Bolt Beranek and Newman Inc.

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Cost and Price Impacts of an 80-dBA Truck Noise Regulation

E.K. Bender, R.L. Bronsdon, and J.A. Kane

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Prepared for:
U.S. Environmental Protection Agency

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PREFACE

This report deals with the incremental price and cost impacts of implementing an 80-dBA noise regulation for medium and heavy duty trucks. The incremental impacts represent the price and cost differential of moving from the current 83-dBA regulation to an 80-dBA regulation. The results are based on updated estimates from the original Background Document, product verification reports, and estimates developed from the Quiet Truck Demonstration Program.

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1. INTRODUCTION

In 1976, the Environmental Protection Agency (EPA) promulgated noise emission regulations for newly manufactured medium and heavy duty trucks. The regulations instituted an 83-dBA maximum noise level that became effective January 1, 1978 and an 80-dBA noise level that was scheduled to become effective January 1, 1982. An extensive analysis of the technology and costs of the regulations was presented in the Background Document that accompanied the promulgation of the regulations.

Early in 1981, the Agency deferred the effective date of the 80-dBA noise level from 1982 to 1983.* This decision was made partially in response to industry contentions that the economic impacts of an 80-dBA level would be more severe than originally estimated because of changes in circumstances since the publication of the regulations and the Background Document in 1976. The Agency retained Bolt Beranek and Newman Inc. (BBN) to prepare estimates of the incremental costs and price impacts of an 80-dBA regulatory level, given current levels of truck noise. This report presents the findings of BBN's analysis.

This analysis is based in part on two data sources that were not available in 1976:

- Product verification data submitted by truck manufacturers to EPA
- Results of the EPA-sponsored Demonstration Truck Program.

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*_Federal Register_, Vol. 46, No. 17, Jan. 27, 1981.

BBN integrated these new data sources with information (updated as appropriate) from the original Background Document. The results of this analysis are summarized below and described in the remainder of this report. The BBN cost and price estimates are given in current 1980 dollars and are the *incremental* costs of moving from an 83-dBA to an 80-dBA regulatory level.

The estimates presented in this report were prepared under significant constraints. One must recognize these constraints in evaluating the estimates. The analysis had to be completed within 2 months. This short time frame and budgetary constraints prohibited a detailed engineering analysis of the specific treatments that would be required on a model-by-model basis for compliance with an 80 dBA level. Recognizing these constraints, BBN developed an analytical approach that made maximum use of available data and excluded physical inspection or field testing. The estimates presented here are based on this approach.

In addition to these constraints, it should also be recognized that product verification (PV) data, upon which a major portion of this report is based, represents worst case truck configurations. The PV data set therefore, is biased towards higher emission levels. The estimates of required noise reduction and the price of that reduction would be similarly biased.

Table 1 presents a summary of the medium and heavy duty truck market in calendar year 1980 and BBN's estimates of the incremental price of complying with an 80-dBA regulatory level. The market distribution data show the change that has occurred in recent years. Diesel-powered trucks now account for two thirds of the market, in comparison to one third reported in the 1976 Background Document. Each of the three compliance price series yields increases that are generally less than the $240 to $786 price increases (inflated to 1980 dollars) originally estimated by the Agency.

Section 2 of this report describes BBN's approach to estimating the market share of specific engines. Section 3 reports on the observed noise levels of those engines and BBN's approach to estimating required noise reduction. The estimated initial price impacts are presented in Sec. 4, and operating cost impacts are presented in Sec. 5.

TABLE 1 MARKET DISTRIBUTION AND COMPLIANCE PRICE SUMMARY, MEDIUM AND HEAVY TRUCK 80-dBA REGULATION – 1980.

U.S. Total Factory Sales	Classes 5 & 6	Classes 7 & 8	Total
Estimated Unit Sales			
• Gasoline	56,152	23,551	79,703
• Diesel	15,268	151,404	166,672
• Total	71,420	174,955	246,375
Percent Sales			
• Gasoline	22.8	9.6	32.4
• Diesel	6.2	61.4	67.6
• Total	29.0	71.0	100.0
Estimated Incremental Compliance Price			Sales-Wgtd Average
• Gasoline	$ 63.61	$ 40.25	$ 52.32
• Diesel*			
– Series 1	183.16	162.37	164.40
– Series 2	203.19	159.50	163.68
– Series 3	449.66	345.37	352.35

*Series 1 – Estimates based on improved exhaust systems and other source noise reduction at $80/dBA; Series 2 – Estimates based on improved exhaust systems and other source noise reduction at $70 to $140/dBA; Series 3 – Estimates based on Demonstration Truck Program experience of $129/dBA and a different estimation procedure.

Sources: Motor Vehicle Manufacturers Association Releases FS3 (2/4/81), FS5 (2/3/81), FS3-Supplement (3/4/81); BBN estimates.

2. DISTRIBUTION OF ENGINE MODELS

The dominant noise sources for both medium and heavy trucks are related to the engine selected. Engine casing noise, exhaust noise, and intake noise characteristics vary from engine to engine somewhat independently of the truck in which the engine is placed. The final measured truck noise level reflects the manufacturers' attempts to block, absorb, and muffle these engine sources. These efforts are often independent of cab type, vehicle class, or other vehicle characteristics.

Recognizing this, BBN chose to undertake an analysis of the market share of each engine and the noise level of trucks powered by each engine. This section describes the procedure by which BBN derived estimates of the 1980 market share of each engine model.

2.1 Diesel Engines

BBN estimated the market share of each engine model on the basis of:

- Sales of diesel-powered trucks by class and by truck manufacturer
- The distribution of engines by engine manufacturer and truck manufacturer
- The distribution of standard and optional engines by truck class, model, and manufacturer.

The Motor Vehicle Manufacturers' Association (MVMA) publishes several truck data series. One series reports sales of each truck manufacturer for 8 weight classes. A second series reports the distribution of diesel engines in trucks by engine manufacturer and truck manufacturer. BBN reviewed these data series and found that class 1 and 2 trucks were powered with engines from one group of engine manufacturers, while class 6, 7 and 8 trucks were powered with engines from an entirely different group of engine manufacturers* BBN therefore developed the distribution of diesel engines by engine manufacturer for class 6, 7 and 8 trucks directly from the MVMA data by subtracting the entries for class 1 and 2 trucks from the overall totals. This distribution is shown in Table 2.

Table 2 shows 1,203 Chevrolet trucks powered by Caterpillar engines. However, no published data show the distribution of these engines by specific engine model.** To estimate the distribution of specific models of engines, BBN constructed a matrix listing all the standard and optional engines available for each truck model produced. The *1980 Diesel Truck Index* was the primary source used to construct this matrix. Product literature was a secondary source. The matrix lists 122 specific truck models among 7 truck manufacturers and 80 specific engine models among 8 engine manufacturers. There are 668 engine-truck combinations -- 209 standard combinations and 459 optional combinations. Eighty-five percent of all combinations involved turbo-charged engines.

The information from the engine model/truck model matrix was combined with information upon which Table 2 is based to construct an allocation matrix for each manufacturer. Table 3 is an example of an allocation matrix for GMC trucks. There are control totals for each class and each engine manufacturer. The cell entries show the number of times a specific engine is offered as standard or as an option. Using this information and the allocation procedure described below, BBN estimated the number of specific engine

*There were no Class 3,4 or 5 diesel powered trucks reported by MVMA. C. F. MVMA Series FS-5, February 3, 1981

**Theoretically, one could obtain this information from the Vehicle Identification Number, but it is not available from commercial reporting services.

TABLE 2 DISTRIBUTION OF TRUCK SALES BY ENGINE MANUFACTURERS AND TRUCK MANUFACTURERS CLASS 6, 7, AND 8 DIESEL TRUCKS, 1980.

Truck Manufacturer	Engine Manufacturers							
	Caterpillar	Cummins	Detroit Diesel	International Harvester	Mack	Mercedes	Other	Total Sales
Chevrolet	1,203	236	3,563					5,002
GM	3,966	6,192	13,738					23,896
Ford	18,126	7,464	10,996					36,586
International Harvester	2,402	16,744	4,554	14,535				38,235
Mack	390	1,871	464		21,542		351	24,618
Freightliner	1,379	6,372	2,114					9,865
Kenworth	1,967	6,441	2,261					10,669
Peterbilt	1,441	4,259	1,287					6,987
White	566	4,669	1,618					6,853
Mercedes						646		646
Chrysler		168					1,056	1,224
Other	487	748	856					2,091
TOTAL SALES	31,927	55,164	41,451	14,535	21,542	646	1,407	166,672

Sources: Motor Vehicle Manufacturers' Association; BBN Estimates

TABLE 3 ALLOCATION OF ENGINES - GMC TRUCKS:
STANDARD (STD) AND OPTIONAL (OPT) ENGINE APPLICATIONS.

Engine Model	Class 6		Class 7		Class 8		Control Total
	Std	Opt	Std	Opt	Std	Opt	
Caterpillar							3,966
3206		2					
3406						2	
Cummins							6,192
230				2		2	
290				8		6	
350				7		6	
400						3	
Detroit Diesel							13,738
4-53	2						
6V-53	2						
6-71				4		4	
8V-71			4	2	4	2	
6V-92				3		3	
8V-92				1		1	
Control Total	5,545		2,127		16,224		23,896

models that were sold by each truck manufacturer. The results for each manufacturer are aggregated to obtain the overall distribution of 1980 engine model sales.

The BBN procedure allocated control totals among engine models on the basis of the number of times the engine was listed as a standard or optional engine. Standard engines received double weighting in the allocation process. The normal allocation procedure was first to allocate small control totals and then allocate residuals. Table 3 is an example: We first allocated the 3966 Caterpillar engines on GMC vehicles (c.f., Table 2) equally between class 6 and class 8. Then we calculated Class 6 Detroit Diesel applications as a residual of the class 6 control total. We were left with 2 engine makes, Cummins and Detroit Diesel, and 2 classes, 7 and 8. We allocated the 2127 class 7 applications between the 2 engine manufacturers on the basis of the number of times engines were available as standard or optional and then solved for class 8 applications as a residual from the engine control totals.

At this point, there was an allocation to each class/engine manufacturer combination. Each of these totals was allocated to a specific engine model on the basis of the number of times that engine was listed as standard or optional. For example, the 1033 Cummins engines for class 7 GMC trucks were allocated on the basis of 2/17, 8/17, 7/17, given the entries in Table 3. The output of this exercise for GMC trucks is shown in Table 4.

We repeated the allocation procedure for each truck manufacturer. The basic procedure was to construct an allocation matrix with control totals and then allocate to specific models on the basis of the model's availability. Tables comparable to Tables 3 and 4 were constructed for each truck manufacturer. The results for each truck manufacturer were aggregated to estimate the sales of each engine model.

TABLE 4 ESTIMATED DISTRIBUTION OF ENGINES - GMC TRUCKS 1980.

Engine	Class 6	Class 7	Class 8	Total
Caterpillar	1,983	-	1,983	3,966
3208	1,983	-		1,983
3406	-	-	1,983	1,983
Cummins	-	1,033	5,159	6,192
230	-	122	606	728
290	-	486	2,064	2,550
350	-	425	1,943	2,368
400	-	-	-	546
Detroit Diesel	3,562	1,094	9,082	13,738
4-53	1,781	-	-	1,781
6V-53	1,781	-	-	1,781
6-71	-	243	2,018	2,261
8V-71	-	608	5,046	5,654
6V-92	-	182	1,514	1,696
8V-92	-	61	504	565
TOTAL	5,545	2,127	16,224	23,896

Table 5 presents the results of this exercise. Of 166,672 diesel-powered trucks reported by MVMA to have been shipped in 1980, BBN was able to allocate specific engine models to 163,357. The 3,315 unallocated engines are accounted for by the 1,224 trucks produced by Chrysler for export and the 2,091 "other" trucks reported by MVMA. Cummins had the largest market share, 33.2 percent, with the Formula and NTC 290 engines having 18.5 percent of the market. Detroit Diesel accounted for one quarter of the market and had 4 engines, each of which had approximately 5 to 6 percent of the market. Caterpillar accounted for 19.3 percent of the market, and the 3406 was clearly the most popular Caterpillar engine. It is noteworthy that 2 engines, the Caterpillar 3406 and the Cummins 290, accounted for approximately one third of the market.

There is undoubtedly some degree of error in the distribution presented in Table 5 because of the working assumptions upon which the allocation process was based. Nevertheless, the estimated distribution is a reasonable basis upon which to proceed. The control totals minimize the potential for large errors and provide a basis for estimating sales of specific engine models.

2.2 Gasoline Engines

The 1980 sales of gasoline-powered medium and heavy duty trucks are summarized in Table 6. General Motors accounted for approximately half of the market, while Ford captured almost 40 percent. Gasoline engines are more prevalent in class 5 and 6 vehicles than in class 7 and 8 vehicles.

TABLE 5 DISTRIBUTION OF ENGINES - DIESEL-POWERED CLASS 6, 7, AND 8 TRUCKS; 1980 SHIPMENTS.

