as a random isotropic acoustic source whose acoustic power output is characterized by a spectral density $W(f)$ in watts per hertz at frequency f. It is also assumed that this acoustic power is radiated into a half space. These assumptions imply that $I_r(f)$, the intensity spectral density of the source, is the same on the surface of any hemisphere in the half space which has the source at its center. It is given by

$$I_r(f) = \frac{W(f)}{2\pi r^2} \quad \text{(Watts per cm}^2\text{ per Hz.)}, \qquad (A.1)$$

where r is the distance in cm from the source to a field point of interest. For the purposes of this analysis it will be assumed that the activity site structure, upon which the truck noise impinges is at some single representative distance from the source. This distance is the r in Equation (A.1).

Now let the surface area of the structure of interest be composed of m different types of partitions (i.e., walls, windows, etc.) and let the i^{th} type have an area A_i and a transmission coefficient $\tau_i(f)$. Also let $I_i(f)$ be the intensity spectral density transmitted through the i^{th} type surface. Then the total power spectral density $W_T(f)$ transmitted into the structure is

$$W_T(f) = \sum_{i=1}^{m} A_i \cdot I_i(f). \qquad (A.2)$$

Here,

$$I_i(f) = \tau_i(f) \cdot I_R(f). \qquad (A.3)$$

Thus,

$$W_T(f) = I_R(f) \cdot \sum_{i=1}^{m} A_i \, \tau_i(f). \qquad (A.4)$$

The transmittance $T(f)$ for the composite surface is defined by

$$T(f) = \sum_{i=1}^{m} A_i \, \tau_i(f). \qquad (A.5)$$

By Equations (A.4) and (A.5),

$$W_T(f) = T(f) \cdot I_R(f) = \frac{T(f) \cdot W(f)}{2\pi R^2}. \qquad (A.6)$$

It is noted that transmission coefficients $\tau_i(f)$ are not customarily reported directly in the literature. Transmission loss $\delta_\tau(f)$ is usually given in decibels. The quantities $\tau_i(f)$ and $\delta_\tau(f)$ are related as follows:

$$\delta_\tau(f) = 10 \log_{10} [\tau_i(f)]^{-1}. \qquad (A.7)$$

Thus,

$$\tau_i(f) = 10^{-\left[\frac{\delta_\tau(f)}{10}\right]}. \qquad (A.8)$$

The acoustic energy, produced by the truck with acoustic power density $W(f)$, which has been transmitted from the outside environment to the activity site interior can now be estimated. For this, the well-known architectural acoustics formula

$$I_\lambda(f) = \frac{W_\tau(f)}{A(f)} \qquad (A.9)$$

= mean intensity spectral density (watts per cm^2 per Hz) inside the room.

is employed, where $A(f)$ is the total number of "absorption units" inside the room in cm^2. $A(f)$ is customarily given in square feet and is then called Sabins. Absorption units in cm^2 are more convenient in the present instance.

The absorption $A(f)$ can be computed as follows. Let the interior of the room be bounded by N different types of surfaces (i.e., plaster wall, carpets, etc.) and let each type surface have an area A_j in cm^2 and an absorption coefficient α_j. In addition, let the room contain M objects each contributing $U_k(f)$ absorption units. Then the total number of absorption units in the room is

$$A(f) = \sum_{j=1}^{N} A_j \alpha_j(f) + \sum_{k=1}^{M} U_k(f) . \qquad \text{(A.10)}$$

Values of $\alpha_j(f)$ and $U_k(f)$ are tabulated for many surfaces and objects and are readily available in the literature.

Combining Equations (A.6) and (A.9), one of the basic formulas of this analysis is obtained:

$$I_R(f) = \left[\frac{T(f)}{2\pi R^2 \cdot A(f)} \right] W(f) . \qquad \text{(A. 11)}$$

Equation (A. 11) relates the intensity spectral density inside the room to the spectral density of the acoustic power of the source, the distance of the source from the structure, the transmittance and absorption terms associated with the room. The equation is valid for a single frequency f. If it were desired to compute the total unweighted intensity between two frequencies f_1 and f_2, then one simply integrates:

$$J(f_1, f_2) = \int_{f_1}^{f_2} I_R(f)\, df \quad \text{(Watts/cm}^2\text{)}. \qquad \text{(A.12)}$$

Now, in this project report, the quantity used for intensity is the A-weighted intensity. This means that each component $I_n(f)$ is weighted by a factor $\beta(f)$. Values of $\beta(f)$ can be obtained in various places such as Reference 1.

The curve A in Figure 2.3 of Reference 1 plots $\delta_\beta(f)$ vs. f

where
$$\delta_\beta(f) = 10 \log_{10} \beta(f). \tag{A.13}$$

Thus,
$$\beta(f) = 10^{\left[\frac{\delta_\beta(f)}{10}\right]}. \tag{A.14}$$

A few typical values of $\beta(f)$ are as shown in Table A-1.

TABLE A-1 TYPICAL VALUES OF $\beta(f)$

f (Hz)	$\beta(f)$
50	.0008
100	.0100
200	.0790
500	.5000
1000	1.0000
5000	1.0000

The formula for A-weighted intensity which corresponds to Equation (A.12) is

$$J(f_1, f_2) = \int_{f_1}^{f_2} \beta(f) \cdot I_n(f)\, df, \tag{A.15}$$

By Equations (A. 11) and (A. 15):

$$J(f_1, f_2) = \frac{1}{2\pi r^2} \int_{f_1}^{f_2} \frac{T(f) \cdot \beta(f)}{A(f)} W(f)\, df \,. \qquad \text{(A.16)}$$

Equation (A. 16) applies to any frequency band where $f_1 \leq f \leq f_2$. However, most measurement data are available in octave bands and so some simplifications are made in Equation (A.16) in order to use the octave band data. First the most commonly employed octave bands are defined in Table A-2.

TABLE A-2

OCTAVE BANDS AND SYMBOLS

Octave Band No. p	Octave Band Intensity J_p (Watts/cm)	Octave Band Center Freq. f_c (Hz)	Octave Band* Lower Freq. f_l (Hz)	Octave Band Upper Freq. f_u (Hz)
1	J	31.5	22.3	44.6
2	J	63	44.6	89.2
3	J	125	88.4	176.8
4	J	250	176.8	353.6
5	J	500	353.6	707.1
6	J	1,000	707.1	1,414.2
7	J	2,000	1,414.2	2,828.4
8	J	4,000	2,828.4	5,656.9
9	J	8,000	5,656.9	11,313.7

In Table A.2,

f_c = Center frequency of p^{th} octave band,

f_L = Lower frequency of p^{th} octave band,

f_u = Upper frequency of p^{th} octave band.

Some relations between octave band frequencies are:

$$f_u = 2 f_L ,$$

$f_u - f_L$ = Band width of p^{th} octave band,

$$f_c = \sqrt{f_L f_u} = \sqrt{2}\, f_L = \frac{\sqrt{2}}{2} f_u . \qquad \text{(A. 17)}$$

For convenience, the following notation is adopted:

$$J(f_L, f_u) \equiv J_p = \text{A-weighted intensity in } p^{th} \text{ octave band.} \qquad \text{(A. 18)}$$

By Equations (A-16) and (A-18),

$$J_p = \frac{1}{2\pi r^2} \int_{f_L}^{f_u} \frac{T(f) \cdot \beta(f)}{A(f)} W(f)\, df . \qquad \text{(A. 19)}$$

In order to make use of available data for the evaluation of the integral of Equation (A. 19), inside the p^{th} octave band it is assumed that the quantities $A(f)$, $T(f)$ and $W(f)$ are all constant and have values corresponding to f_c, the center frequency of the octave band. That is, $A(f)$, $T(f)$ and $W(f)$ are replaced in the integrand of Equation (A-19) by the constants $A(f_c)$, $T(f_c)$ and $W(f_c)$. Further, denoting these quantities by A_p, T_p and W_p, then Equation (A.19) becomes

$$J_p = \frac{1}{2\pi r^2} \frac{T_p W_p}{A_p} \beta_p , \qquad p = 1, 2, \ldots, 9. \quad \text{(A.20)}$$

where

$$\beta_p = \int_{f_L}^{f_u} \beta(f)\,df . \quad \text{(A.21)}$$

The quantity β_p may be estimated in various ways, but since it does not appear in later formulas, it will not be considered further.

Equation (A.20) gives the octave band intensity J_p inside a room in terms of the acoustic power spectral density of the source W_p. Ordinarily, the W_p is not known. Thus, this quantity is replaced by a quantity which is known and measured, namely the dB(A) level produced in a pass-by test at a prescribed distance. The distance is usually 50 feet but here it is allowed to be arbitrary r_o in cm. Using Equation (A.1) and integrating Equation (A.15) gives

$$J_{op} = \frac{1}{2\pi r_o^2} \int_{f_L}^{f_u} \beta(f) \cdot W(f)\,df . \quad \text{(A.22)}$$

If the same approximations are made in Equation (A.22) as were made in Equation (A.20), then Equation (A.22) becomes

$$J_{op} = \frac{W_p \beta_p}{2\pi r_o^2} . \quad \text{(A. 23)}$$

Using Equation (A.23), W_p can be eliminated from Equation (A.20). Thus, Equation (A.20) becomes

$$J_p = \left(\frac{r_o}{r}\right)^2 \cdot \frac{T_p}{A_p} \cdot J_{op} . \quad \text{(A. 24)}$$

Equation (A.24) gives a simple relation between the A-weighted octave band levels inside the room and those at the standard test distance r_o.

At this point, it is useful to introduce a normalized spectrum for the source. Define the normalizied A-weighted p^{th} octave band component as $\hat{J}_{op}$; that is,

$$\hat{J}_{op} = \frac{J_{op}}{\sum_p J_{op}} \equiv \frac{J_{op}}{J_{o\sigma}} . \quad \text{(A. 25)}$$

Now, spectra having the same shape as J_{op}, the one actually measured, but having different intensities can be generated by simply multiplying all $\hat{J}_{op}$ by the same constant η . Thus, for a typical case, one can determine $\hat{J}_p$ and raise or lower the total power, keeping the spectrum shape the same. This was done here using two spectra, one for low speed high acceleration truck operation and the other for high constant speed truck operation. These spectra are shown in Figures E.1 and E.2, respectively, of Appendix E.