Engine Manufacturer and Model	Total Shipments 1980	Unallocated	Total Allocated	Medium (Class 6)	Heavy (Classes 7 & 8)
Caterpillar	31,927	487	31,440	5,605	25,835
• 3208			7,619	4,865	2,754
• 3306			231	--	231
• 3406			23,123	740	22,383
• 3408			467	--	467
Cummins	55,164	916	54,248	236	54,012
• 230			5,433	33	5,400
• 250			2,700	--	2,700
• 290/300			30,153	94	30,059
• 350			11,449	85	11,364
• 400			3,436	24	3,412
• 450 & others			1,077	--	1,077
Detroit Diesel	41,451	856	40,595	7,125	33,470
• 6-71			8,670	584	8,086
• 6V-92			9,954	1,402	8,552
• 8V-71			9,868	467	9,401
• 8V-92			7,606	175	7,431
• 4-53			2,015	2,015	--
• 6V-53			2,015	2,015	--
• 8.2L			467	467	--
International	14,535	0	14,535	2,422	12,113
• 9.0 Liter			4,360	1,453	2,907
• DT(I) 466			10,175	969	9,206
Mack	21,542	0	21,542	None	21,542
• ETZ 477			1,380		1,380
• ETZ 673			4,971		4,971
• ETAZ 673			3,867		3,867
• ETZ 675			4,695		4,695
• ENDT 676			4,143		4,143
• ETAZ 1000			2,486		2,486
Scania	351	0	351	None	351
Mercedes - OM 325	646	0	646	646	--
Other	1,056	1,056	0	--	--
Total	166,672	3,315	163,357	16,034	147,323

Source: BBN estimates.

TABLE 6 DISTRIBUTION OF GASOLINE TRUCK SALES BY MANUFACTURER CLASSES 5, 6, 7, AND 8, 1980.

Manufacturer	Classes 5 & 6	Classes 7 & 8	Total Number	Total Percent
Chevrolet	15,566	861	16,427	23.1
Ford	10,177	17,457	27,634	38.9
GMC	17,776	842	18,618	26.2
International Harvester	4,759	3,640	8,399	11.8
Subtotal	48,278	22,800	71,078	100.0
"Other"	7,874*	751	8,625*	-
TOTAL	56,152	23,551	79,703	-

*Primarily vehicles manufactured by Chrysler for export. All calculations based on 71,078 vehicles.

Sources: Motor Vehicle Manufacturers' Association Releases FS3 (2/4/81), FS5 (2/5/81), FS3-Supplement (3/4/81); BBN estimates.

It was not necessary to estimate the market share of each gasoline engine model because of the relatively low noise levels of gasoline-powered trucks. A preliminary review of product verification report noise levels, discussed in Sec. 3, showed that Ford and GMC vehicles were already below 80 dBA, while International Harvester gasoline-powered vehicles were just slightly above. The cost to quiet these vehicles could be estimated for each manufacturer without disaggregating the analysis to individual engines. Hence, BBN did not estimate the market share of gasoline engine models.

3. ESTIMATION OF REQUIRED NOISE REDUCTION

This section presents the procedure BBN used to estimate the required noise reduction for each of the engines identified in Sec. 2 to comply with the 80-dBA regulation. Truck noise sources are grouped as either 1) exhaust noise or 2) noise from all other sources. The latter category encompasses primarily engine, fan, and transmission noise. Since the overall truck noise level is the sum of the two constituent levels, we are able to generate a family of curves that show the relationship between exhaust noise and all other noise, and overall truck noise. This information is then used to determine the reduction of the constituent noise sources required to reduce overall truck noise to a 77.5-dBA design level for the 80-dBA regulatory level.

Figure 1 presents the general relationship between exhaust noise and other noise sources, and overall truck noise. The level of exhaust noise is shown along the horizontal axis. The overall noise level of the truck is shown on the vertical axis. The family of curves in Fig. 1 shows the level of all other sources. Referring to Fig. 1, we see exhaust noise of 80 dBA and other noise of 80 dBA (i.e., the curve labeled 80) which correspond to an overall truck noise level of 83 dBA. Likewise, exhaust noise of 75 dBA and other noise of 75 dBA yield an overall level of 78 dBA. Other combinations of exhaust and other source noise correspond to different levels of overall truck noise.

The relationships shown in Fig. 1 provide a framework to determine the amount and type of noise reduction required. We define a design goal of 77.5 dBA to ensure compliance with the proposed 80-dBA regulation. Given this design goal and the relationships in Fig. 1, we can define three distinct types of noise reduction strategies:

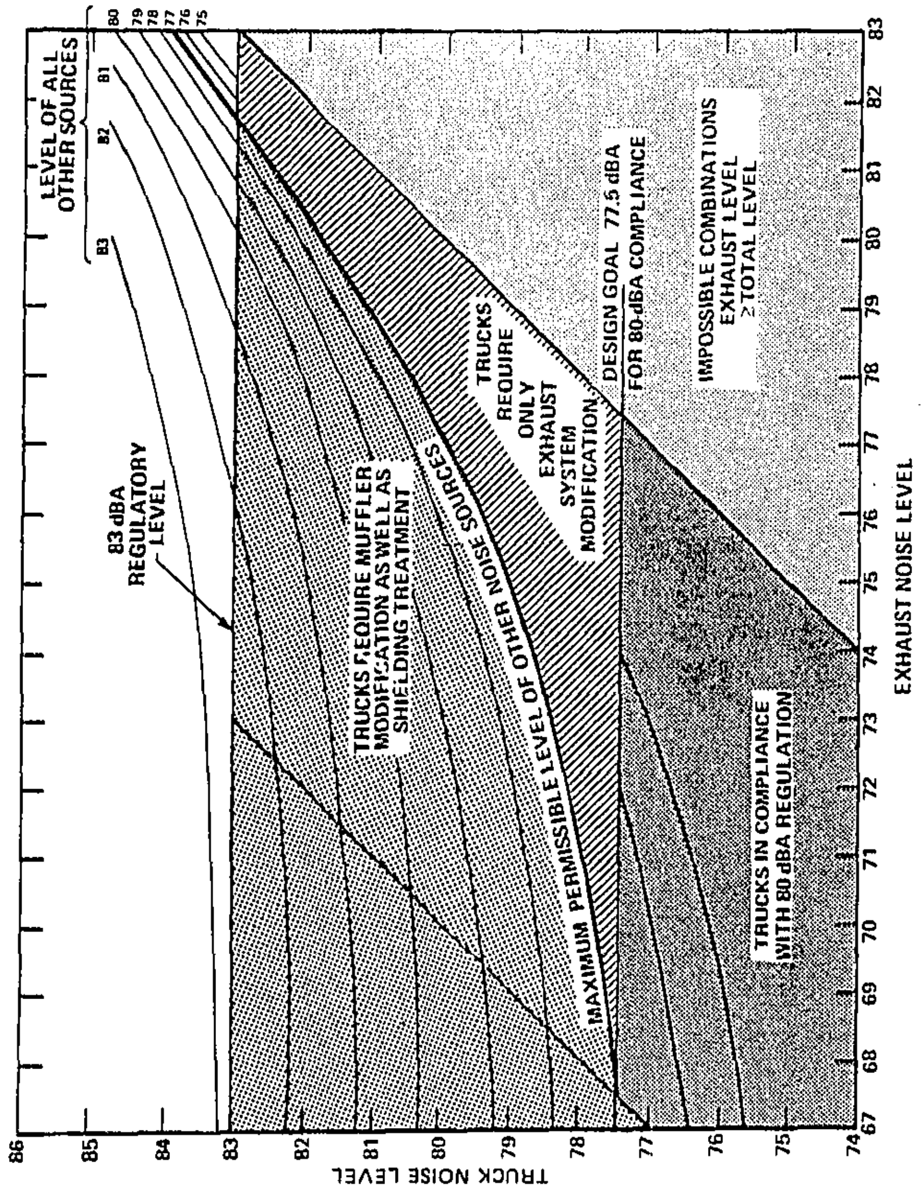

FIG. 1 GENERAL RELATIONSHIP BETWEEN THE TOTAL VEHICLE NOISE LEVEL, EXHAUST NOISE LEVEL, AND THE LEVEL OF NOISE FROM ALL OTHER SOURCES.

- Trucks already in compliance with an 80-dBA regulation and requiring *no* treatments
- Trucks requiring *only* exhaust system modification to comply with an 80-dBA regulation
- Trucks requiring *both* exhaust system modification and shielding treatments to comply with an 80-dBA regulation.

These three strategies are shown in the three different shaded areas in Fig. 1.

Trucks already in compliance are shown in the lower left corner of Fig. 1. Trucks that currently have other source noise at or below 77 dBA can meet the 77.5-dBA design goal by installing better exhaust systems. The effect is to move downward and to the left along the other source noise curves until an overall level of 77.5 dBA is achieved. Trucks that have other source noise in excess of 77 dBA require a two-step process to achieve compliance. First, other source noise must be reduced to 77 dBA (or lower). Once that level of other source noise is achieved, then exhaust system improvements can be used to achieve compliance.

We note that while 77.5 dBA may prove to be the design goal for a truck regulated to 80 dBA, there is no guarantee that all manufacturers will wish to achieve this level, since even a 79-dBA truck is in compliance. This trend can be seen in the product verification data for the 83-dBA regulation. While the noise level of the average truck is currently 80 dBA, there are as many whose noise level is above 80 dBA as below. Our estimates of required noise reduction are based on a design goal of 77.5 dBA. Any variation from that goal will affect the estimates of cost.

3.1 Diesel Engines

The major determining factor in the generation of truck noise is the engine. An analysis of the diesel truck market has shown that 15 engine models from 3 main manufacturers are used in more than 75% of trucks sold. As a result, our analysis of required noise reduction has been carried out for each of these engines.

The analytical framework represented in Fig. 1 provided a method to identify specific reduction goals. Product verification (PV) data provided information on current noise levels. We applied the PV data to our analytical framework to identify specific treatments for each engine to meet a 77.5-dBA design level.

We reviewed and processed the PV data to calculate the mean, standard deviation, minimum and maximum noise levels for all trucks in the PV data containing a particular engine. We processed 4,223 records from the PV data. The results of that exercise are shown in Table 7. We see, for example, that trucks with a Cummins 290 engine have an average noise level of 79.9 dBA and a standard deviation of 1.5 dBA. Given these observed values and a normal distribution, we can infer that 68 percent of Cummins 290-powered vehicles have noise levels of 78.4 to 81.4 dBA.

To determine how the distribution of truck noise levels, summarized in Table 7, mapped into the family of curves relating exhaust noise to all other sources, shown in Fig. 1, we made certain assumptions about the nature of the trucks' exhaust systems. While specific exhaust models were reported in some PV submissions, the data supplied to BBN described only the exhaust system configuration (Single Vertical Muffler, Vertical Stack or SVV, etc.). From this information, it was possible to identify several alternative types of mufflers, which could be expected to be found on the quietest and on the noisiest trucks. The quietest muffler

TABLE 7. DISTRIBUTION OF NOISE LEVELS OF TRUCKS WITH DIESEL ENGINES.

Engine Manufacturer and Model	Average SPL	Standard Deviation	No. of Observations
Caterpillar			
• 3208	80.9	1.2	139
• 3306	-	-	-
• 3406	80.1	1.45	893
• 3408	80.8	1.09	1099
Cummins			
• 230	79.4	1.7	93
• 250	79.8	1.3	39
• 290/300	79.9	1.5	233
• 350	79.8	1.4	168
• 400	80.6	1.1	203
• 450 & others	-	-	-
Detroit Diesel			
• 6-71	80.8	1.6	267
• 6V-92	79.9	1.4	318
• 8V-71	80.2	1.6	144
• 8V-92	80.7	1.3	391
• 4-53	81.8	1.0	9
• 6V-53	82.2	1.8	42
• 8.2L	79.8	0.5	6
International			
• 9.0 Liter	81.4	1.3	10
• DT(I) 466	80.8	1.3	16
Mack			
• ETZ 477	81.3	0.8	9
• ETZ 673 • ETAZ 673 • ETZ 675 • ENDT 676	80.1	1.1	113
• ETAZ 1000	80.0	1.2	14
Scania	-	-	-
Mercedes - OM 325	80.0	1.40	17
Other	-	-	-
Total			4223

Source: EPA Product Verification Reports - Summary Tabulations.

of the correct configuration was then assumed to be on the truck with the lowest reported noise level, and the noisiest muffler was assumed to be on the truck with the highest reported noise level. Between these two end points was drawn a straight line that defines the relationship between exhaust noise, noise from all other sources, and the overall reported truck noise level for a given type of engine. This is shown as line MN on Fig. 2.

Given the standard deviations presented in Table 7, error could be introduced into the analysis by considering only the mean noise level of an engine. It would be proportionately more expensive to quiet an 82-dBA truck to 77.5 dBA than to treat a 78-dBA truck, irrespective of the average value. We therefore considered the treatments (and subsequently costs) of quieting the average, noisier-than-average, and quieter-than-average engine for each engine model. We define these categories as:

average - ± one standard deviation around the mean value (e.g., 78.4 to 81.4 dBA for Cummins 290 engine)

noisier-than-average - greater than one standard deviation above the mean but less than 83 dBA (e.g., 81.4 to 83 dBA for Cummins 290 engines)

quieter-than-average - less than one standard deviation below the mean but greater than the 77.5-dBA design level (e.g., 77.5 to 78.4 dBA for Cummins 290 engines).

The midpoints of these 3 ranges were then plotted on the defined relationship of exhaust noise, other source noise, and overall truck noise for each engine type. These are shown as points $\overline{X}$, A, and B on line MN in Fig. 2. The same exercise was replicated for each of the engine models identified in the PV data. The results of that exercise are presented in Appendix A.

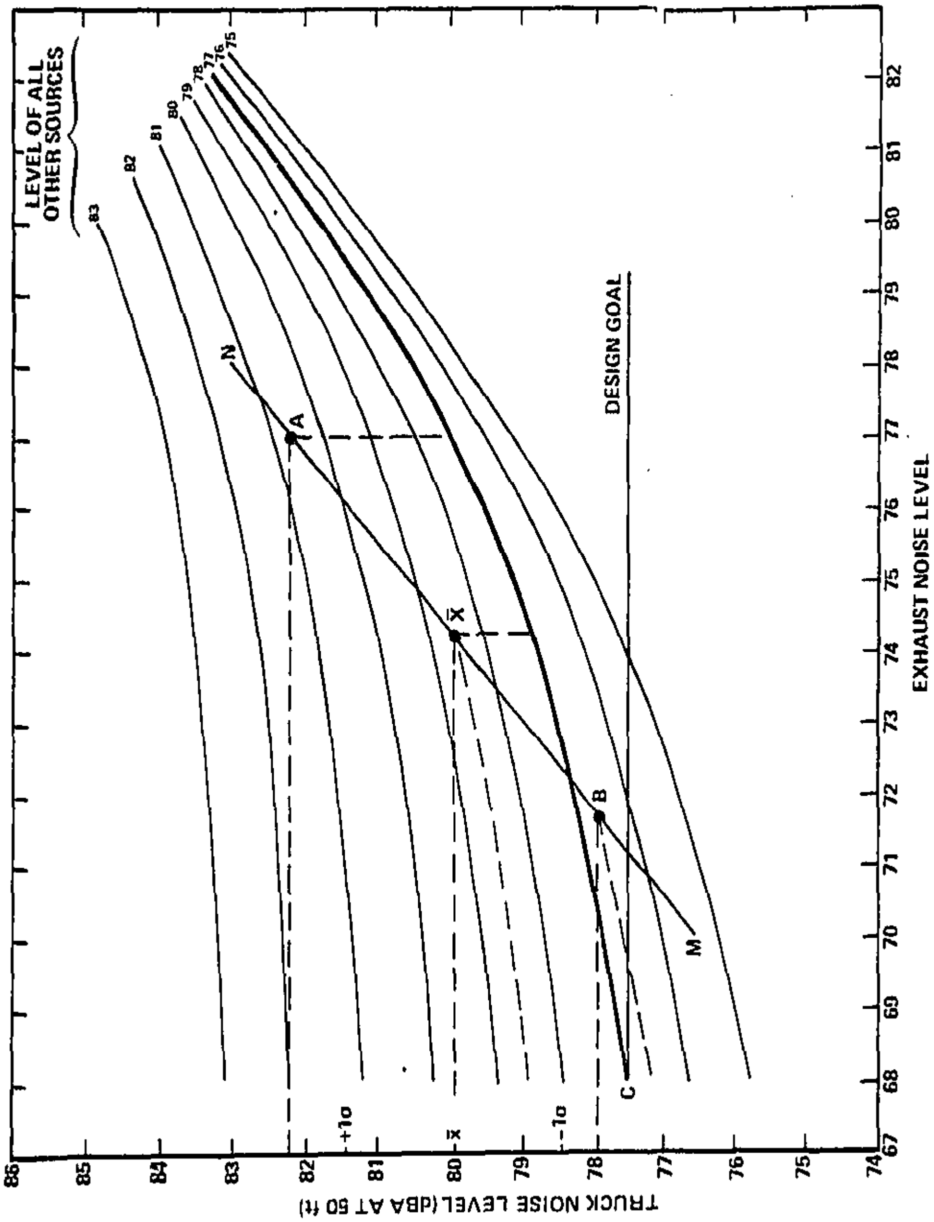

FIG. 2. NOISE REDUCTION APPROACH FOR A CUMMINS 290 ENGINE.

The final step in estimating the required noise treatments was to identify how treatments would be applied. For example, one could dramatically reduce other source noise through shielding, but leave the exhaust system untouched. On the other hand, even the quietest exhaust system might not bring overall truck noise to the 77.5-dBA design level. We determined the most cost-effective method of applying noise control treatments by reviewing available information. We specifically reviewed the noise reduction attributable to enclosures and exhaust systems reported in the Background Document and from the Demonstration Truck Program. We also examined the 1980 costs of these treatments. The available data show that exhaust system modifications are more cost-effective than enclosures and shielding to achieve a given level of noise reduction. Therefore, our procedure for applying treatments was to maximize the use of exhaust system modifications and to reduce other source noise only as much as necessary. The effect of this was to employ only as much shielding as necessary to reduce other source noise to 77 dBA and then reduce exhaust noise to 68 dBA, thereby reaching the design goal of 77.5 dBA.

These analyses are shown for the Cummins 290 engine in Fig. 3. The average truck with a noise level of 79.9 dBA will require a 1.5-dB reduction in the level of all sources other than exhaust and a 6-dB reduction in existing exhaust noise, which can be achieved with a better muffler. The higher level truck will require 3.6 dB of shielding as well as 9 dB of extra exhaust noise reduction. The quieter trucks will require only a 6-dB reduction in exhaust level.

3.2 Gasoline Engines

Product verification data for the major gasoline engines used in medium and heavy trucks are shown in Table 8. It is clear that in most cases little or no treatment would be required to

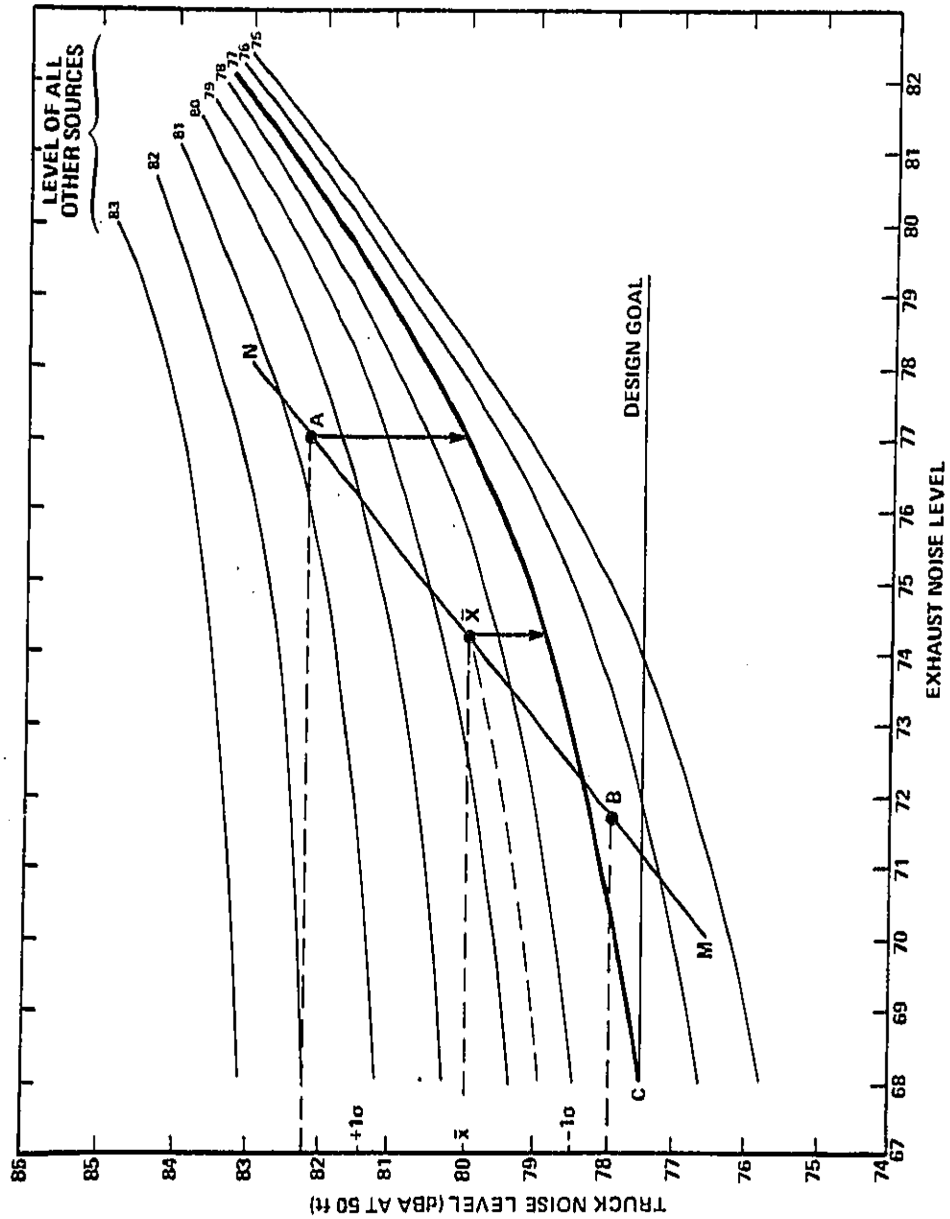

FIG. 3. APPROACH TO COSTS OF NOISE REDUCTION FOR A CUMMINS 290 ENGINE.

TABLE 8. DISTRIBUTION OF NOISE LEVELS BY GASOLINE ENGINES.

Manufacturer and Engine Displacement (cu in.)	Average SPL	Standard Deviation	No. of Observations
Ford	76.8	-	72
• 300	78.4	0.77	5
• 330	77.6	2.50	10
• 351	76.7	1.59	8
• 361	76.1	1.72	13
• 370	76.4	3.23	22
• 391	77.2	1.81	14
General Motors*	79.4	-	30
• 292	80.4	3.21	3
• 350	78.8	2.52	18
• 366	80.1	1.47	9
International Harvester	80.6	-	32
• 345	80.2	3.61	19
• 391	81.2	1.81	3
• 392	81.4	2.64	4
• 404	81.2	1.22	6

*Includes both Chevrolet and GMC trucks.

Sources: EPA product verification reports - summary tabulations.

reach the target level of 77.5 dBA. Table 9 shows estimates of treatments. Although far less data are available to pinpoint existing exhaust noise levels for gasoline engines, BBN's analysis of the available data indicated that a 6-dB reduction in exhaust noise would be sufficient to bring all Ford and General Motors engines into compliance. International Harvester engines are used only in International Harvester trucks. Given their noise levels in Table 8, BBN concluded that they will require an additional 1.4-dB reduction in engine noise levels through better shielding and underhood absorption in addition to 6 dBA of exhaust noise reduction.

These estimates for gasoline-engine-powered trucks are not based on data comparable to that available for muffler noise levels of diesel-engine-powered trucks. Discussions with muffler manufacturers indicated that present exhaust noise levels of about 79 dBA could be reduced to 73 dBA with better mufflers. This finding indicates that all other noise sources for an 81-dBA truck would total about 76 dBA and would have to be reduced by approximately 1.4 dBA to reach the 77.5-dBA goal.

TABLE 9 SUMMARY OF NOISE REDUCTION BY MANUFACTURER - GASOLINE-POWERED TRUCKS.

	Required dBA Reduction		Percent With Treatment
	Exhaust	Other Sources	
Ford	6	0	15
General Motors	6	0	100
International Harvester	6	1.4	100

Source: BBN estimates.

4. ESTIMATED INITIAL PRICE IMPACTS

The estimates of required noise reduction discussed in Sec.3 are the bases of estimated price increases presented in this section. Three price series are presented for diesel engines, and one price series for gasoline engines.*

4.1 Diesel Engines - Series 1 and 2

The first two series of estimated price increases are based on estimates of the required noise reduction from exhaust noise and all other sources. The essential steps in estimating the price of these reductions for each diesel engine model are:

1) Develop a family of curves depicting the relationships among overall truck noise, exhaust noise, and noise from all other sources. (These are shown in Sec. 3 and Appendix A.)

2) Estimate for each engine the percent of trucks at different overall noise levels on the basis of product verification noise levels and an assumed normal distribution.

3) Estimate for an average, noisier-than, and a quieter-than-average truck the amount of noise reduction that would be required for the exhaust system and "all other" sources.

4) Estimate the price of "all other" noise sources reduction on the basis of BBN estimates. (The estimated price per dBA for side shields, enclosures, etc. varies between series 1 and 2.)

*In this section, we refer to the *price* of noise reduction. This is the incremental price increase a purchaser would pay when buying a truck meeting an 80 dBA regulated level, as compared with a truck meeting the present 83 dBA level.

5) Estimate the price of exhaust system noise reduction based on noise levels and prices of alternative mufflers.

6) Estimate the overall price impact for each of the three trucks (average, noisier-than-average, quieter-than-average), and then estimate the weighted price on the basis of a normal distribution.

The easiest way to understand this procedure is to work through a specific example. We therefore present the pricing analysis for the Cummins 290 engine for which the estimated noise reduction was described in Sec. 3.1. Since we have already described how we developed the family of curves for exhaust, "all other," and overall noise, we begin this example at the second step in the procedure.

Estimate the Percent of Trucks at Different Noise Levels

The product verification data show that trucks powered by Cummins 290 series engines have a mean noise level of 79.9 dBA and a standard deviation of 1.5 dBA. We assume this distribution is normally distributed around the mean. We observe that the upper end of the distribution is effectively truncated at 83 dBA because of the current regulatory level. Given the normal distribution of these observations, the percent of the observations at various noise levels can be calculated from the area under the normal curve.