In Equation (A.24), J_{op} is replaced by $\eta \hat{J}_{op}$ to become

$$J_p = \left(\frac{r_o}{r}\right)^2 \cdot \frac{T_p}{A_p} \cdot \eta \hat{J}_{op} . \qquad \text{(A.26)}$$

The total intensity inside the room, summed over all the octave bands, is defined as J_σ and is given by

$$J_\sigma = \sum_{p=1}^{9} J_p = \eta \left(\frac{r_o}{r}\right)^2 \sum_{p=1}^{9} \frac{T_p \hat{J}_{op}}{A_p} . \qquad \text{(A.27)}$$

For convenience, define the parameter g as

$$g = \sum_{p=1}^{9} \frac{T_p \hat{J}_{op}}{A_p} , \qquad \text{(A.28)}$$

and, thus

$$J_\sigma = \eta g \left(\frac{r_o}{r}\right)^2 . \qquad \text{(A.29)}$$

The intensity at the reference distance r_o is $\eta \hat{J}_{op}$ summed over p:

$$\sum_{p=1}^{9} \eta \hat{J}_{op} = \eta \sum_{p=1}^{9} \hat{J}_{op} = \eta . \qquad \text{(A.30)}$$

The overall dB(A) level of the source at r_o is

$$\delta_o = 10 \log_{10}\left(\frac{\eta}{10^{-16}}\right) , \qquad \text{(A.31)}$$

and the dB(A) level inside the room at r is

$$\delta_r = 10 \log\left(\frac{J_\sigma}{10^{-16}}\right) . \qquad \text{(A.32)}$$

By Equations (A. 29), (A. 31) and (A. 32), then

$$\delta_o = \delta_r + 10 \log_{10} \left[\left(\frac{r_o}{r} \right)^2 \cdot \left(\frac{1}{q_g} \right) \right] . \qquad \text{(A. 33)}$$

Equation (A.33) gives the overall dB(A) level δ_o of a truck, having a prescribed spectrum and measured at distance r_o, which will produce a dB(A) level δ_r in a room which is at a distance r and has specified absorption and transmission loss. For the calculations in this project report, δ_r was taken as 10 dB(A) above the ambient for the given scenario.

APPENDIX B: ARCHITECTURAL-ACOUSTIC DESCRIPTION OF THE ACTIVITY SITE STRUCTURES

Two fundamental considerations enter into the architectural-acoustic description of the structure at a particular activity site. These considerations involve (1) the loss of acoustic energy on sound passage through the partition of a structure and (2) the absorption of sound by the surfaces within the activity space of the structure.

To account for the phenomena associated with these considerations, each activity site was defined in terms of physical geometry, structural material, and interior furnishings. Tables B-1, B-2 and B-3 provide architectural-acoustic data for the apartment room, frame house room, and office room, respectively, considered in this study.

TABLE B.1

DESCRIPTION OF APARTMENT ROOM

Site Component	Description
Exterior Wall	90 ft transmission area.
	Construction: brick, laid on edge with gypsum plaster on both sides.
	Transmission loss: see Reference 1, page 434.
Window	30 ft transmission area.
	Construction: single 1/8 inch thick pane with 1.626 lbs/ft surface density.
	Transmission loss: see Reference 2, page 109.
Interior Walls & Ceiling	740-ft surface area.
	Construction: plaster, gypsum, scratch and brown coats on metal lath on wood studs.
	Absorption: see reference 1, page 425.
Floor	300-ft surface area.
	Construction: pile carpet on 1/8 inch felt.
	Absorption: see Reference 1, page 424.
Draperies	120-ft surface area.
	Construction: 18 oz./yd velours.
	Absorption: see Reference 1, page 424.
People	Four adults seated in American loge chairs.
	Absorption: see Reference 1, page 426.

TABLE B. 2
DESCRIPTION OF FRAME HOUSE ROOM

Site Component	Description
Exterior Wall	280-ft transmission area.
	Construction: 1/2 inch thick lime plaster on wood lath.
	Transmission loss: see Reference 1, page 428.
Windows	70-ft transmission area.
	Construction: single 1/8 inch-thick pane with 1,626 lbs/ft surface density.
	Transmission loss: see Reference 2, page 109.
Interior Walls	500-ft surface area.
	Construction: plaster, gypsum, scratch and brown coats on metal lath on wood studs.
	Absorption: see Reference 1, page 425.
Ceiling	300-ft surface area.
	Construction: 1-inch thick type M-2 acoustic Celotex 12-inch x 12-inch tiles.
	Absorption: see Reference 1, page 409.
Floor	300-ft surface area.
	Construction: linoleum on concrete.
	Absorption: see Reference 1, page 424.
Chairs	Two tablet arm chairs with seats down, upholstered with Durano plastic seat covering and mohair side vents.
	Absorption: see Reference 1, page 426.
People	Two adults.
	Absorption: see Reference 1, page 423.

TABLE B.3
DESCRIPTION OF OFFICE ROOM

Site Component	Description
Exterior Wall	60-ft transmission area. Construction: brick, laid on edge with gypsum plaster on both sides. Transmission loss: see Reference 1, page 434.
Windows	60-ft surface area. Construction: single 1/8 inch-thick pane with 1,626 lbs/ft surface density. Transmission loss: see Reference 2, page 109.
Interior Walls	500-ft surface area. Construction: plaster, gypsum, scratch and brown coats on metal lath on wood studs. Absorption: see Reference 1, page 425.
Ceiling	300-ft surface area. Construction: 1-inch thick type M-2 acoustic Celotex 12-inch x 12-inch tiles. Absorption: see Reference 1, page 409.
Floor	300-ft surface area. Construction: linoleum on concrete. Absorption: see Reference 1, page 424.
Chairs	Two tablet arm chairs with seats down, upholstered with Durano plastic seat covering and mohair side vents. Absorption: see Reference 1, page 426.
People	Two adults. Absorption: see Reference 1, page 426.

REFERENCES FOR APPENDIX B

1. Knudson, V. O. and C. M. Harris, Acoustical Designing in Architecture, John Wiley & Sons, Inc., 1950.
2. Richardson, E. E., Technical Aspects of Sound, Vol. I, Elsener Publishing Co., 1953.

APPENDIX C: CALCULATION OF THE TOTAL ABSORPTION FOR THE APARTMENT ACTIVITY SITE

The total absorption of each activity space for the environmental activity sites was calculated by summing the number of absorption units associated with major sound absorbing surfaces within the activity space of the site of interest. Here, an absorption unit is defined as the product coefficient of a surface and the related surface area.

Table C. 1 summarizes the steps taken to obtain the total absorption for the apartment environmental activity site.

Table C. 2 provides some comments on the column data in Table C. 1

TABLE C. 2 COMMENTS ON TABLE C. 1

Column	Comments
1	Octave band center frequencies, Hz.
2, 3, 4	= absorption coefficient (see Appendix B). A = surface area, cm . A = Absorption, Absorption Units.
5	Absorption for four persons, absorption units (see Appendix B).
6	These values are the sum of (1) the A data of columns 2 through 4 and (2) the data of column 5, absorption units.

TABLE C-1
ABSORBENCY OF THE APARTMENT INTERIOR

COLUMN NUMBERS								
1	2		3		4		5	6
Octave Band Center Frequency	Carpeting $A = 278,700\ cm^2$		Walls and Ceiling $A = 687,500\ cm^2$		Drapes $A = 111,500\ cm^2$		People	Octave Band Total Absorption
Hz	α	αA	α	αA	α	αA		
125	.11	30,700	.02	13,800	.05	5,600	11,200	61,100
250	.14	39,000	.03	20,600	.12	13,400	14,100	87,200
500	.37	103,100	.04	27,500	.35	39,000	16,700	186,400
1000	.43	119,800	.06	41,300	.45	50,200	18,600	229,800
2000	.27	75,300	.06	41,300	.38	42,400	19,300	178,200
4000	.25	69,700	.03	20,600	.36	40,100	20,300	150,500

APPENDIX D: CALCULATION OF THE TOTAL TRANSMITTANCE OF THE APARTMENT ACTIVITY SITE

The total transmittance for the structure associated with each environmental activity site was calculated by summing the transmittance associated with major sound transmitting partitions for each particular structure. Here, transmittance is defined as the product of the transmission coefficient of a partition and the related surface area.

Table D. 1 summarizes the steps taken to obtain the total transmittance for the apartment activity site. Table D. 2 provides some comments on the column data in Table D. 1.

TABLE D-2 COMMENTS ON TABLE D-1

Column	Comments
1	Octave band center frequencies, Hz.
2, 3	= transmission coefficient (see Appendix B)
	A = surface area, cm
	= transmittance, transmission units.
4	These values are the sum of the data of columns 2 and 3.

TABLE D-1.

TRANSMITTANCE OF THE APARTMENT STRUCTURE

Column Numbers					
1	2		3		4
Octave Band Center Frequency (Hz)	Windows $A = 2.787 \times 10^4\ cm^2$		Walls $A = 8.361 \times 10^4\ cm^2$		Octave Band Total Transmittance
	τ	τA	τ	τA	
125	17.430×10^{-3}	485.8	12.589×10^{-4}	105.3	591.1
250	4.416×10^{-3}	123.1	1.000×10^{-4}	8.4	131.5
500	1.108×10^{-3}	30.9	2.000×10^{-4}	16.8	47.7
1000	$.277 \times 10^{-3}$	7.7	$.126 \times 10^{-4}$	1.1	8.8
2000	$.069 \times 10^{-3}$	1.9	$.013 \times 10^{-4}$	.1	2.0
4000	$.017 \times 10^{-3}$	0.5	$.006 \times 10^{-4}$	0	.5