We estimated prices for an average, quieter-than-average, and a noisier-than-average engine, rather than estimate the price for the average Cummins 290 engine alone. If one dealt only with the average engine, one would fail to account for the relatively greater expense of quieting engines in the upper end of the distribution. This cost would not be exactly offset by the cost of quieting the below-average engines. We treated engines within one standard deviation of the mean as an average engine. Quieter-than-average engines ranged from 77.5 dBA to one standard deviation below the mean; noisier-than-average engines ranged from one standard deviation above the mean to 83.0 dBA. We used the midpoint of each of these ranges to estimate required noise reduction and the price of the reduction. Table 10 summarizes this exercise for Cummins 290 series engines.

TABLE 10. DISTRIBUTION OF CUMMINS 290 ENGINE BY TRUCK NOISE LEVEL.

Range (dBA)	Range Midpoint	Percent in Range
less than 77.5	-	5.5
77.5 to 78.4	77.9	10.4
78.4 to 81.4 (±1σ)	79.9 ($\bar{X}$)	68.3
81.4 to 83.0	82.2	15.8

Estimate Noise Reduction for Exhaust and "All Other" Sources

Figure 3 in Sec. 3 shows the family of curves for the Cummins 290 engine. The average observation, shown as $\bar{X}$ on line MN, corresponds to exhaust (E) noise of 74 and all other (A) noise of 78.5, i.e., midway between the 78 and 79 curves. The above-average observation, A, has exhaust noise of 77 dBA and (A) noise of approximately 80.6. The below-average point, B, corresponds to exhaust of approximately 71.5 and (A) noise of 76.7. In this step, we determine how to move from B, $\bar{X}$, and A to 77.5 dBA.

We assume that the manufacturer will use as much exhaust noise reduction as possible since this type of reduction is relatively less expensive than other forms of noise reduction. Hence, at $\overline{X}$, one would move down to the 77 "all other" curve with 1.5 dBA of (A) noise reduction and then move along that curve by reducing exhaust noise to 68 dBA. The combination of 77 (A) noise and 68 (E) noise results in a 77.5-dBA overall noise level.

This procedure is followed for the above-average and below-average observations. The results are summarized in Table 11. Note that no (A) noise reduction is required for the below-average observation.

TABLE 11. REQUIRED SOURCE NOISE REDUCTION - CUMMINS 290 ENGINE

	Below-Average	Average	Above-Average
Observed Overall Level	77.9	79.9	82.2
Other Source Level			
• Observed	76.7	78.5	80.6
• Target	76.7	77.	77.
Exhaust Source Level			
• Observed	71.5	74.8	77.
• Target	68.	68.	68.

Estimate the Price of "All Other" Noise Source Reduction

The required (A) noise reduction generally ranged from 2 to 4 dBA. BBN analyzed data from the Background Document and the Demonstration Truck Program to estimate the price of treatments to reduce "all other" (A) noise. Information presented in the Background Document, updated to 1980 prices, is summarized below:

- Side Shields

  2 to 3-dBA reduction
  $180 price in 1980*
  $60-90/dBA

- Side Shields

  4-dBA reduction
  $360 price in 1980
  $90/dBA

The following information was available from the Demonstration Truck Program:

- GMC Brigadier

  6 dBA of engine/transmission noise reduction
  $715 price in 1980**
  $119/dBA

- International Harvester F-4370

  8.9 dBA of engine/transmission noise reduction
  $795 price in 1980**
  $89/dBA

BBN used this information to estimate the price of (A) noise reduction. Given the observed variation in price per dBA, two series were developed:

- Series 1 - a uniform price of $80/dBA
- Series 2 - a variable price per dBA depending on the required reduction:

*Inflated by Producer Price Index for Transportation Equipment: 1973 = 115.1; 1980 = 206.8.

**These are 1979 dollar estimates from the Demonstration Truck Program inflated to 1980 dollars @ 9.5 percent.

- 0 to <2.5 dBA $71/dBA
- 2.5 to <4.5 dBA $90/dBA
- 4.5 to 6.0 dBA $110/dBA
- >6 dBA $140/dBA

The rationale for Series 1 was that trucks seldom required more than 4 dBA of (A) noise reduction, and $80 was roughly the average of the updated price of 2 to 4 dBA of reduction from the Background Document.* The rationale for Series 2 was to make maximum use of the data available and to reflect the general increase in costs that are incurred with each incremental dB of noise reduction.

In the example of the Cummins 290 series engine, the required (A) noise reduction was 1.5 dBA, i.e., 78.5 dBA to 77 dBA. The price was $120 for Series 1 and $106.50 for Series 2. The price for the above-average engine was $288 for Series 1 (3.6 dBA @ $80) and $324 for Series 2 (3.6 dBA @ $90). There was no reduction in (A) noise required for below-average engines.

Estimate the Price of Exhaust Noise Reduction

BBN estimated the price of improved exhaust systems on the basis of information supplied by a major muffler manufacturer and pricing procedures used by BBN in the Demonstration Truck Program. The manufacturer's catalogue for diesel engine exhaust systems shows the mufflers available for *each engine model* and the noise-level of the muffler in that application. That information is publicly available. BBN also obtained a price list which was used to estimate OEM prices, and an overview of the performance objectives and price impacts of mufflers designed to meet an 80-dBA regulatory level. That information is not publicly available and was released to BBN for "computational purposes."

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* $180/2.5 dBA = $72; $360/4 dB = $90.

BBN worked with this information to estimate the incremental price of reducing exhaust system noise from current levels. The muffler that corresponded to the exhaust noise level for the average, above-average, and below-average observations for each engine was identified in the manufacturer's catalogue. The price of each "baseline" muffler was recorded. In those instances where there was not a perfect match, BBN assumed the baseline was the next noisier muffler. We then identified the muffler that would yield the target exhaust noise level. All exhaust systems were assumed to be single-muffler systems since the available information indicated that exhaust noise levels could be reduced to the required levels by using single "new technology" mufflers - i.e., new mufflers the manufacturer would supply to meet an 80-dBA regulatory level. The significance of this assumption is that it eliminated the need to estimate incremental costs (exclusive of mufflers) of converting single-exhaust systems to dual-exhaust systems.

Again in the case of the Cummins 290 series example, the exhaust noise of the average 290 series of approximately 74 dBA corresponds to a currently available muffler. The required noise reduction of 6 dBA to 68 dBA could be achieved by a "new technology" muffler designed for an 80-dBA regulation. This new model would be in effect a derivative of a currently available muffler that has an exhaust noise level of 70 dBA. The price of the 74-dBA muffler was estimated from published fleet price lists. The price of the 68-dBA muffler was estimated from the price of the currently available 70-dBA muffler plus an escalation factor derived from discussions with industry sources. The incremental price of the target 68-dBA exhaust system is estimated to be $19.90. That estimate is the difference at the OEM level of the two mufflers times a 1.4 markup at the truck manufacturer level times a 1.35 markup at the truck dealer level. The results of this exercise for the 290 series are summarized in Table 12. Note that in estimating the price of the below-average engine, we made a worst-case assumption that the baseline was a 74-dBA muffler rather than the available 70-dBA muffler, since no muffler exactly matches the estimated 71-dBA exhaust noise for the below-average engine.

TABLE 12. SUMMARY OF CALCULATIONS - EXHAUST SYSTEM PRICE INCREASES; CUMMINS 290 SERIES ENGINES

	Distribution of Truck Noise				
Range	<77.5	77.5 - 78.4	78.4 - 81.4	81.4 - 83.0	Total
Midpoint		77.9	79.9	82.2	
Percent of total	5.5	10.5	68.3	15.8	100.0
Exhaust System Noise					
• Initial					
- level (dBA)		71	≈74	77	
- OEM $		42.83	42.83	21.43	
• Target					
- level		≈68	≈68	≈68	
- OEM $		53.36	53.36	53.36	
• Price Increase					
- OEM $		10.53	10.53	32.13	
- Consumer $		19.90	19.90	60.35	

Estimate the Overall Price Increase

The final step is to combine the price of (A) noise reduction with the price of exhaust noise reduction and estimate the weighted price. Table 13 summarizes the process. The estimated price increases range from $19.90 for quieter-than-average vehicles to $384.34 for noisier than-average vehicles. The total price increases are then weighted by the "percent of total" to obtain the distribution weighted price increase. The representative calculation for Series 1 is:

Quieter-than-Average:	0.105 x	$ 19.90 =	$ 2.11
Average:	0.683 x	139.90 =	95.57
Noisier-than-Average:	0.158 x	348.35 =	55.06
Distribution Weighted Price		=	$152.74

The distribution weighted price is the average price increase for vehicles powered by Cummins 290 series engines under Series 1 assumptions.

TABLE 13 SUMMARY OF PRICE INCREASES:
CUMMINS 290 SERIES ENGINES.

	Distribution of Truck Noise				
Range	<77.5	77.5 - 78.4	78.4 - 81.4	81.4 - 83.0	Total
Midpoint		77.9	79.9	82.2	
Percent of total	5.5	10.5	68.3	15.8	100.0
"All Other" Noise Price Increases					
• Series 1			$120.00	$288.00	
• Series 2			106.50	324.00	
Exhaust System Price Increases		$19.90	$ 19.90	$ 60.35	
Total Price Increases					
• Series 1		$19.90	$139.90	$348.35	
• Series 2		19.90	126.40	384.35	
Weighted Price Increases					
• Series 1		$ 2.11	$ 95.57	$ 55.06	$152.7[illegible]
• Series 2		2.11	86.35	60.75	149.2[illegible]

Tables 14 to 19 present the results of this analysis for each engine model in each vehicle class. A market weighted price is presented in each table. It is based on the distribution weighted price for each engine and is the market share of the class. Refer, for example, to the Cummins 290 entry in Table 18. We see the $152.74 distribution weighted price is weighted by its estimated 18.5-percent market share to yield a market weighted price of $28.26. The market share price for each engine is summed to obtain a total price for the percent of the market for which entries are

TABLE 14 ESTIMATED COMPLIANCE PRICE BY ENGINE MODEL; SERIES 1 - CLASS 6 VEHICLES.

ENGINE MANUFACTURER AND MODEL	PERCENT OF CLASS 6 MARKET	ESTIMATED COMPLIANCE PRICE LOW	AVERAGE	HIGH	DISTRIBUTION WEIGHTED PRICE	MARKET WEIGHTED PRICE
CATERPILLAR	34.96					
3208	30.34	23.53	135.53	177.61	124.30	37.71
3206						
3406	4.62	12.87	107.90	316.35	125.25	5.79
3408		59.90	180.35	228.70	168.78	0.00
CUMMINS	1.48					
230	0.21	8.00	147.87	372.49	160.06	0.34
250		40.00	187.87	352.49	188.17	0.00
290	0.59	19.90	139.90	346.35	152.74	0.90
350	0.53	81.63	151.63	392.08	175.63	0.93
400	0.15	47.27	230.32	399.71	227.03	0.34
450 AND OTHERS						
DETROIT DIESEL	44.43					
6-71	3.64	19.90	60.35	80.35	56.68	2.06
6V-92	8.74	40.22	80.22	295.28	106.07	9.27
8V-71	2.91	24.23	103.28	200.66	104.98	3.05
8V-92	1.09	44.32	224.24	359.30	216.66	2.36
4-53	12.57	160.00	349.63	417.63	330.22	41.51
6V-53	12.57	67.96	180.96	200.96	165.81	20.84
8.2 LITER	2.91		81.61		81.61	2.37
INTERNATIONAL	15.10					
9.0 LITER	9.06		354.41		354.41	32.11
DT(I) 466	6.04		268.25		268.25	16.20
MACK	0.00					
ETZ 477						
ETZ 673						
ETAZ 673			203.96		203.96	0.00
ETZ 675			203.96		203.96	0.00
ENDT 676			203.96		203.96	0.00
ETAZ 1000			203.96		203.96	0.00
SCANIA	0.00					
MERCEDES DM325	4.03					
TOTAL - SUM						175.78
TOTAL - PRORATED	100.00					183.16

TABLE 15 ESTIMATED COMPLIANCE PRICE BY ENGINE MODEL; SERIES 2 - CLASS 6 VEHICLES.

ENGINE MANUFACTURER AND MODEL	PERCENT OF CLASS 6 MARKET	ESTIMATED COMPLIANCE PRICE LOW	AVERAGE	HIGH	DISTRIBUTION WEIGHTED PRICE	MARKET WEIGHTED PRICE
CATERPILLAR	34.96					
3208	30.34	23.53	125.13	163.21	114.92	34.87
3206						
3406	4.62	12.87	98.00	348.35	123.54	5.71
3408		55.40	166.85	212.95	156.36	0.00
CUMMINS	1.48					
230	0.21	7.00	134.38	412.49	157.14	0.33
250		35.50	169.88	389.99	181.34	0.00
290	0.59	19.90	126.40	384.35	149.21	0.88
350	0.53	31.63	138.13	432.08	166.53	0.88
400	0.15	44.57	208.72	441.71	218.54	0.33
450 AND OTHERS						
DETROIT DIESEL	44.43					
6-71	3.64	19.90	60.35	80.35	56.68	2.06
6V-92	8.74	40.22	75.72	325.28	107.74	9.42
8V-71	2.91	24.23	97.88	187.16	99.16	2.89
8V-92	1.09	42.07	203.54	397.30	208.19	2.27
4-53	12.57	142.00	535.38	560.13	476.74	59.93
6V-53	12.57	69.96	167.46	185.21	154.41	19.41
8.2 LITER	2.91		74.41		74.41	2.17
INTERNATIONAL	15.10					
9.0 LITER	9.06		393.51		393.51	35.65
DT(1) 466	6.04		301.25		301.25	18.20
MACK	0.00					
ETZ 477						
ETZ 673			182.36		182.36	0.00
ETAZ 673			182.36		182.36	0.00
ETZ 675			182.36		182.36	0.00
ENDT 676			182.36		182.36	0.00
ETAZ 1000						
SCANIA	0.00					
MERCEDES OM325	4.03					
TOTAL - SUM						195.00
TOTAL - PRORATED	100.00					203.19

TABLE 16 ESTIMATED COMPLIANCE PRICE BY ENGINE MODEL;
SERIES 1 - CLASSES 7 AND 8 VEHICLES.

ENGINE MANUFACTURER AND MODEL	PERCENT OF CLASS 7&8 MARKET	ESTIMATED COMPLIANCE PRICE LOW	AVERAGE	HIGH	DISTRIBUTION WEIGHTED PRICE	MARKET WEIGHTED PRICE
CATERPILLAR	17.54					
3208	1.87	23.53	135.53	177.61	124.30	2.32
3206	0.16					
3406	15.19	12.87	107.90	316.35	125.25	19.03
3408	0.32	59.90	180.35	228.70	168.78	0.54
CUMMINS	36.66					
230	3.67	8.00	147.87	372.49	160.06	5.87
250	1.83	40.00	187.87	352.49	188.17	3.44
290	20.40	19.90	139.90	348.35	152.74	31.16
350	7.71	81.63	151.63	392.08	175.63	13.54
400	2.32	47.27	230.32	399.71	227.03	5.27
450 AND OTHERS	0.73					
DETROIT DIESEL	22.71					
6-71	5.49	19.90	60.35	80.35	56.68	3.11
6V-92	5.80	40.22	80.22	295.28	106.07	6.15
8V-71	6.38	24.23	103.28	200.66	104.98	6.70
8V-92	5.04	44.32	224.24	359.30	216.66	10.92
4-53	0.00	160.00	349.63	417.63	330.22	0.00
6V-53	0.00	67.96	180.96	200.96	165.81	0.00
8.2 LITER	0.00		81.61		81.61	0.00
INTERNATIONAL	8.22					
9.0 LITER	1.97		354.41		354.41	6.98
DT(1) 466	6.25		268.25		268.25	16.77
MACK	14.62					
ETZ 477	0.94					
ETZ 673	3.37		203.96		203.96	6.87
ETAZ 673	2.62		203.96		203.96	5.34
ETZ 675	3.19		203.96		203.96	6.51
ENDT 676	2.81		203.96		203.96	5.73
ETAZ 1000	1.69					
SCANIA	0.24					
MERCEDES OM325	0.00					
TOTAL - SUM						156.25
TOTAL - PRORATED	99.99					162.37

TABLE 17 ESTIMATED COMPLIANCE PRICE BY ENGINE MODEL; SERIES 2 - CLASSES 7 AND 8 VEHICLES.

ENGINE MANUFACTURER AND MODEL	PERCENT OF CLASS 7&8 MARKET	ESTIMATED COMPLIANCE PRICE			DISTRIBUTION WEIGHTED PRICE	MARKET WEIGHTED PRICE
		LOW	AVERAGE	HIGH		
CATERPILLAR	17.54					
3208	1.87	23.53	125.13	163.21	114.92	2.15
3206	0.36					
3406	15.19	12.87	98.00	348.35	123.54	18.77
3408	0.32	55.40	166.85	212.95	156.36	0.50
CUMMINS	36.66					
230	3.67	7.00	134.38	412.49	157.14	5.77
250	1.83	35.50	169.88	389.99	181.34	3.32
290	20.40	19.90	126.40	384.35	149.21	30.44
350	7.71	31.63	138.13	432.08	166.53	12.84
400	2.32	44.57	208.72	441.71	218.54	5.07
450 AND OTHERS	0.73					
DETROIT DIESEL	22.71					
6-71	5.49	19.90	60.35	80.35	56.68	3.11
6V-92	5.80	40.22	75.72	325.28	107.74	6.25
8V-71	6.38	24.23	97.88	187.16	99.16	6.33
8V-92	5.04	42.07	203.54	397.30	208.19	10.49
4-53		142.00	535.38	560.13	476.74	0.00
6V-53		69.96	167.46	185.21	154.41	0.00
8.2 LITER			74.41		74.41	0.00
INTERNATIONAL	8.22					
9.0 LITER	1.97		393.51		393.51	7.75
DT(I) 466	6.25		301.25		301.25	18.83
MACK	14.62					
ETZ 477	0.94					
ETZ 673	3.37		182.36		182.36	6.15
ETAZ 673	2.62		182.36		182.36	4.78
ETZ 675	3.19		182.36		182.36	5.82
EHDT 676	2.81		182.36		182.36	5.12
ETAZ 1000	1.69					
SCANIA	0.24					
MERCEDES OM325	0.00					
TOTAL - SUM						153.49
TOTAL - PRORATED	99.99					159.50

TABLE 18 ESTIMATED COMPLIANCE PRICE BY ENGINE MODEL;
SERIES 1 - TOTAL MARKET VEHICLES.

ENGINE MANUFACTURER AND MODEL	PERCENT OF TOTAL MARKET	ESTIMATED COMPLIANCE PRICE			DISTRIBUTION WEIGHTED PRICE	MARKET WEIGHTED PRICE
		LOW	AVERAGE	HIGH		
CATERPILLAR	19.30					
3208	4.70	23.53	135.53	177.61	124.30	5.84
3206	0.10					
3406	14.20	12.87	107.90	316.35	125.25	17.79
3408	0.30	59.90	180.35	228.70	168.78	0.51
CUMMINS	33.2					
230	3.30	8.00	147.87	372.49	160.06	5.28
250	1.60	40.00	187.87	352.49	188.17	3.01
290	18.50	19.90	139.90	348.35	152.74	28.26
350	7.00	81.63	151.63	392.08	175.63	12.29
400	2.10	47.27	230.32	399.71	227.03	4.77
450 AND OTHERS	0.70					
DETROIT DIESEL	24.80					
6-71	5.30	19.90	60.35	80.35	56.68	3.00
6V-92	6.10	40.22	80.22	295.28	106.07	6.47
8V-71	6.00	24.23	103.28	200.66	104.98	6.30
8V-92	4.70	44.32	224.24	359.30	216.66	10.18
4-53	1.20	160.00	349.63	417.63	330.22	3.96
6V-53	1.20	67.96	180.96	200.96	165.81	1.99
8.2 LITER	0.30		81.61		81.61	0.24
INTERNATIONAL	8.90					
9.0 LITER	2.70		354.41		354.41	9.57
DT(1) 466	6.20		268.25		268.25	16.63
MACK	13.20					
ETZ 477	0.80					
ETZ 673	3.00		203.96		203.96	6.12
ETAZ 673	2.40		203.96		203.96	4.90
ETZ 675	2.90		203.96		203.96	5.91
ENDT 676	2.60		203.96		203.96	5.30
ETAZ 1000	1.50					
SCANIA	0.20					
MERCEDES OM325	0.40					
TOTAL - SUM						158.32
TOTAL - PRORATED	100.00					164.40

TABLE 19 ESTIMATED COMPLIANCE PRICE BY ENGINE MODEL; SERIES 2 - TOTAL MARKET VEHICLES.

ENGINE MANUFACTURER AND MODEL	PERCENT OF TOTAL MARKET	ESTIMATED COMPLIANCE PRICE			DISTRIBUTION WEIGHTED PRICE	MARKET WEIGHTED PRICE
		LOW	AVERAGE	HIGH		
CATERPILLAR	19.30					
3208	4.70	23.53	125.13	163.21	114.92	5.40
3206	0.30					
3406	14.20	12.87	98.00	348.35	123.54	17.54
3408	0.30	55.40	166.85	212.95	156.36	0.47
CUMMINS	33.2					
230	3.30	7.00	134.38	412.49	157.14	5.19
250	1.60	35.50	169.88	389.99	181.34	2.90
290	18.50	19.90	126.40	384.35	149.21	27.60
350	7.00	31.63	138.13	432.08	166.53	11.66
400	2.10	44.57	208.72	441.71	218.54	4.59
450 AND OTHERS	0.70					
DETROIT DIESEL	24.80					
6-71	5.30	19.90	60.35	80.35	56.68	3.00
6V-92	6.10	40.22	75.72	325.28	107.74	6.57
8V-71	6.00	24.23	97.88	187.16	99.16	5.95
8V-92	4.70	42.07	203.54	397.30	208.19	9.78
4-53	1.20	142.00	535.38	560.13	476.74	5.72
6V-53	1.20	69.96	167.46	185.21	154.41	1.85
8.2 LITER	0.30		74.41		74.41	0.22
INTERNATIONAL	8.90					
9.0 LITER	2.70		393.51		393.51	10.62
DT(I) 466	6.20		301.25		301.25	18.68
MACK	13.20					
ETZ 477	0.80					
ETZ 673	3.00		182.36		182.36	5.47
ETAZ 673	2.40		182.36		182.36	4.38
ETZ 675	2.90		182.36		182.36	5.29
ENDT 676	2.60		182.36		182.36	4.74
ETAZ 1000	1.50					
SCANIA	0.20					
MERCEDES OM325	0.40					
TOTAL - SUM						157.62
TOTAL - PRORATED	100.00					163.68

available -- generally about 95 to 99 percent of the market. That estimate is then prorated upward to 100 percent of the market. Again referring to Table 18, we see this exercise yields our estimate of $164.40. This is the overall price increase for all trucks under Series 1 assumptions.

4.2 Diesel Engines - Series 3

A third series of price increases was estimated by using an approach different from that of Series 1 and 2. The Series 3 estimates are based on the overall average noise reduction required for each engine and the price increases estimated in the Demonstration Truck Program. Instead of disaggregating truck noise into exhaust and all other sources, we based Series 3 estimates on the overall noise level of the truck. For example, Cummins 290-powered vehicles have a mean noise level of 79.9 dBA, and thus need 2.4 dBA of overall noise reduction to attain a 77.5-dBA design level.

To estimate an overall price per dBA to use in this approach, we reviewed the price increases estimated in the Demonstration Truck Program. We focused on the GMC Brigadier and International Harvester F-4370. The overall noise level of the Brigadier was reduced by 10.3 dBA for a price of $1,174. The International Harvester F-4370 had 8.9 dBA of noise reduction for a price increase of $1,302. The two observations average $129/dBA.

The price of $129/dBA was multiplied by the number of A-weighted decibels required to bring the average vehicle powered by each engine model to a 77-dBA design level. For example, the average Cummins 290 vehicle is 79.9 dBA, or 2.4 dBA above the design target. Therefore the price increase for this engine is $309.60, i.e., 2.4 dBA @ $129/dBA.

The results of this exercise are presented in Tables 20 to 22. Referring to Table 22, we see the overall total price increase of $352.

The $352 Series 3 estimate reflects BBN's experience in reducing truck noise to 72 dBA, as opposed to 77.5 dBA. Given the increasing marginal cost per dBA that is associated with virtually every noise reduction application, we observe that this estimate likely overstates the price increase associated with a 77.5-dBA design level. However, it establishes an upper bound based on the Agency's experience with prototype vehicles.

The Series 3 estimate is twice as large as the Series 1 and 2 market weighted price increases. It is, however, roughly comparable to the "high" estimated compliance price for Series 1 and 2. The difference between the series largely reflects the fact that Series 3 is based on the average price of relatively large noise reductions, e.g., 9 to 10 dBA, whereas Series 1 and 2 are based on making the most cost-effective reductions possible over a relatively small range. Series 1 and 2 implicitly assume all shielding above the frame rail and single exhaust systems. Series 3 is based on the price of full (below the frame rail) enclosures and dual-exhaust systems.

Comparing Series 1, 2, and 3, the average price increase for trucks to comply with an 80-dBA regulatory level is estimated to be $164 to $352. Some vehicles would have price increases of $300 to $500, as shown in the high estimated compliance price column in Tables 14 to 19. Other vehicles would have estimated price increases of less than $50 as shown in the low estimated compliance price column.

TABLE 20 ESTIMATED COMPLIANCE PRICE BY ENGINE MODEL; SERIES 3 - CLASS 6 VEHICLES.

Engine Manufacturer and Model	Percent of Market	Noise Reduction (dBA)	Noise Reduction Price	Distribution Weighted Price
Caterpillar				
• 3208	30.3	3.4	438.60	132.90
• 3306	-	-	-	-
• 3406	4.6	2.6	335.40	15.43
• 3408	-	-	-	-
Cummins				
• 230	0.2	1.9	245.10	0.49
• 250	-	-	-	-
• 290	0.6	2.4	309.60	1.86
• 350	0.5	2.3	296.70	1.48
• 400	0.2	3.1	399.90	0.80
• 450 & others	-	-	-	-
Detroit Diesel				
• 6-71	3.6	3.3	425.70	15.33
• 6V-92	8.7	2.4	309.60	26.94
• 8V-71	2.9	2.7	348.30	10.10
• 8V-92	1.1	3.2	412.80	4.54
• 4-53	12.6	4.3	554.70	69.89
• 6V-53	12.6	4.7	606.30	76.39
• 8.2L	2.9	2.3	296.70	8.60
International				
• 9.0 Liter	9.0	3.9	503.10	45.28
• DT(I) 466	6.0	3.3	425.70	25.54
Mack*				
• ETZ 477				
• ETZ 673				
• ETAZ 673				
• ETZ 675				
• ENDT 676				
• ETAZ 1000				
Scania*				
Mercedes OM 325	4.0	2.5	322.50	12.90
TOTAL - SUM	100.0			448.48
TOTAL - PRORATED				449.66

*Does not produce Class 6 Trucks.