APPENDIX E: TYPICAL MEASURED TRUCK OPERATION NOISE

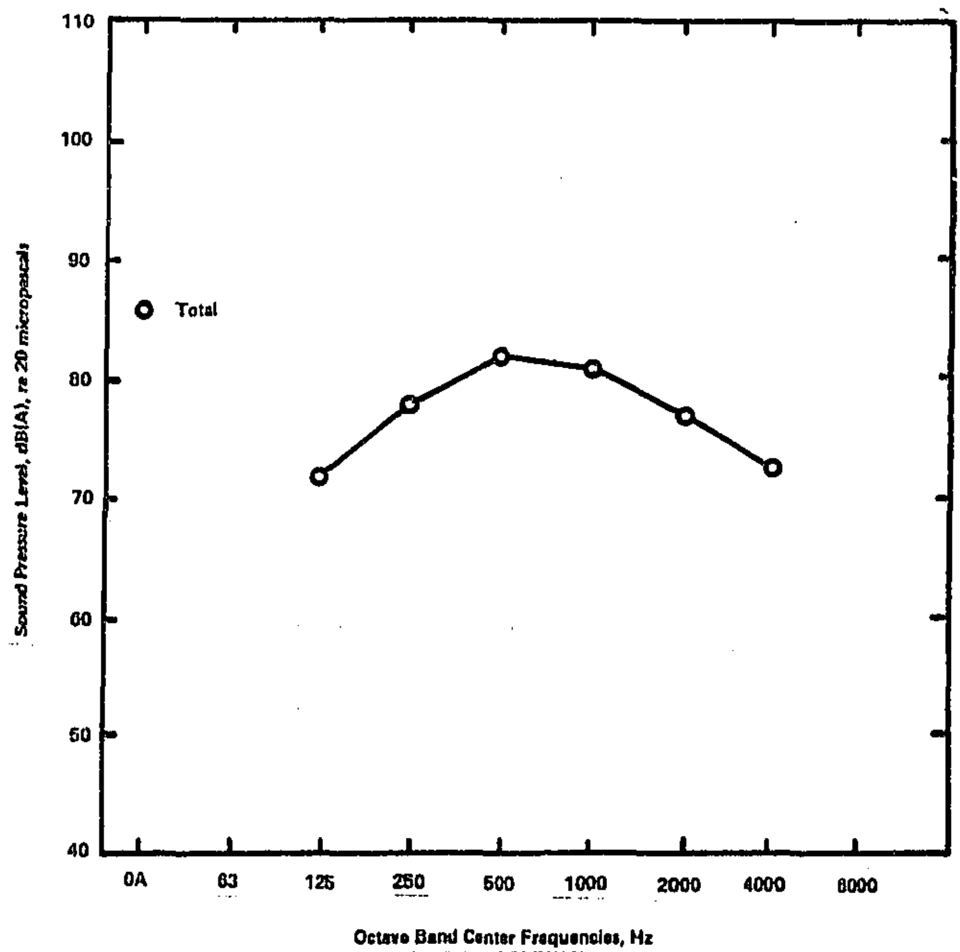
Noise spectrum associated with the two most common truck operations were selected for study. These were (1) low speed, high acceleration truck operation and (2) constant high speed truck operation. Review of available literature led to the selection of the overall noise levels and spectrum for the particular truck operations below.

Truck Noise at Low-Speed, High-Acceleration Operation

Low speed high acceleration truck operation usually occurs when a truck at standstill begins movement. This condition has been recognized as one producing relatively high levels of noise. The data shown in Figure E-1 are considered typical and representative of noise associated with the subject truck operating condition (Reference 1).

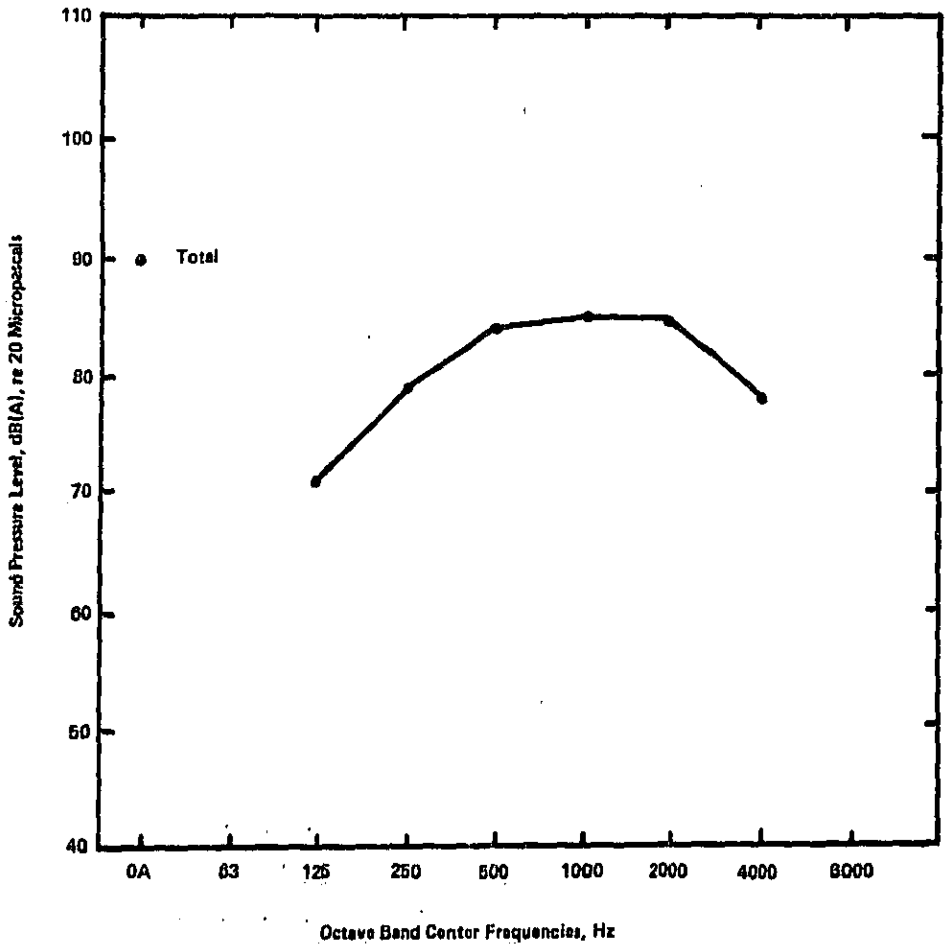
Truck Noise at Constant High Speed Operation

Constant high speed truck acceleration usually occurs when a truck is operating on a freeway. Noise levels generated during this mode of operation have also received considerable attention. The data shown in Figure E-2 are considered typical and representative of noise generated during constant high-speed truck operation (Reference 2).



Test Site and Procedure Similar to SAE J366b Specifications.

Figure E-1 Typical Measured Low-Speed, High-Acceleration Truck Operation Noise



Noise Measured at 50 Feet From Centerline of Road

Figure E-2 Typical Measured Constant High-Speed Truck Operation Noise.

REFERENCES FOR APPENDIX E

1. Wyle Laboratories Communication R/59161 with EPA, Table 2 (SAE J366 data), January 1974.

2. "Truck Noise III-A: Preliminary Noise Diagnosis of Freightliner Datum Truck-Tractor," Department of Transportation Report DOT-TST-73-6, May 1973.

APPENDIX F: CALCULATIONS TO NORMALIZE THE LOW SPEED HIGH-ACCELERATION TRUCK NOISE SPECTRUM

To facilitate their usage in the procedure developed to obtain the truck noise levels at 50 feet that might preclude annoyance, the truck noise spectra of Figures E-1 and E-2 were normalized to a total sound intensity of one watt/cm .

Table F-1 summarizes the steps taken in this normalization process for the noise spectrum associated with the low speed, high acceleration truck operation. Table F-2 provides some comments on the column data in Table F-1.

TABLE F. 2

COMMENTS ON TABLE F. 1

Column	Comments
1	Octave band center frequencies, Hz
2	Sound level data from Figure E-1
3	Column 2 data converted to sound intensities
4	Individual column 5 data divided by the sum of the column 5 values.

TABLE F-1

NORMALIZATION OF THE LOW-SPEED, HIGH-ACCELERATION TRUCK NOISE SPECTRUM

Column Numbers			
1	2	3	4
Octave Band Center Frequency Hz	Octave Band Sound Level dB(A)	Octave Band Sound Intensity Watts/cm^2	Normalized Octave Band Sound Intensity
125	72	1.58×10^{-9}	.036
250	78	6.31×10^{-9}	.146
500	82	15.84×10^{-9}	.366
1000	81	12.59×10^{-9}	.290
2000	77	5.01×10^{-9}	.116
4000	73	2.00×10^{-9}	.046

APPENDIX G: CALCULATION OF ACTIVITY SITE FACTORS FOR THE APARTMENT ACTIVITY SITE

The activity site factor, q_p for the p^{th} octave band, is defined as

$$q_p = \frac{T_p \hat{J}_{op}}{A_p} \tag{G.1}$$

where A_p and T_p are the p^{th} octave band absorption and transmission loss for the particular activity site structure of interest and $\hat{J}_{op}$ is the normalized A-weighted sound intensity of the truck noise for the p^{th} octave band. These activity site factors summed over all octave bands of interest to give the parameter q. See Equation (A.28) of Appendix A.

Table G.1 summarizes the steps taken to obtain the activity site factors for the apartment activity site. Table G.2 provides some comments on the column data in Table G.1.

TABLE G.2 COMMENTS ON TABLE G.1

COLUMN	COMMENTS
1	Octave Band Center Frequencies
2	Data from Column 6 of Table C.1, Absorption Units
3	Data from Column 4 of Table D.1, Transmission Units
4	Data from Column 4 of Table F.1
5	These values are the product of the data of Columns 3 and 4 divided by the data of Column 2 (see Equation (G.1)

TABLE G-1

CALCULATION OF SITUATIONAL FACTORS FOR THE APARTMENT ACTIVITY SITE

Column Numbers				
1	2	3	4	5
Octave Band Center Frequency Hz	Octave Band Absorption A_p	Octave Band Transmittance T_p	Octave Band Normalized Truck Noise $\hat{J}_{op}$	Octave Band Situational Factor g_p
125	61,000	591.1	.036	3488×10^{-7}
250	87,200	131.5	.146	2202×10^{-7}
500	186,400	47.7	.366	937×10^{-7}
1000	229,800	8.8	.290	111×10^{-7}
2000	178,200	2.0	.116	13×10^{-7}
4000	150,500	.5	.046	2×10^{-7}

APPENDIX H: PROCEDURE USED TO OBTAIN THE TRUCK NOISE LEVELS AT 50 FEET THAT MIGHT PRECLUDE ANNOYANCE

The following steps were taken to obtain the desired truck noise levels:

Step 1: Depending on the human activity and activity site (e. g., a thought process in an apartment), the acceptable ambient noise level was increased by 10 dB(A) to represent the level of the extraneous intrusive noise likely to provoke a strong feeling of annoyance.

Step 2: Using the appropriate absorption data for the activity spaces (e.g., an apartment interior), the total absorption units for each activity site were calculated.

Step 3: Using the appropriate transmission loss data for the activity site (e. g., an apartment building), the transmittance of the structure separating the activity space from the truck noise was calculated.

Step 4: Using the appropriate truck noise spectrum, a normalized noise spectrum was calculated to facilitate the analysis.