TABLE 21 ESTIMATED COMPLIANCE PRICE BY ENGINE MODEL; SERIES 3 - CLASSES 7 AND 8 VEHICLES.

Engine Manufacturer and Model	Percent of Market	Noise Reduction (dBA)	Noise Reduction Price	Distribution Weighted Price
Caterpillar				
• 3208	1.9	3.4	438.60	8.33
• 3306	0.2	-	-	-
• 3406	15.2	2.6	335.40	50.98
• 3408	0.3	3.3	425.70	1.28
Cummins				
• 230	3.7	1.9	245.10	9.07
• 250	1.8	2.3	296.70	5.34
• 290	20.4	2.4	309.60	63.16
• 350	7.7	2.3	296.70	22.85
• 400	2.3	3.1	399.90	9.20
• 450 & others	0.7	-	-	-
Detroit Diesel				
• 6-71	5.5	3.3	425.70	23.41
• 6V-92	5.8	2.4	309.60	17.96
• 8V-71	6.4	2.7	348.30	22.29
• 8V-92	5.0	3.2	412.80	20.64
• 4-53	0.0	4.3	554.70	-
• 6V-53	0.0	4.7	606.30	-
• 8.2L	0.0	2.3	296.70	-
International				
• 9.0 Liter	2.0	3.9	503.10	10.06
• DT(I) 466	6.3	3.3	425.70	26.82
Mack				
• ETZ 477	0.9	3.8	490.20	4.41
• ETZ 673	3.4	2.6	335.40	11.40
• ETAZ 673	2.6	2.6	335.40	8.72
• ETZ 675	3.2	2.6	335.40	10.73
• ENDT 676	2.8	2.6	335.40	9.39
• ETAZ 1000	1.7	2.5	322.40	5.48
Scania	0.2	-	-	-
Mercedes OM 325	0.0	2.5	322.50	-
TOTAL - SUM	100.0			341.53
TOTAL - PRORATED				345.37

TABLE 22 ESTIMATED COMPLIANCE PRICE BY ENGINE MODEL; SERIES 3 - TOTAL MARKET VEHICLES.

Engine Manufacturer and Model	Percent of Market	Noise Reduction (dBA)	Noise Reduction Price	Distribution Weighted Price
Caterpillar				
• 3208	4.7	3.4	438.60	20.60
• 3306	0.1	-	-	-
• 3406	14.2	2.6	330.40	47.63
• 3408	0.3	3.3	425.70	1.27
Cummins				
• 230	3.3	1.9	245.10	8.09
• 250	1.6	2.3	296.70	4.75
• 290	18.5	2.4	309.60	57.28
• 350	7.0	2.3	296.70	20.77
• 400	2.1	3.1	399.90	8.40
• 450 & others	0.7	-	-	-
Detroit Diesel				
• 6-71	5.3	3.3	425.70	22.56
• 6V-92	5.1	2.4	309.60	15.79
• 8V-71	6.0	2.7	348.30	20.90
• 8V-92	4.7	3.2	412.80	19.40
• 4-53	1.2	4.3	554.70	6.65
• 6V-53	1.2	4.7	606.30	7.27
• 8.2L	0.3	2.3	296.70	0.89
International				
• 9.0 Liter	2.7	3.9	503.10	13.58
• DT(I) 466	6.2	3.3	425.70	26.39
Mack				
• ETZ 477	0.8	3.8	490.20	3.92
• ETZ 673	3.0	2.6	335.40	10.06
• ETAZ 673	2.4	2.6	335.40	8.05
• ETZ 675	2.9	2.6	335.40	9.73
• ENDT 676	2.6	2.6	335.40	8.72
• ETAZ 1000	1.5	2.5	332.40	4.83
Scania	0.2	-	-	-
Mercedes OM 325	0.4	2.5	332.50	1.29
TOTAL - SUM	100.0			348.28
TOTAL - PRORATED				352.35

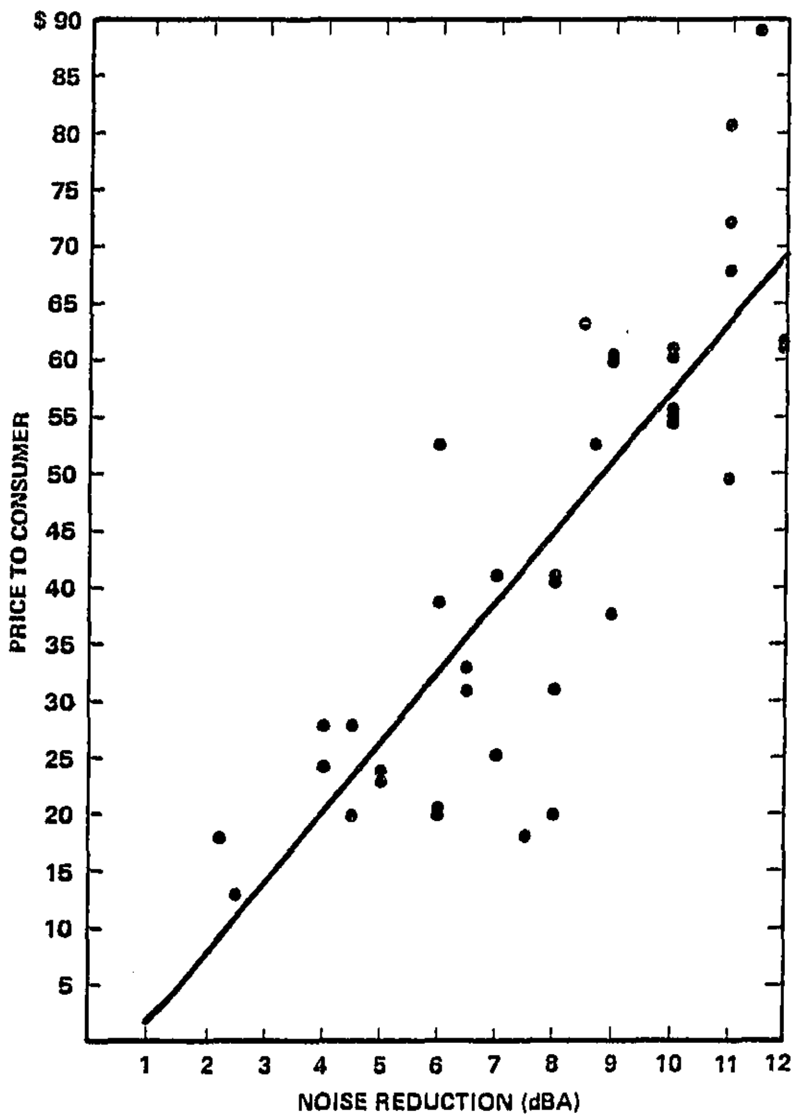

FIGURE 4. RELATION OF EXHAUST NOISE REDUCTION AND PRICE.

4.3 Gasoline Engines

The data in Sec. 3 show that gasoline-powered trucks are considerably quieter than their diesel engine counterparts. The vehicles reported by GM and Ford, were either at or near a 77.5-dBA design level. We concluded that relatively minor noise reduction would be required, and that most of the reduction could be achieved through exhaust noise reduction. We also concluded that a small amount of "other" noise source reduction would be required for the International Harvester vehicles.

Data on the price of mufflers for gasoline trucks comparable to that for diesel trucks were not available. However, the extensive analysis of the price and noise levels of mufflers for diesel engines provided a more than adequate basis upon which to estimate prices of mufflers for gasoline-powered trucks. There were 37 observations for exhaust noise reduction and the corresponding price of that reduction from the analysis in Sec. 4.1. These observations are shown graphically in Fig. 4. We used these 37 observations to regress price increase as a function of exhaust noise reduction in A-weighted decibels. The resulting regression curve is shown as the dark solid line in Fig. 4. The estimated equation is:

$$Y = 0.152067 \times e^{x} + 2.47214 \quad (1)$$

where

Y = consumer price increase

x = dBA of exhaust noise reduction

Table 23 presents summary statistics for this muffler price equation. Given BBN's estimate of 6 dBA of exhaust noise reduction we estimate the price to be $64.

TABLE 23 SUMMARY STATISTICS - MUFFLER PRICE EQUATION

Coefficient	Value	Standard Deviation	"T" Value
Intercept	2.47214	0.126335	19.568
Scope	0.152067	0.015093	10.076

Coefficient of Determination (R^2) = 0.743
"F" Value = 101.518

Note that the exponential form of the equation corresponds to the pattern of increasing marginal cost of quieting.

The price of other noise source reduction was assumed to be $80/dBA. This was the Series 1 assumption and was chosen as the most conservative assumption.

Table 24 summarizes BBN's estimates of the amount of noise reduction required for each manufacturer and the corresponding price. We concluded that an exhaust noise reduction of 6 dBA would be sufficient for both GMC and Ford vehicles. We assumed that 100 percent of the GMC vehicles would require this exhaust treatment vs 15 percent of the Ford vehicles. Our rationale was that Ford vehicles were, on average, below 77.5 dBA, but that the upper end of the distribution - i.e., the 15 percent greater than one standard deviation - would require some exhaust noise reduction. Finally, we assumed all IH vehicles would require 6 dBA of exhaust and 1.4 dBA of other source noise reduction.

The price increase for each manufacturer was then weighted by sales by class. This weighting, which was based on MVMA sales data, is presented in Table 25. The result was an estimated overall increase of $52.32; $63.61 for Class 5 and 6 vehicles and $40.25 for Class 7 and 8 vehicles.

TABLE 24 SUMMARY OF NOISE REDUCTION AND PRICES BY MANUFACTURER: GASOLINE-POWERED TRUCKS.

	Required dBA Reduction		Noise Treatment Cost		Percent With Treatment	Weighted Price
	Exhaust	Other Sources	Exhaust	Other Sources		
Ford	6	0	64	0	15	9.60
General Motors	6	0	64	0	100	64
International Harvester	6	1.4	64	112	100	176

Source: BBN estimates.

TABLE 25 COMPLIANCE PRICE BY CLASS - 80 dBA LEVEL; GASOLINE-POWERED TRUCKS.

	Treatment Weighted Price	Percent Market Share		
		Classes 5 & 6	Classes 7 & 8	All Classes
Ford	$ 9.60	21.1	76.6	38.9
General Motors	64.00	69.0	7.4	49.3
International Harvester	176.00	9.9	16.0	11.8
Sales Weighted Price	-	$63.61	$40.25	$52.32

Source: BBN estimates.

5. OPERATING COST IMPACTS

The treatments described in Sec. 4 will have an impact on fuel costs and maintenance costs. This section contains BBN's estimates of these incremental costs.

5.1 Incremental Fuel Costs

Fuel economy will be affected by three parameters. Increases in weight due to treatment panels and heavier mufflers will cause increased fuel costs. Increases in backpressure from more efficient mufflers will also cause increased fuel costs. Decreases in the amount of power required because of the addition of clutched fans will, on the other hand, decrease fuel costs. These parameters have been evaluated for each of the engines used in the medium and heavy diesel classes and for gasoline engines as a general class.

The Background Document presents estimates of incremental fuel costs based on the same three parameters identified above. BBN used the same analytical framework presented in the Background Document, but updated the information on weight, backpressure, and clutched fans. The discussion below describes how BBN developed updated estimates for each of these parameters.

The analysis of treatment costs presented in Sec. 4 is based upon an estimate of the noise reduction required from shielding and the muffler necessary to reach the design goal of 77.5 dBA. Muffler weight increases are known for each of the specific mufflers chosen. Noise shielding weights were derived from a linear regression of data from the Background Document and three of the four heavy trucks currently being quieted by BBN for EPA. These data are shown in Fig. 5 along with the estimated regression line. As can be seen in Table 26, the greatest reduction in noise required was 3.8 dBA for the IH 9-liter diesel engine in medium duty trucks and would require 100 lb of enclosure. The average enclosure weight is about 40 lb.

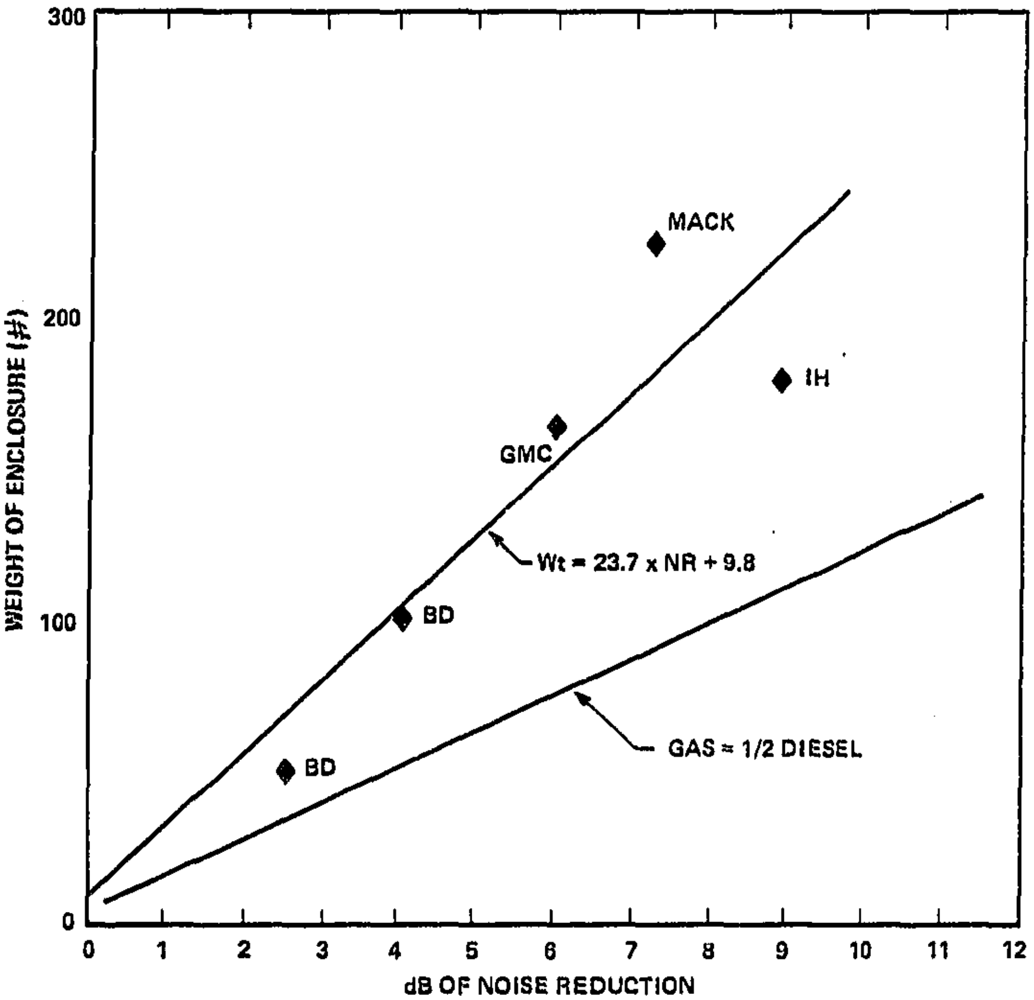

FIG. 5. WEIGHT OF NOISE REDUCTION TREATMENTS.
DEMONSTRATION TRUCK AND BACKGROUND DOCUMENT (BD) DATA.

TABLE 26. INCREASE IN WEIGHT DUE TO 80-dBA LEVEL.

	Engine	Average Noise Reduction Required	Wt of Enclosure	Wt increase of Muffler	Total Weight Increase	Percent of Market
Medium Diesel	Cat 3208	1.0	33	11	44	0.30
	DD					
	6V-92	0.5	22	16	38	0.09
	4-53	2.7	74	0	74	0.12
	6V-53	1.4	43	25	68	0.12
	IH 9 Liter	3.8	100	43	143	0.09
	Weighted average increase in total weight = 65 lb					
Heavy Diesel	Cat 3406	1.2	38	8	46	0.15
	Cummins					
	290	1.5	45	8	53	0.20
	350	1.5	45	8	53	0.08
	DD					
	6-71	0	0	18	18	0.05
	6V-92	0.5	22	16	38	0.06
	8V-71	0.6	24	33	57	0.06
	8V-92	2.3	64	16	80	0.05
	IH DTI-406	3.3	88	7	95	0.06
	Mack	2.4	67	10	77	0.12
	Weighted average increase in total weight = 57 lb					
Gasoline	Ford	*				
	GM	*				
	IH	1.4	21	No basis for estimate	21	0.1
	Weighted average increase in total weight = 2.1 lb					

*Noise reduction not required.

The additional weight for the muffler and exhaust system accessories was added to the enclosure weight. The total added weight was then sales-weighted to obtain the following sales-weighted average weight increases:

- A 65-lb increase for medium duty diesel trucks,
- A 57-lb increase for heavy duty diesel trucks,
- A 2-lb increase for gasoline engine trucks.

The 2-lb estimate reflects the fact that only 10 percent of the gasoline trucks represented in the PV data set will need any noise treatment other than an improved muffler.

Increased exhaust backpressure has an adverse affect on fuel costs. Using published backpressure values for the selected mufflers, we calculated an average value of backpressure increase for medium and heavy duty diesel engine trucks. These values are shown in Table 27.

TABLE 27. INCREASE IN BACKPRESSURE DUE TO 80-dBA LEVEL.

Medium		Heavy	
Engine	Backpressure Increase (Hg)	Engine	Backpressure Increase (Hg)
3208	1.06	3406	2.05
6V-92	-0.1	290	1.78
4-53	0.62	350	1.85
6V-53	1.21	6-71	0.85
		6V-92	-0.1
		8V-71	-0.1
		8V-92	-0.14
Average = 0.6975		Average = 0.884	

The final constituent in the calculation of fuel costs is the reduction in required power due to a clutched fan drive. Virtually all of the heavy duty diesel trucks and 90 percent of the medium duty diesel trucks already have been equipped with clutched fans to provide improved mileage. On the basis of the percentages observed in the product verification data, some 50 percent of gasoline-engined trucks use clutched fans. Thus, only those trucks not currently using clutched fans can assume the benefits to fuel costs associated with switching. Entries from Table 6-8 of the Background Document indicate that a medium duty diesel truck can save 9 hp and a medium duty gasoline truck can save 4.5 hp by employing a clutched fan.

The estimated incremental annual fuel cost of an 80-dBA regulation is presented in Table 28. The values presented in the table

TABLE 28. CHANGES IN ANNUAL FUEL COSTS ASSOCIATED WITH 80-dBA REGULATORY LEVEL.

Engine Type	Medium Trucks*	Medium w/o Fan Clutch	Heavy Duty Trucks†
Diesel**	$10.49	$-390.08	$150.39
Gas††	0.16	-398.30	0.30

*Assume 18,740 mi/yr. Ten percent of medium diesels benefit from addition of clutched fan. Fifty percent of medium gasoline trucks benefit from addition of clutched fan.

†Assume 63,769 mi/yr.

**Fuel price $1.25/gal.

††Fuel price $1.35/gal.

Source: BBN estimates.

are derived in a manner similar to that in the Background Document and are based on weight and backpressure estimates derived in this analysis. These estimates were multiplied first by the values in Tables 6-6 to 6-10 of the Background Document and then by fuel costs of $1.25 for diesel and $1.35 for gasoline to determine the changes in annual fuel costs associated with going from an 83-dBA regulatory level to an 80-dBA level. For all classes but the heavy diesel trucks, improvements due to the use of fan clutches still dominate the fuel cost estimates.

5.2 Incremental Maintenance Costs

Two factors would increase the costs of maintaining vehicles that comply with an 80-dBA regulatory level:

- the cost of more expensive replacement mufflers
- the cost of removing shields during routine maintenance.

These estimated costs are presented below.

An analysis was made of the difference in the replacement price of mufflers between the mufflers currently installed and those that would be installed; the base for our analysis is the analysis presented in Sec. 4. The overall average differential was $46.33, which represents the incremental price of a replacement muffler for an 80-dBA regulatory level in comparison to the current 83-dBA level. Therefore, it is only the "parts" cost - $46.33 - that would change. Assuming a 4-year lifetime for diesel mufflers yields an annual increase in exhaust maintenance costs of $11.58 for diesel-powered vehicles. The increase would be $12.54 for class 6 diesel trucks and $11.48 for classes 7 and 8.

The incremental replacement muffler price for gasoline-powered vehicles was estimated on a comparable basis. The major difference was that detailed price data for mufflers were not available to BBN. We assumed that medium duty gasoline trucks would have incremental replacement muffler costs of $15, while the same cost would be $25 for heavy duty trucks. Discussions with industry sources suggested that a 2-year muffler life was reasonable for gasoline engines. This results in an estimated muffler maintenance cost increase of $8.97/yr -- $7.50/yr for classes 5 and 6, and $12.50/yr for classes 7 and 8.

Table 29 presents a summary of the estimated muffler maintenance costs of an 80-dBA regulatory level.

TABLE 29 ANNUAL MUFFLER MAINTENANCE COSTS
80-dBA REGULATION.

Engine	Classes 5 & 6	Classes 7 & 8	Total
Diesel	$12.54	$11.48	$11.58
Gasoline	7.50	12.50	8.97

The cost of incremental maintenance time for removing side shields was estimated on the basis of results from the Demonstration Truck Program. We explicitly assume that full enclosures are not installed on any vehicles, and hence there are no access restrictions underneath the vehicle. Reduction of noise other than exhaust noise is achieved by engine compartment treatments, such as absorptive treatments, side shields, and other seals.

Data from the Demonstration Truck Program indicate that it takes 1 minute and 10 seconds (1:10) to remove and replace panels L1 and R1 on the GMC Brigadier. These two panels are above the frame rail on each side of the engine. They do not need to be removed for general engine service. The operator of the Brigadier has removed the panels, on average, once per month.

We assumed panels would be removed once a month on 80-dBA diesel trucks and that it would take an extra 15 min/yr to remove and reinstall panels. Typical service rates are $25/hr. Therefore, the incremental cost is $6.25 for panel removal. We then made an allowance for the panels themselves to be maintained and for access restriction penalties. We estimate the incremental annual maintenance costs of side shields and engine compartment seals to be $12.50 for diesel-powered trucks.

Gasoline-powered trucks would have lower maintenance costs because only a small percentage of the population would require enclosures. Given the $12.50 estimate for diesel-powered trucks, we believe $5.00 is a reasonable estimate for incremental maintenance of engine compartment noise treatments for gasoline-powered trucks.

5.3 Operating Cost Summary

Table 30 presents a summary of operating cost increases for an 80-dBA regulatory level. The average diesel engine truck would have higher costs because of increased fuel costs for heavy duty diesels. These vehicles already have realized the benefits for clutched fans. The average gasoline engine truck would have a decrease in operating costs because of fuel savings from clutched fans on medium duty vehicles.

TABLE 30 SUMMARY OF ANNUAL OPERATING COST INCREASES, 80-dBA REGULATORY LEVEL.

Engine	Classes 5 & 6	Classes 7 & 8	Total
Diesel			
• fuel	-$ 29.57	$150.39	$133.90
• maint	25.04	24.08	24.17
Annual Cost	- 4.53	174.47	158.07
Gasoline			
• fuel	-$199.07	$ 0.30	-$140.16
• maint	12.50	17.50	13.98
Annual Cost	- 186.57	17.80	- 126.18

APPENDIX A

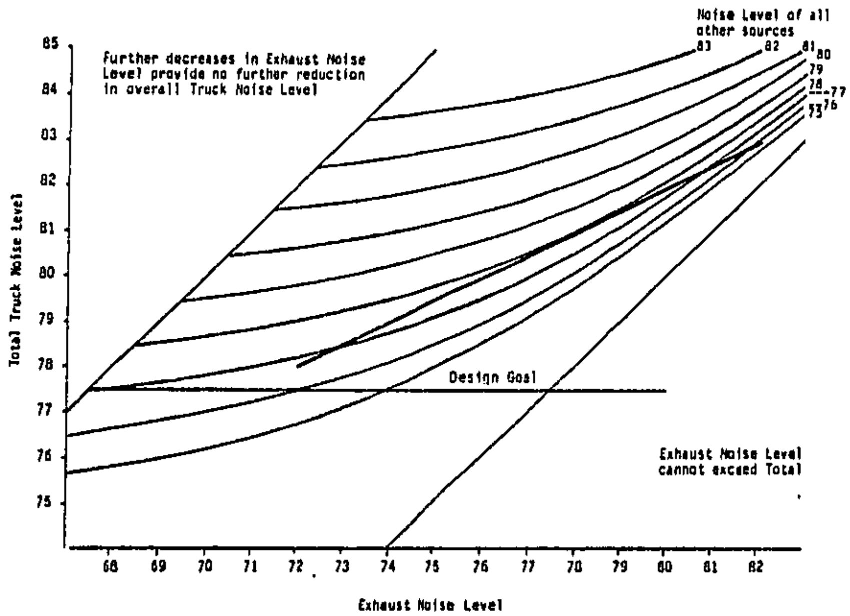

FIG. A-1 NOISE EMISSIONS FROM TRUCKS USING THE CATERPILLAR 3208 ENGINE.

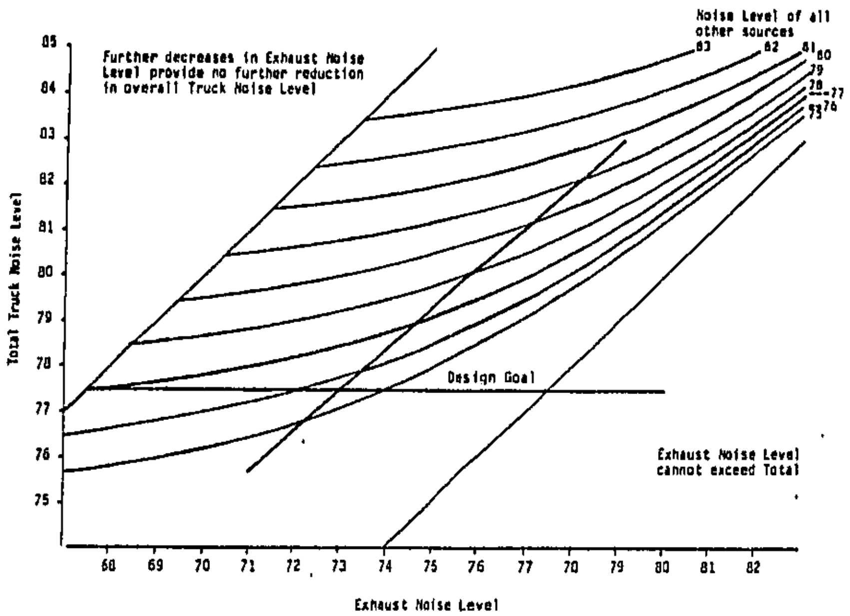

FIG. A-2 NOISE EMISSIONS FROM TRUCKS USING THE CATERPILLAR 3406 ENGINE.