Step 5: Using the data generated in Steps 1 through 4 above, truck noise levels at 50 feet that might preclude annoyance were calculated for different human activities in various activity spaces at particular activity sites.

APPENDIX I DETAILED INITIAL COST ESTIMATES TO QUIET MEDIUM AND HEAVY DUTY TRUCKS

The noise control treatments considered in this analysis are listed in Table I-1. Table I-2 shows which treatments apply to a given vehicle as a function of noise level, and the truck retail price increase associated with the treatments.

TABLE I.1 NOISE CONTROL KEY

System	Code	Description of Noise Control Measure	Source Level or Noise Reduction
Fan	a1	Use of larger slower turning fan with shrouding	80 dB(A)
	a2	Larger slower turning fan with thermostat control to eliminate shutters or control their opening	75 dB(A)
	a3	Best technology fan system	65 dB(A)
Exhaust	b1	Best available system	75 dB(A)
	b2	Advanced system better than pres- ently available	75 dB(A)
	b3	Best technology exhaust system	65 dB(A)
Engine	c1	Close fitting covers and isolated or damped exterior parts supplied by engine manufacturer	2 – 3 dB(A) Noise Reduction
Cab	d1	Underhood treatment such as acous- tic absorbing material, side	2 – 4 dB(A)
	d2	Partial or full engine enclosures	10 – 15 dB(A) Noise Reduction

TABLE I.2 ESTIMATED CUSTOMER PRICE INCREASES FOR QUIETED TRUCKS

Engine Class[1]	Market Share[2]	Model 1, 83 dB(A)					Model 2, 80 dB(A)					Model 3, 75 dB(A)				
		Fan	Exhaust	Engine	Cab	Total	Fan	Exhaust	Engine	Cab	Total	Fan	Exhaust	Engine	Cab	Total
M.D. Gasoline Engines	65%	a1	-	-	-		$100 a2	$ 25 b1	-	-	$ 125	$150 a3	$ 50 b2	-	$100 d1	$300
H.D. Diesel Engines Manufacturer A	12%	$100 a2	$ 50 b1	-	-	$150	$100 a2	$ 50 b1	$200 c1	-	$ 350	$150 a3	$100 b2	-	$750-1250 d2	$1000-1500
H.D. Diesel Engines Manufacturer B	6%	$100 a2	$ 50 b1	$275 c1	-	$425	$100 a2	$ 50 b1	-	$850 d2	$1000	$150 a3	$100 b2	-	$850-1250 d2	$1000-1500
H.D. Diesel Engines Manufacturer B	6%	$100 a2	$ 25 b1	$200 c1	-	$325	$100 a2	$ 25 b1	-	$675 d2	$ 800	$150 a3	$ 75 b2	-	$775 d2	$1000
H.D. Diesel Engines Manufacturer C	4.8%	-	-	-	-	$0	$100 a2	$ 25 b1	-	-	$ 125	$150 a3	$ 75 b2	$200 c1	$100 d1	$525
M.D. Diesel Engines Manufacturer D	2.2%	$100 a2	$ 25 b1	-	-	$125	$100 a2	$ 25 b1	$ 85 c1	$100 d1	$ 210	$150 a3	$ 75 b2	-	$775-1275 d2	$1000-1500
H.D. Diesel Engines Manufacturer D	1.5%	a1	-	-	-		$100 a2	$ 50 b1	-	-	$ 150	$150 a3	$100 b2	-	$750-1250 d2	$1000-1500
H.D. Diesel Engines Manufacturer A	0.9%	$100 a2	$100 b2	-	-	$200	$100 a2	$100 b2	$200 c1	-	$ 400	$150 a3	$150 b2	-	$800-1300 d2	$1000-1500
M.D. Diesel Engines Manufacturer E	0.77%	$100 a2	-	-	-	$100	$100 a2	$ 25 b1	$175 c1	-	$ 300	$150 a3	$ 75 b2	-	$775-1275 d2	$1000-1500
H.D. Diesel Engines Manufacturer C	0.47%	$100 a2	-	-	-	$100	$100 a2	$ 25 b1	$175 c1	-	$ 400	$150 a3	$ 75 b2	-	$775-1275 d2	$1000-1500
H.D. Diesel Engines Manufacturer F	0.225%	$100 a2	$ 25 b1	-	-	$125	$100 a2	$ 25 b1	$200 c1	-	$ 325	$150 a3	$ 75 b2	-	$775-1275 d2	$1000-1500
M.D. Diesel Engines Manufacturer G	0.17%	$100 a2	$ 25 b1	-	-	$125	$100 a2	$ 25 b1	$150 c1	-	$ 275	$150 a3	$ 75 b2	-	$775-1275 d2	$1000-1500
H.D. Diesel Engines Manufacturer H	0.015%	-	-	-	-	$0	$100 a2	$ 25 b1	-	-	$ 125	$150 a3	$ 75 b2	$200 c1	$100 d1	$525

[1] M.D. = medium duty, H.D. = heavy duty. M.D. and H.D. refer to severity of service. Exchange: of a noisy engine by a quiet engine is possible within M.D. and H.D. classes.

[2] Percent of medium and heavy duty trucks powered by indicated engine family, 1972.

APPENDIX J: COSTS OF OPERATING QUIET TRUCKS

As was described in Section 7, "Changes in Operating Costs," the effects of adding noise control devices to trucks are (1) to change the cost of their operation and (2) to change their operating capabilities. This second effect, in turn, can be quantified in terms of the extra capital cost necessary to maintain the truck's previous level of service. This appendix contains the detailed calculation of these cost changes.

Tables J-1 and J-2 show the effect of changes in vehicle characteristics on fuel consumption per mile and the gross engine power needed to maintain truck performance. The development of these figures is based on the references at the end of Section 7.

TABLE J.1 EFFECT OF CHANGES IN VEHICLE CHARACTERISTICS ON FUEL CONSUMPTION

	Effect of Change in		
	GVWR (gpm/lb)	Back pressure (gpm/in. Hg)	Accessory Horsepower (gpm/hp)
Gasoline - medium	3.25×10^{-6}	0	.0035
Gasoline - heavy	3.25×10^{-6}	0	.0019
Diesel - medium	1.77×10^{-6}	.00050	.0019
Diesel - heavy	1.77×10^{-6}	.00021	.0010

Source: Reference No. 1.

TABLE J 2 EFFECT OF CHANGES IN VEHICLE CHARACTERISTICS ON GROSS ENGINE POWER NEEDED TO MAINTAIN A GIVEN TOP SPEED

	Effect of Change in		
	GVWR (hp/lb)	Back pressure (hp/in. Hg)	Accessory Horsepower (hp/hp)
Gasoline - medium	.0020	1.4	1
Gasoline - heavy	.0020	2.1	1
Diesel - medium	.0020	2.0	1
Diesel - heavy	.0020	3.0	1

The fuel consumption sensitivities in Table J-1 can be converted into cost coefficients by multiplying gallons per mile by the annual mileage and the average price of fuel per gallon. Values for these quantities are given in Table J-3. The corresponding annual costs are shown in Table J-4.

TABLE J-3 ANNUAL MILEAGE AND FUEL PRICES BY TYPE OF TRUCK

	Annual Mileage[1] (10^3 mi/yr)	Fuel Price[2] ($/gal)
Gasoline - medium	10	.50
Gasoline - heavy	18	.50
Diesel - medium	21	.30
Diesel - heavy	54	.30

[1]Source: Data reduced from U.S. Bureau of Census (tape), 1973.

[2]Estimate based on *Oil and Gas Journal*, March 11, 1974.

TABLE J-4

ANNUAL OPERATING COST INCREASES AS A RESULT OF CHANGES IN GVWR, BACKPRESSURE, AND ACCESSORY HORSEPOWER

	Annual Operating Cost Increase Per Unit		
	GVWR ($/lb)	Back pressure ($/in. Hz)	Accessory Horsepower ($/hp)
Gasoline - medium	.016	0	17.50
Gasoline - heavy	.029	0	17.10
Diesel - medium	.011	3.15	11.97
Diesel - heavy	.029	3.40	16.20

The cost of the incremental horsepower requirements shown in Table J-2 can be computed by multiplying the horsepower figures by the cost per unit horsepower. Manufacturers' data reported in reference 1, indicate that the average price per horsepower for medium and heavy duty diesel engines is $16 and $24, respectively. Assuming that gasoline engines cost 60% of their diesel equivalents, the corresponding unit prices for gasoline horsepower are approximately $10 and $14. Multiplying these unit costs by the figures in Table J-2 gives the indirect capital cost per unit change in vehicle characteristics, as shown in Table J-5.

TABLE J.5. INDIRECT INCREASE IN CAPITAL COST AS A RESULT OF CHANGES IN GVW, BACKPRESSURE, AND ACCESSORY HORSEPOWER

	Capital Cost Increase Per Unit		
	GVWR ($/lb)	Backpressure ($/in. Hg)	Accessory Horsepower ($/hp)
Gasoline - medium	.020	14.0	10
Gasoline - heavy	.028	29.4	14
Diesel - medium	.032	32.0	16
Diesel - heavy	.048	72.0	24

To obtain the actual costs associated with the various noise levels, modeled, we must multiply the cost coefficients of Tables J-4 and J-5 by the changes in truck characteristics which would be induced by the necessary noise control measures. These changes are shown in Table J-6 for the noise control treatments listed in Table I-1 of Appendix I. The total cost increase (operating or indirect capital) for a particular level and truck category is thus obtained by finding the changes in truck characteristics for those treatments (Table J-6), multiplying these by the operating or indirect capital cost coefficients (Tables J-4 and J-5) as appropriate, and summing the results over all treatments for that truck category and level. When this is done for operating costs, the results shown in Table J-7 are obtained.

TABLE J-6 CHANGES IN TRUCK OPERATING CHARACTERISTICS FOR NOISE CONTROL TREATMENTS[1]

Code	Treatment	ΔGVW (lb) Med	ΔGVW (lb) Hvy	ΔBack pressure (in. H_2O) Med	ΔBack pressure (in. H_2O) Hvy	Δhp Med	Δhp Hvy	ΔMaintenance Cost ($/yr) Med	ΔMaintenance Cost ($/yr) Hvy
a1	Large Fan					(3)	(7)		
a2	Large Fan with Thermostat Control					(6)	(15)		
a3	Best Tech. Fan System					(6)	(15)		
b1	Best Available Muffler	0	0	0	0			$ 9[4]	$ 19[4]
b2	Advanced Muffler	100	200	0	0			$ 19[4]	$ 38[4]
b3	High Tech. Muffler	100	200	15	15			$ 38[4]	$ 76[4]
c1	Covers	0	0						
d1	Underhood Treatment	0	0						
d2	Enclosure	250	500					$150[2]	$300[3]

[1]Source: Estimates by noise control engineers based on past truck-quieting experience .

[2]Represents 10 man-hours per year at a burdened labor rate of $15/man-hour.

[3]Represents 20 man-hours per year at a burdened labor rate of $15/man-hour.

[4]Includes incremental cost of replacing muffler three times in 8 years.

TABLE J.7. CHANGES IN ANNUAL COST (FUEL PLUS MAINTENANCE EXPENSES) CAUSED BY NOISE CONTROL TREATMENTS (INCLUDES FAN SAVINGS)

	Annual Cost Change[1]		
	Model 1	Model 2	Model 3
Gasoline - medium	$ 53)	($ 96)	($ 84)
Gasoline - heavy	($120)	($238)	($210)
Diesel - medium	($ 63)	($ 63)	$ 51
Diesel - heavy	($224)	($ 66)	$116

[1]Parentheses denote net savings.

The table shows that the changes in operating cost, as computed, are almost always net savings, due to the reduced power requirement of the fan. Such savings could be ascribed to other than the noise control effort, however, because (1) truck operators could use the fan power savings to increase speed; and (2) market forces could dictate such a beneficial design modification eventually, even without considererations of noise reduction. Therefore, the the operating costs have been recomputed to exclude the fan horsepower savings. The results are shown in Table J.8.

TABLE J-8 CHANGES IN ANNUAL COST (FUEL PLUS MAINTENANCE EXPENSES) CAUSED BY NOISE CONTROL TREATMENTS (WITHOUT FAN SAVINGS)

	Annual Cost Increase		
	Model 1	Model 2	Model 3
Gasoline - medium	0	$ 9	$ 21
Gasoline - heavy	0	$ 19	$ 44
Diesel - medium	$ 9	$ 9	$123
Diesel - heavy	$19	$176	$359

The cost of extra horsepower needed to maintain the original level of service is shown in Table J-9. The fan savings result in a smaller required total engine output, hence a reduction in the initial price. For the reasons listed in the preceding paragraph, however, these savings may not be realized. The indirect capital cost increase is therefore shown in Table J-10 with fan savings excluded. The cost of extra horsepower required by noise control treatments is negligible.

TABLE J-9 CHANGES IN CAPITAL COST INDIRECTLY CAUSED BY NOISE CONTROL TREATMENTS (INCLUDES FAN SAVINGS)

	Capital Cost Change ( ) Denotes Net Savings		
	Model 1	Model 2	Model 3
Gasoline - medium	($ 30)	($ 60)	($ 58)
Gasoline - heavy	($ 98)	($210)	($204)
Diesel - medium	($ 96)	($ 96)	($ 85)
Diesel - heavy	($360)	($336)	($326)

TABLE J-10 CHANGES IN CAPITAL COST INDIRECTLY CAUSED BY NOISE CONTROL TREATMENTS (WITHOUT FAN SAVINGS)

	Capital Cost Increase		
	Model 1	Model 2	Model 3
Gasoline - medium	0	0	$ 2
Gasoline - heavy	0	0	$ 6
Diesel - medium	0	0	$11
Diesel - heavy	0	$12	$3[illegible]

APPENDIX K: COMPUTATION OF EQUIVALENT TRUCK PRICE INCREASES

This apppendix contains the detailed calculations for the results summarized in Table 7-6 in the test. The equivalent price increase for a given truck category is obtained by summing the direct price change (Table 7-1), the indirect price change (Table 7-3a or 7-3b) and the net present value of the charge in operating cost (Table 7-2a or 7-2b). Net present value is evaluated over 10 years at 10% interest.

Tables K-1 through K-3 show the computation of equivalent price changes for each of the three models employed in this document.

TABLE K-1 CALCULATION OF EQUIVALENT PRICE FACTOR — MODEL 1

Type	Direct Price Change[1]	Indirect Price Change[2]	Present Value of Change in Operating Cost[3]	Total
Without Fan Savings				
Gasoline - medium	$ 0	$ 0	$ 0	$ 0
Gasoline - heavy	0	0	0	0
Diesel - medium	104.16	0	55.30	159.46
Diesel - heavy	194.56	0	116.74	311.30
With Fan Savings[4]				
Gasoline - medium	$100.00	($ 30)	($ 325.63)	($ 255.63)
Gasoline - heavy	100.00	(98)	(737.28)	(735.28)
Diesel - medium	120.83	(96)	(387.07)	(362.24)
Diesel - heavy	214.65	(360)	(1,376.26)	(1,521.61)

[1]Source: Table 7-1.

[2]Source: Tables 7-3a and 7-3b.

[3]Source: Tables 7-2a and 7-2b. Net present value computed over 10 years at 10% interest (PV factor = 6.144).

[4]The "with fan savings" case assumes that all trucks will adopt fan treatments, thereby incurring both costs and benefits.

TABLE K-2 CALCULATION OF EQUIVALENT PRICE FACTOR – MODEL 2

Type	Direct Price Change[1]	Indirect Price Change[2]	Present Value of Change in Operating Cost[3]	Total
Without Fan Savings				
Gasoline - medium	$125.00	$ 0	$ 55.30	$ 180.30
Gasoline - heavy	125.00	0	116.74	241.74
Diesel - medium	264.16	0	55.30	319.46
Diesel - heavy	487.62	12	1,081.34	1,580.90
With Fan Savings				
Gasoline - medium	$125.00	($ 60)	($ 589.82)	($ 524.82)
Gasoline - heavy	125.00	(210)	(1,462.27)	(1,547.27)
Diesel - medium	264.16	(96)	(387.07)	(218.91)
Diesel - heavy	487.62	(336)	(405.50)	(253.88)

[1] Source: Table 7-1.

[2] Source: Tables 7-4a and 7-4b.

[3] Source: Tables 7-3a and 7-3b. Net present value computed over 10 years at 10% interest (PV factor = 6.144).

TABLE K-3 CALCULATION OF EQUIVALENT PRICE FACTOR - MODEL 3

Type	Direct Price Change[1]	Indirect Price Change[2]	Present Value of Change in Operating Cost[3]	Total
Without Fan Savings				
Gas - medium	$ 300.00	$ 2	$ 129.02	$ 431.02
Gas - heavy	300.00	6	270.34	576.34
Diesel - medium	1,129.12	11	755.71	1,895.83
Diesel - heavy	1,119.32	35	2,205.70	3,360.02
With Fan Savings				
Gas - medium	$ 300.00	($58)	($516.10)	($274.10)
Gas - heavy	300.00	(204)	(1,290.24)	(1,194.24)
Diesel - medium	1,129.12	(85)	313.34	1,357.46
Diesel - heavy	1,119.32	(326)	712.70	1,506.02

1. Source: Data from table 7-1; computational procedure from page 7-16
2. Source: Tables 7-4a and 7-4b.
3. Source: Tables 7-3a and 7-3b. Net present value computed over 10 years at 10% interest (PV factor = 6.144).

APPENDIX L: IMPACT OF QUIETING OPTIONS ON TRUCK VOLUME

This appendix presents detailed forecasts of truck volume for each truck category under the three models developed with hypothetical standards and effective dates. The method of computation is described in Section 7.

TABLE L-1 REVISED VOLUME FORECAST (WITHOUT FAN SAVINGS) GASOLINE – MEDIUM DUTY

Year	Baseline Forecast	Volume Reduction		
		Model 1	Model 2	Model 3
1976	203,900	0	0	0
1977	206,800	0	0	0
1978	209,800	0	4,616	4,616
1979	212,800	0	4,682	4,682
1980	215,700	0	4,745	4,745
1981	218,700	4,811	11,482	11,482
1982	221,600	4,875	11,634	11,634
1983	224,600	11,792	11,792	11,792
1984	228,500	11,996	11,996	11,996
1985	231,500	12,154	12,154	12,154
1986	234,400	12,306	12,306	12,306
1987	237,400	12,464	12,464	12,464
1988	241,300	12,668	12,668	12,668
1989	244,300	12,826	12,826	12,826
1990	248,200	13,031	13,031	13,031
1991	251,200	13,188	13,188	13,188
1992	255,100	13,393	13,393	13,393
1993	258,100	13,550	13,550	13,550
1994	262,000	13,755	13,755	13,755
1995	265,900	13,960	13,960	13,960
1996	269,900	14,170	14,170	14,170
1997	273,800	14,375	14,375	14,375
1998	276,800	14,532	14,532	14,532
1999	280,700	14,737	14,737	14,737
2000	284,700	14,974	14,974	14,947

TABLE L-2 REVISED VOLUME FORECAST (WITHOUT FAN SAVINGS) GASOLINE – HEAVY DUTY

Year	Baseline Forecast	Volume Reduction		
		Model 1	Model 2	Model 3
1976	40,400	0	0	0
1977	39,400	0	0	0
1978	38,100	0	564	564
1979	38,400	0	568	568
1980	38,600	0	571	571
1981	38,700	573	1,366	1,366
1982	38,800	574	1,370	1,370
1983	38,800	1,370	1,370	1,370
1984	38,700	1,366	1,366	1,366
1985	38,600	1,363	1,363	1,363
1986	38,400	1,356	1,356	1,356
1987	38,100	1,345	1,345	1,345
1988	37,700	1,331	1,331	1,331
1989	37,200	1,313	1,313	1,313
1990	36,600	1,292	1,292	1,292
1991	35,900	1,267	1,267	1,267
1992	35,000	1,236	1,236	1,236
1993	33,900	1,197	1,197	1,197
1994	32,800	1,158	1,158	1,158
1995	31,500	1,112	1,112	1,112
1996	32,800	1,158	1,158	1,158
1997	34,200	1,207	1,207	1,207
1998	35,700	1,260	1,260	1,260
1999	37,200	1,313	1,313	1,313
2000	38,800	1,370	1,370	1,370

TABLE L-3 REVISED VOLUME FORECAST (WITHOUT FAN SAVINGS) DIESEL – MEDIUM DUTY

Year	Baseline Forecast	Volume Reduction		
		Model 1	Model 2	Model 3
1976	3,100	0	0	0
1977	3,200	49	49	49
1978	3,200	49	49	99
1979	3,200	49	49	99
1980	3,300	51	51	102
1981	3,300	102	102	604
1982	3,400	105	105	623
1983	3,400	623	623	623
1984	3,500	641	641	641
1985	3,500	641	641	641
1986	3,600	659	659	659
1987	3,600	659	659	659
1988	3,700	677	677	677
1989	3,700	677	677	677
1990	3,800	696	696	696
1991	3,800	696	696	696
1992	3,900	714	714	714
1993	3,900	714	714	714
1994	4,000	732	732	732
1995	4,100	751	751	751
1996	4,100	751	751	751
1997	4,200	769	769	769
1998	4,200	769	769	769
1999	4,300	787	787	787
2000	4,300	787	787	787

TABLE L-4 REVISED VOLUME FORECAST (WITHOUT FAN SAVINGS) DIESEL — HEAVY DUTY

Year	Baseline Forecast	Volume Reduction		
		Model 1	Model 2	Model 3
1976	164,600	0	0	0
1977	173,600	1,493	1,493	1,493
1978	184,900	1,590	1,590	8,117
1979	194,600	1,674	1,674	8,543
1980	204,400	8,973	8,973	8,973
1981	214,300	9,408	9,408	19,994
1982	225,200	9,886	9,886	21,011
1983	236,200	22,037	22,037	22,037
1984	248,300	23,166	23,166	23,166
1985	260,400	24,295	24,295	24,295
1986	273,600	25,527	25,527	25,527
1987	287,900	26,861	26,861	26,861
1988	302,300	28,205	28,205	28,205
1989	316,800	29,557	29,557	29,557
1990	333,400	31,106	31,106	31,106
1991	350,100	32,664	32,664	32,664
1992	367,000	34,241	34,241	34,241
1993	385,100	35,930	35,930	35,930
1994	404,200	37,712	37,712	37,712
1995	424,500	39,606	39,606	39,606
1996	443,200	41,351	41,351	41,351
1997	461,800	43,086	43,086	43,086
1998	481,300	44,905	44,905	44,905
1999	501,800	46,818	46,818	46,818
2000	523,200	48,815	48,815	48,815

TABLE L-5 REVISED VOLUME FORECAST (WITH FAN SAVINGS) DIESEL – MEDIUM DUTY

Year	Baseline Forecast	Volume Reduction		
		Model 1	Model 2	Model 3
1976	3,100	0	0	0
1977	3,200	0	0	0
1978	3,200	0	0	0
1979	3,200	0	0	0
1980	3,300	0	0	0
1981	3,300	0	0	433
1982	3,400	0	0	446
1983	3,400	446	446	446
1984	3,500	459	459	459
1985	3,500	459	459	459
1986	3,600	472	472	472
1987	3,600	472	472	472
1988	3,700	485	485	485
1989	3,700	485	485	485
1990	3,800	498	498	498
1991	3,800	498	498	498
1992	3,900	511	511	511
1993	3,900	511	511	511
1994	4,000	524	524	524
1995	4,100	538	538	538
1996	4,100	538	538	538
1997	4,200	551	551	551
1998	4,200	551	551	551
1999	4,300	564	564	564
2000	4,300	564	564	564

TABLE L-6 REVISED VOLUME FORECAST (WITH FAN SAVINGS) DIESEL — HEAVY DUTY

Year	Baseline Forecast	Volume Reduction		
		Model 1	Model 2	Model 3
1976	164,600	0	0	0
1977	173,600	0	0	0
1978	184,900	0	0	0
1979	194,600	0	0	0
1980	204,400	0	0	0
1981	214,300	0	0	8,958
1982	225,200	0	0	9,413
1983	236,200	9,873	9,873	9,873
1984	248,300	10,379	10,379	10,379
1985	260,400	10,885	10,885	10,885
1986	273,600	11,436	11,436	11,436
1987	287,900	12,034	12,034	12,034
1988	302,300	12,636	12,636	12,636
1989	316,800	13,242	13,242	13,242
1990	333,400	13,936	13,936	13,936
1991	350,100	14,634	14,634	14,634
1992	367,000	15,341	15,341	15,341
1993	385,100	16,097	16,097	16,097
1994	404,200	16,896	16,896	16,896
1995	424,500	17,744	17,744	17,744
1996	443,200	18,526	18,526	18,526
1997	461,800	19,303	19,303	19,303
1998	481,300	20,118	20,118	20,118
1999	501,800	20,975	20,975	20,975
2000	523,200	21,870	21,870	21,870

APPENDIX M: FIRST-YEAR OPERATING COSTS FOR QUIETED TRUCKS

This appendix presents the basis for the data contained in Tables 7-13a and 7-13b. Annual costs per truck were obtained by summing, for each truck category, the depreciation, cost of capital, and operating and maintenance expenses. Depreciation was computed using a 10-year straight-line method. The cost of capital was assumed to be 10%. Annual operating and maintenance costs were obtained from Tables 7-1a and 7-2b. The figures in those tables were computed using average annual mileages; since the first-year mileages are of interest, the numbers in the tables were multiplied by the scale factors in Table M-1 below. The scale factors represent the ratio of first-year to average annual mileage as obtained from analyzing U.S. Bureau of the Census data (see references, Section 7).

TABLE M-1 SCALE FACTORS FOR COMPUTING FIRST-YEAR OPERATING AND MAINTENANCE COSTS

Category	Scale Factor
Gasoline - medium	2.30
Gasoline - heavy	1.83
Diesel - medium	1.43
Diesel - heavy	1.35

The first-year annual costs computed in this manner are shown in Tables M-2 through M-4.

TABLE M-2 INCREASED FIRST-YEAR COSTS PER TRUCK – MODEL 1
( ) REPRESENTS SAVINGS

	Depreciation[1]	Cost of Capital[2]	Quantity and Maintenance[3]	Total
	Without Fan Savings			
Gasoline - medium	0	0	0	0
Gasoline - heavy	0	0	0	0
Diesel - medium	$10.42	$10.42	$ 13.00	$ 33.84
Diesel - heavy	19.46	19.46	26.00	64.92
	With Fan Savings			
Gasoline - medium	$ 7.00	$ 7.00	($121.00)	($107.00)
Gasoline - heavy	.20	.20	(220.00)	(219.60)
Diesel - medium	2.48	2.48	(90.00	(85.12)
Diesel - heavy	(14.35)	(14.35)	(303.00)	(321.70)

[1]10-year straight-line depreciation.
[2]10% cost of capital.
[3]Obtained from Tables 7-2a, 72-b, and M-1.

TABLE M-3 INCREASED FIRST-YEAR COSTS PER TRUCK – MODEL 2
( ) REPRESENTS SAVINGS

	Depreciation[1]	Cost of Capital[2]	Quantity and Maintenance[3]	Total
	Without Fan Savings			
Gasoline – medium	$12.50	$12.50	$ 21.00	$ 46.00
Gasoline – heavy	12.50	12.50	35.00	60.00
Diesel – medium	26.42	26.42	13.00	65.84
Diesel – heavy	48.76	48.76	238.00	335.52
	With Fan Savings			
Gasoline – medium	$ 6.50	$ 6.50	($221.00)	($208.00)
Gasoline – heavy	(8.50)	(8.50)	(436.00)	(453.00)
Diesel – medium	16.82	16.82	(90.00)	(56.36)
Diesel – heavy	15.16	15.16	(89.00	(58.68)

[1]10-year straight-line depreciation.
[2]10% cost of capital.
[3]Obtained from Tables 7-2a, 7-2b, and M-1.

TABLE M-4 INCREASED FIRST-YEAR COSTS PER TRUCK — MODEL 3
( ) REPRESENTS SAVINGS

	Depreciation[1]	Cost of Capital[2]	Quantity and Maintenance[3]	Total
	Without Fan Savings			
Gasoline - medium	$ 30.20	$ 30.20	$ 48.00	$108.40
Gasoline - heavy	30.60	30.60	81.00	142.42
Diesel - medium	114.01	114.01	176.00	404.02
Diesel - heavy	115.43	115.43	485.00	715.86
	With Fan Savings			
Gasoline - medium	$ 24.20	$ 24.20	($193.00)	($144.60)
Gasoline - heavy	9.60	9.60	(385.00)	(365.80)
Diesel - medium	104.41	104.41	(73.00)	135.82
Diesel - heavy	79.33	79.33	(157.00)	1.66

[1]10-year straight-line depreciation.
[2]10% cost of capital.
[3]Obtained from Tables 7-2a, 7-2b, and M-1.

APPENDIX N: IMPACT OF LEAD TIMES ON MANUFACTURERS OF "NOISY" ENGINES

Acoustical consultants have estimated that, at the current state of the art, it will take six years on a normal, orderly lead time basis to quiet noisy diesel truck engines to a noise standard such as that used for model 2. The time required is almost the same under model 3. Noisy engines now constitute 30% to 40% of the truck market. Most of the noisy engines are produced by one of the major engine manufacturers with a strong market position. It would appear that the stance of the manufacturer on this matter is that only a three-year quieting program would be required and that he is not at a competitive disadvantage with respect to quieting his engines.

Furthermore, it is possible that a priority R&D effort possibly utilizing "new" as opposed to "available" technology could provide the necessary modifications required to meet the standards in Model 2 in three years. If noisy engines cannot, in fact, be quieted in three years, a model 2 noise standard in that time frame will have impacts on that particular manufacturer. However, the competitive position of this major producer of noisy engines would be one of a short-term competitive disadvantage. In the longer term, it is believed that this producer has the demonstrated financial, business management, and technical resources to compete effectively. Within a few years of the effective date of the levels used in model 2, or possibly months, the competitive disadvantage would be eliminated. Any one of a number of factors could cause this:

1. Results of a new R&D program that was not ready for the effective date of Model 2 or its equivalent.

2. The possible introduction of new engines now in development, which are quieter.

3. Implementation of a standard similar to that in model 3 which imposes the same general level of technological requirements on quiet engines as noisy engines. Prior to the effective date of such model 3 levels, some new trucks would probably incorporate these designs in an orderly changeover of complete product lines. These trucks could meet levels such as those "noisy" engines in model 2.

4. After three years have passed and the off-the-shelf technology has been applied to permit use of "noisy" engines. On a priority basis the normal, orderly lead time should be able to be cut for some large-volume truck models to less than 3 years after enforcement of a standard similar to that in model 2.

The reputation of the noisy engine producer with end users is very strong. It is likely that this truck manufacturer would make an effort to use his other popular engines, especially since the supply of overall engines may be affected if the noisy engines cannot be utilized under regular production conditions. It is, however, envisioned that the weakness of this producer of truck engines will be taken advantage of by other engine producers who could be expected to respond with a major effort to penetrate the large and growing truck market. Again, since the weakness will probably be only temporary, it is unlikely that there would be long-term investments that would reflect the "noisy" proucer's absolute decline in the market.

The noisy engine producer can be expected to make short-term concessions and take other actions to protect his market position against competitive inroads while bringing about a solution to the problem he may face by having lagged behind ofther truck engine manufacturers in the area of noise control.

According to U.S. Department of Commerce data, 439,310 diesel engines were produced in 1972. Of these, 41% were for the automotive industry, of which almost 100% were for medium or heavy duty trucks. Trucks are the largest single market segment for diesel engines. The noisy engines represent 12% to 16% of the total diesel engine market. Currently, the diesel engine market is capacity constrained - some producers are on allocation and new order lead times are often over one year.

In the short run, based on the above factors, the following scenario has been developed to consider the possible consequences if noise standards cannot be met by the noisy engines:

1. A shortage of diesel engines occurs in the truck market, since noisy engines cannot be used or require much higher costs to use.

2. The supply of quiet engines is capacity constrained. Prices are firm and profits of producers of quiet engines are high. Quiet engines are allocated to truck manufacturers. Allocations will reflect an attempt to develop long-term relationships, with each manufacturer of quiet taking best advantage of his pattern of parts distribution, service, and other competitive strengths. Quiet engines are shifted from other less noise-sensitive markets to the truck market, reflecting both

the opportunity in the truck market and the strong price competition in the other markets from noisy engines which cannot be used in trucks. Manufacturers of quiet engines will compute less in small markets which show little growth opportunity.

3. The producer of noisy engines will shift sales emphasis from the truck market to less noise-sensitive markets. To maintain volume, price weakness will become common. Temporary noise rebates may be made to truck manufacturers by engine manufacturers as partial compensation for customizing required to use noisy engines. Cooperative programs will be established with primary truck manufacturer customers to speed the development of such changes as cab redesign, which will be required if noisy engines are to be used and, at the same time, to prepare for lower future noise levels. The engine horsepower specifications will be derated if this will improve noise characteristics. The volume of noisy engine production will decline. Market share of the truck market will decline; his profits will decline; and unemployment will occur in plants producing noisy engines.

The extent of time over which the above scenario will take place depends on the length of time required for the noisy engine manufacturer to become fully competitive again. Anything longer than three to six months would result in a loss in competitive position that would take years to regain.

APPENDIX O: PROJECTIONS BASED ON TRUCK POPULATION AND USE DATA

Many of tables and figures in Sections 3 and 8 were derived from data acquired by the Bureau of the Census. In this appendilx, the census data base and the operations performed with these data are discussed.

DATA BASE

The Bureau of the Census has conducted surveys of a statistical sample of trucks registered in the 50 states and the District of Columbia in 1963, 1967, and 1972, in order to collect and publish data on the characteristics and use of the nation's truck resources. A facsimile of the questionnaire used in the 1972 survey is included at the end of this appendix.

The data obtained from this survey are available in the form of a magnetic tape which consists of records for a sample of 99,8?0 trucks and the expansion factors necessary to extend this sample to obtain estimates for the entire 1972 truck population.

The expansion factor associated with each truck is the number by which the truck's statistical parameters are multiplied to estimate an equivalent number of trucks in the U. S. Truck Population. For example, there is a large number of pickup trucks in use, many of which have similar physical and usage characteristics. Therefore it is not necessary to sample as large a proportion of pickup trucks as, say, medium duty diesel trucks, since under these conditions, pickup trucks would have a higher expansion factor than medium duty diesel trucks.

Also, the Census Bureau samples by state, and the truck population of the various states varies widely. To obtain equal confidence limits on data sampled for each state, it is not necessary to sample the same percentage of the state's truck population. Thus, data for each state will tend to have separate expansion factors.

ANALYSIS OF DATA

It was felt that a sample size of 10,000 of the 100,000 trucks on the Bureau of Census tape was adequate for statistical reliability. Accordingly, every tenth truck on the tape was sampled and sorted by model year, category, and engine type as shown in the Table 0-1. Each truck identified by model year, category and engine type is characterized by two parameters: the expansion factor F and the mileage factor . The mileage factor is the truck mileage driven during the 12 months prior to the time the census questionnaire was filled out

TABLE O-1 TRUCK IDENTIFICATION TABLE

Model Year	Medium Duty Truck		Heavy Duty Truck	
	Gasoline	Diesel	Gasoline	Diesel
1931	$F^1_{1931,1}$ $M^1_{1931,1}$ $F^1_{1931,2}$ $M^1_{1931,2}$ ⋮ ⋮			
1932				
1933				
⋮ 1972				

by each truck owner. In these factors, the subscript m represents the model year, i the ith truck found in a particular truck category for a given model year, and the superscript k designates truck category as follows:

- k = 1 represents gasoline engine medium duty trucks
- k = 2 represents diesel engine medium duty trucks
- k = 3 represents gasoline engine heavy duty trucks
- k = 4 represents diesel engine heavy duty trucks

To project future truck population from past production estimates, it is necessary to know the percentage of trucks that survive as a function of age. This is computed from the equation

(O. 1)

Here, the subscript j denotes the age of the truck, and k is a truck category superscript and not a power. Thus the survival factor S is the fraction of trucks in truck category k still surviving j years after production. The number 10 in the right hand side of Equation (O-1) is used to extend the results from the 10,000 truck sample to 100,000 surveyed. P is the truck production term and the are simply the expansion factors for each truck in a given truck category for a particular model year. As an example of the application of Equation (O-1), consider the formula for computing the percentage of gasoline engine heavy duty trucks (k =3) surviving after five years:

With the survival rate available from Eq. (A.1), the truck population T_c^k in calendar year c for truck category k is computed from the equation

$$T_c^k = \sum_{j=0}^{25} P_{c-j}^k \, S_j^k \qquad (0.2)$$

where P_{c-j}^k is the number of trucks in category k produced in the year c-j. Eq. (0.2) represents the convolution of the survival function S with the production function P.

Some of the curves in Section 8 show growth and decline of truck populations manufactured in a several year period from model years m_1 through m_2. These populations are computed from

$$T_{c,m_1,m_2}^k = \sum_{j=c-m_1}^{c-m_2} P_{c-j}^k \, S_j^k \qquad (0.3)$$

Thus, for example, the total truck population in 1990 that is projected to be built and thus will meet an 83 dBA level under the option 2 noise regulation can be computed by summing

$T^1_{1990,1977,1977} + T^2_{1990,1977,1980} + T^3_{1990,1977,1977} + T^4_{1990,1977,1980}$.

The average mileage M_j^k traveled by trucks j years old in truck category k is given by

$$M_j^k = \frac{\sum_i (M_{1971-j,i}^k \, F_{1971-j,i}^k)}{\sum_i F_{1971-j,i}^k} \qquad (0.4)$$

Finally, the mileage-weighted acoustic energy level E_c produced by the total population of trucks in calendar year c is computed as

$$E_c = 10 \log \left[\sum_{k=1}^{4} \sum_{j=1}^{25} P_{c-j}^k S_j^k M_j^k \text{ antilog} \left(\frac{N_{c-j}^k}{10} \right) \right] \qquad (0.5)$$

where N_{c-j}^k is the noise level for a truck in category k produced in the year c-j.

O.M.B. No. 41-S71070; Approval Expires December 31, 197[illegible]

FORM TI-2?? (8-29-71) U.S. DEPARTMENT OF COMMERCE BUREAU OF THE CENSUS

1972 CENSUS OF TRANSPORTATION TRUCK INVENTORY AND USE SURVEY

NOTICE – Response to this inquiry is required by law (Title 13, U.S. Code). By the same law, your report to the Census Bureau is confidential. It may be seen only by sworn Census employees and may be used only for statistical purposes. The law also provides that copies retained in your files are immune from legal process.

INSTRUCTIONS

In correspondence pertaining to this report, please include State and license number.

Return the form in the enclosed pre-addressed postage-paid envelope not later than 15 days after receipt to:

Bureau of the Census
ATT: Transportation Division
Washington, D.C. 20233

1 *(Please correct any error in name and address including ZIP code)* 2

Item 1 – VEHICLE IDENTIFICATION

Please correct any errors or omissions in the identification of the vehicle.

Make	Year model	Registered weight or capacity	State	License No.
3	4	5		

E: Please complete this form whether or not you are still the owner of the vehicle identified in item 1.

Item 2 – OWNERSHIP OF VEHICLE

6

Are you still the owner (or license holder) or lessee of this vehicle?

1 ☐ Yes

2 ☐ No

When did you sell, trade, or otherwise dispose of it? ...... Month and year

Item 3 – ACQUISITION OF VEHICLE

7

How did you acquire this vehicle?

1 ☐ Purchased new

2 ☐ Purchased used – *Specify year purchased* ⟶ ______

3 ☐ Leased from someone else

Item 4 – BASE OF OPERATION

a. What was the principal place from which the vehicle was operated?

City or town		
County 8	State 9	

b. Was this vehicle operated almost entirely in the State named in 4a? 10

1 ☐ Yes

2 ☐ No

Item 5 – VEHICLE MILES

ANNUAL MILES

a. What are the total miles this vehicle was driven during the past 12 months?... Miles 11

If vehicle was idle for the year enter "None." If less than 12 months, estimate probable miles for a year.

LIFE TIME MILES

b. What are the total miles this vehicle has been driven since new?........ Miles [illegible]

Give speedometer (odometer) reading or if not indicated by speedometer, give your best estimate.

Item 6 – LEASED TO OTHERS WITHOUT DRIVER

12

During the past 12 months, did you use this vehicle MOSTLY for leasing or renting (without driver) to others?

1 ☐ No – *Go to item 7 on page 2*

2 ☐ Yes – Was this vehicle usually leased or rented for: [illegible]

1 ☐ Less than 30 days? – [illegible]

2 ☐ 30 days or longer? – [illegible]

Please continue on page 2

Item 7 – MAJOR USE OF THE TRUCK OR COMBINATION

15

H[ow w]as the vehicle mostly used during the past 12 months? *(Mark (X) one box)*

[If] vehicle was leased to someone else (without driver) for periods of 30 days or more, mark (X) ONE box that describes the business of the person or company to whom you leased the vehicle the longest time.

- 01 ☐ Own farm or ranch or other agricultural activity
- 02 ☐ In forestry or lumbering
- 03 ☐ In mining or quarrying
- 04 ☐ In construction, buildings or roads
- 05 ☐ In manufacturing or processing
- 06 ☐ In wholesale and/or retail
- 07 ☐ For-hire transportation – Includes trucking services known as drayage, local cartage, household goods movers, common or contract motor carriers, commercial motor carriers, leased with driver, "owner-operators" under lease or contract.
- 08 ☐ For personal transportation – Used in place of an automobile to go from home to work; for outdoor recreation; camping; fishing; etc.
- 09 ☐ In utilities – telephone, electric, gas, etc.
- 10 ☐ In services – hotel, automobile repair, laundry, funeral services, advertising, plumbing repair, etc.
- 11 ☐ Other – If none of the above applies to the use you make of the vehicle, describe the main use of the vehicle here.

Item 8 – PRINCIPAL PRODUCTS CARRIED

Mark (X) ONE box which indicates product usually carried by this vehicle.

- 01 ☐ Farm products (fruit, grain, livestock, poultry, dairy products, florist and nursery products, etc.)
- 02 ☐ Mining products
- 03 ☐ Logs and other forest products
- 04 ☐ Processed foods (dressed meat, beverages, tobacco, etc.)
- 05 ☐ Textile mill products, including apparel and leather goods, etc.
- 06 ☐ Building materials (lumber, millwork, sand, gravel, glass, concrete, etc.)
- 07 ☐ Household goods (moving)
- 08 ☐ Furniture or hardware (not including household goods moving)
- 09 ☐ Paper products, including printing and publishing products
- 10 ☐ Chemicals or related products (including drugs, paints, fertilizers, etc.)
- 11 ☐ Petroleum or petroleum products
- 12 ☐ Primary metal products (ingot, billets, pipes, sheets, etc.)
- 13 ☐ Fabricated metal products except machinery and transportation equipment
- 14 ☐ Machinery except electrical
- 15 ☐ Electrical machinery, equipment, and supplies, including household appliances
- 16 ☐ Transportation equipment (motor vehicles, trailers, boats, motorcycles, etc.)
- 17 ☐ Scrap, refuse, and garbage
- 18 ☐ Mixed cargoes
- 19 ☐ Used mainly for personal transportation or as a service vehicle such as a "traveling workshop" or is equipped with a crane, compressor, etc.
- 20 ☐ Other – *Describe* →

Item 9 – PICKUP, PANEL, MULTI-STOP OR WALK-IN

a. Does this truck have a pickup, panel, multi-stop or walk-in body?

17

1 ☐ No

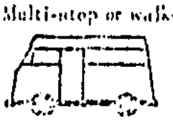
2 ☐ Yes – *Mark (X) the box in front of illustration of type and answer "b" and "c"*

18

1 ☐ Pickup truck

2 ☐ Panel truck

3 ☐ Multi-stop or walk-in



b. Does this pickup, panel, multi-stop or walk-in truck have 4-wheel drive?

19

1 ☐ Yes

2 ☐ No

20

c. Is this pickup, panel, multi-stop or walk-in truck equipped with a camper body or other special camping equipment?

1 ☐ Yes

2 ☐ No

...lease continue below

Item 10 – GROSS VEHICLE WEIGHT

21

Mark (X) ONE box that is nearest the maximum gross weight (empty weight of vehicle plus carried load) at which this truck or combination was operated during the past 12 months.

01 [ ] 6,000 or less	06 [ ] 19,501 to 26,000	11 [ ] 60,001 to 70,000
02 [ ] 6,001 to 10,000	07 [ ] 26,001 to 33,000	12 [ ] 70,001 to 80,000
03 [ ] 10,001 to 14,000	08 [ ] 33,001 to 40,000	13 [ ] 80,001 to 100,000
04 [ ] 14,001 to 16,000	09 [ ] 40,001 to 50,000	14 [ ] 100,001 to 130,000
05 [ ] 16,001 to 19,500	10 [ ] 50,001 to 60,000	15 [ ] 130,001 and over

Item 11 – TYPE AND SIZE OF BODY

Mark (X) ONE box to describe the type of body of the truck or combination. If the power unit is a truck-tractor, report body type of the combination most frequently used with the power unit.

Mark (X) ONE box to indicate length of load space or capacity. If two or more trailing units, (X) box for combined length or capacity.

BODY TYPE

22

01 [ ] Pickup, panel, multi-stop, walk-in
02 [ ] Platform with added devices – such as feed, fertilizer, lime or water spreader; dumping device, etc.
03 [ ] Other platform – including stake, grain, flatbed, low bed, depressed center, etc.
04 [ ] Cattle rack (hogs, calves, and other livestock)
05 [ ] Insulated non-refrigerated van
06 [ ] Insulated refrigerated van
07 [ ] Furniture van
08 [ ] Open top van
[ ] All other enclosed vans
[ ] Beverage
[ ] Utility (body equipped for mobile repair and service, e.g., telephone line truck, electrical utility, etc.)

→ 23

Length of load space (feet)

01 [ ] Under 10
02 [ ] 10 and less than 13
03 [ ] 13 and less than 16
04 [ ] 16 and less than 20
05 [ ] 20 and less than 28
06 [ ] 28 and less than 36
07 [ ] 36 and less than 41
08 [ ] 41 or more

12 [ ] Garbage or refuse collector
13 [ ] Winch or crane, other than wrecker
14 [ ] Wrecker
15 [ ] Pole or logging
16 [ ] Auto transport

→ *Do not specify body size for these types.*

20 [ ] Dump truck or combination → Capacity of dump (water level without side boards) (cubic yards)

21 [ ] Under 5	24 [ ] 10 to 11.9	27 [ ] 18 to 19.9
22 [ ] 5 to 6.9	25 [ ] 12 to 14.9	28 [ ] 20 to 29.9
23 [ ] 7 to 9.9	26 [ ] 15 to 17.9	29 [ ] 30 or more

30 [ ] Tank truck or combination (for liquids) → Liquid capacity of tank (gallons)

31 [ ] Less than 1,000	35 [ ] 4,000 to 5,999
32 [ ] 1,000 to 1,999	36 [ ] 6,000 to 7,999
33 [ ] 2,000 to 2,999	37 [ ] 8,000 to 11,999
34 [ ] 3,000 to 3,999	38 [ ] 12,000 or more

40 [ ] Tank truck or combination (for dry bulk) → Dry bulk capacity (cubic feet)

41 [ ] Less than 300	44 [ ] 900 to 1,199
42 [ ] 300 to 599	45 [ ] 1,200 to 1,499
43 [ ] 600 to 899	46 [ ] 1,500 or more

50 [ ] Concrete mixer → Capacity of mixer (cubic yards)

51 [ ] Less than 6	54 [ ] 8 to 8.9	57 [ ] 11 to 11.9
52 [ ] 6 to 6.9	55 [ ] 9 to 9.9	58 [ ] 12 or over
53 [ ] 7 to 7.9	56 [ ] 10 to 10.9	

60 [ ] Other body types – (If the above descriptions do not satisfactorily describe your vehicle, please enter identifying body type and size or capacity.) →

Item 12 – VEHICLE TYPE 24

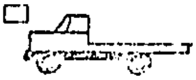
[illegible]s vehicle a single unit truck or is it [illegible]k-tractor?

1 [ ] Single unit truck 2 [ ] Truck-tractor

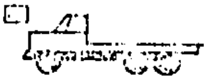
Item 13 – AXLE ARRANGEMENT 25

Mark (X) ONE box that illustrates the AXLE ARRANGEMENT of this truck or truck-tractor with the trailing unit most frequently used with the power unit.

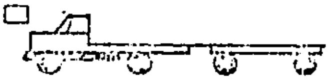
1 [ ]



2 [ ]

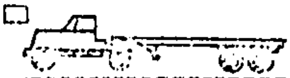


3 [ ]

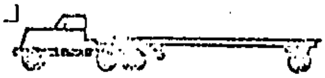


4 [ ]

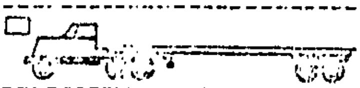
5 [ ]



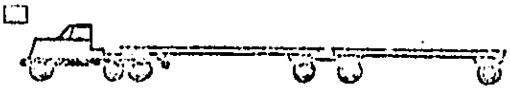
6 [ ]



7 [ ]



8 [ ]



9 [ ] If none of the above applies, please indicate total number of axles on:

	Total axles
Truck or truck-tractor	
Trailing unit(s)	

Item 14 – POWERED AXLES 26

How many driving (powered) axles does this vehicle have? *Report tandem axles as two axles.*

1 [ ] One 3 [ ] Three
2 [ ] Two 4 [ ] Four or more

Item 15 – CAB TYPE 27

Does this vehicle have a tilt cab?

1 [ ] Yes 2 [ ] No

Item 16 – TYPE OF FUEL 28

What type of fuel is used with this vehicle?

1 [ ] Gasoline 2 [ ] Diesel 3 [ ] LPG or other

Item 17 – MAINTENANCE 29

When MAJOR repairs were needed on this vehicle, were they usually done by:

1 [ ] Yourself?
2 [ ] Truck dealer or factory branch?
3 [ ] Own repair shop (set up specifically for maintenance)?
4 [ ] Independent garage?
5 [ ] Other? – *Describe* ________________

Item 18 – AREA OF OPERATION 30

Where was this vehicle MOSTLY operated?

Mark (X) ONE box only.

1 [ ] Mostly in the local area (in or around the city and suburbs, or within a short distance of the farm, factory, mine, or place vehicle is stationed).

2 [ ] Mostly over-the-road (beyond the local area) but usually not more than 200 miles one way to the most distant stop from the place vehicle is stationed.

3 [ ] Mostly over-the-road trips that usually are more than 200 miles one way to the most distant stop from place the vehicle is stationed.

Item 19 – NUMBER OF TRUCKS, TRUCK-TRACTORS AND TRAILERS OPERATED FROM "BASE OF OPERATIONS"

How many trucks, truck-tractors and trailers are you operating from the base named in item 4 on page 1? *Report total number including the vehicle which you described in this questionnaire.*

	Total	
Pickups, panels, multi-stops or walk-ins		31
Other trucks		32
Truck-tractors		33
Trailers (semi and full trailers).		34

Item 20 – Name of person to contact regarding this report	Address *(Number and street, city, State, ZIP code)*	Telephone *(Area code, number, extension)*

CERTIFICATION – This report is substantially accurate and has been prepared in accordance with [illegible]

Item 21 – Signature of person preparing this report	Title