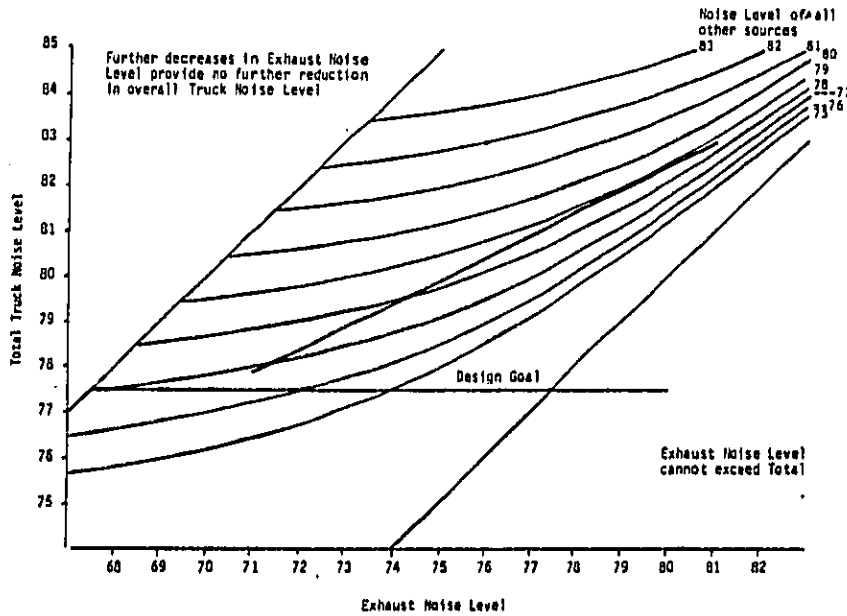

FIG. A-3 NOISE EMISSIONS FROM TRUCKS USING THE CATERPILLAR 3408 ENGINE.

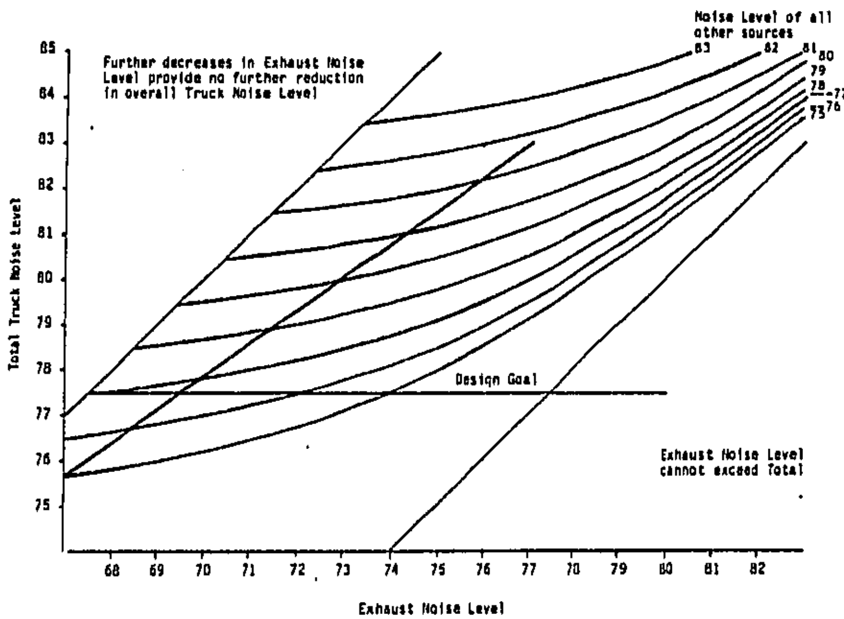

FIG. A-4 NOISE EMISSIONS FROM TRUCKS USING THE CUMMINS 230 ENGINE.

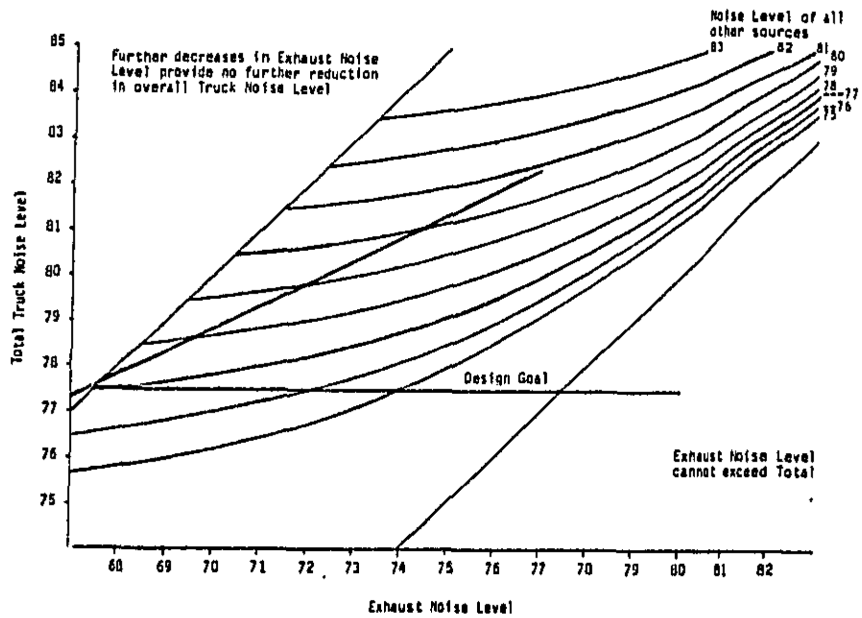

FIG. A-5 NOISE EMISSIONS FROM TRUCKS USING THE CUMMINS 250 ENGINE.

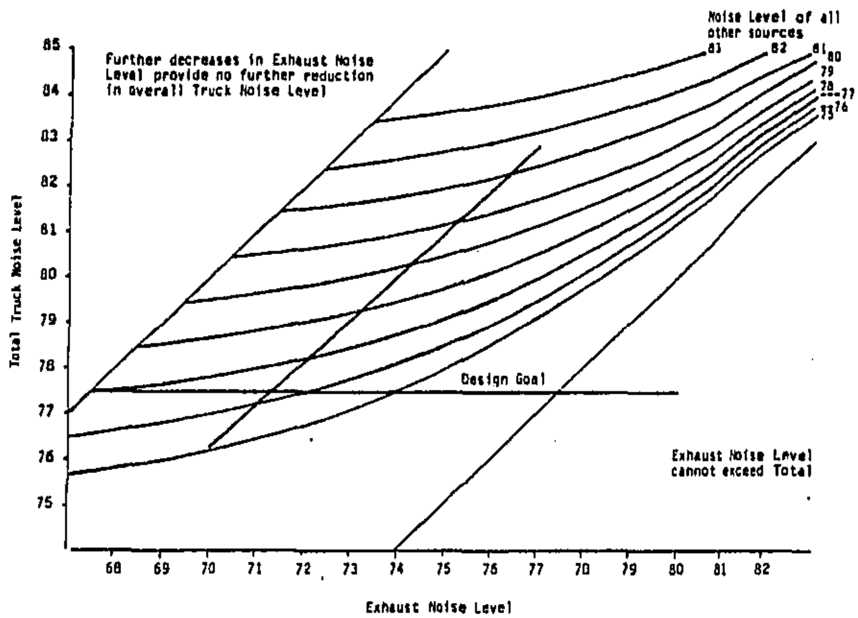

FIG. A-6 NOISE EMISSIONS FROM TRUCKS USING THE CUMMINS 290 ENGINE.

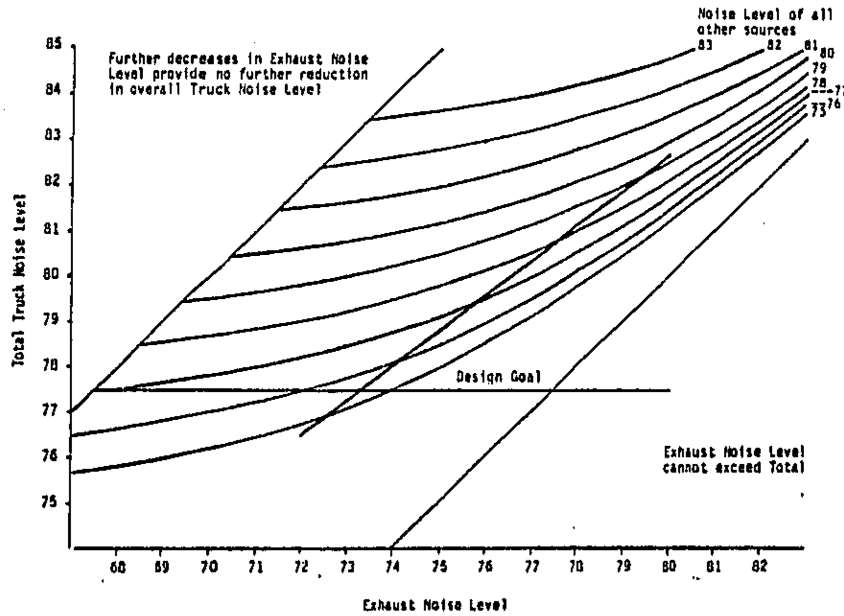

FIG. A-7 NOISE EMISSIONS FROM TRUCKS USING THE CUMMINS 350 ENGINE.

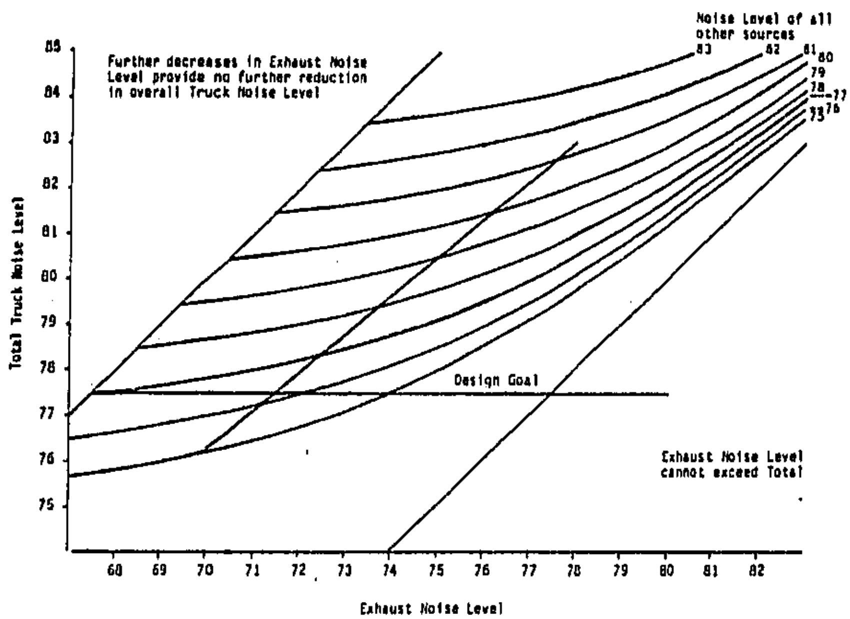

FIG. A-8 NOISE EMISSIONS FROM TRUCKS USING THE CUMMINS 400 ENGINE.

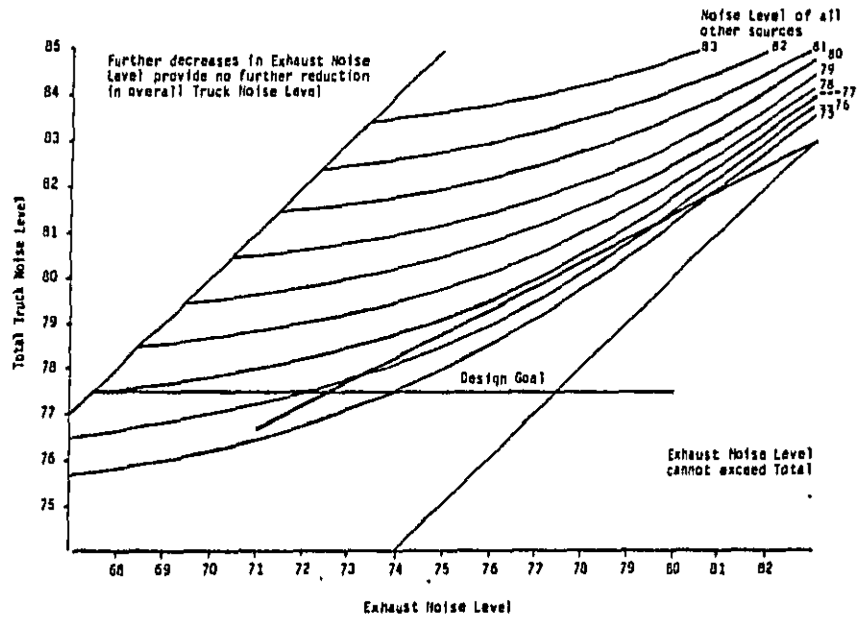

FIG. A-9 NOISE EMISSIONS FROM TRUCKS USING THE DETROIT DIESEL 6-71 ENGINE.

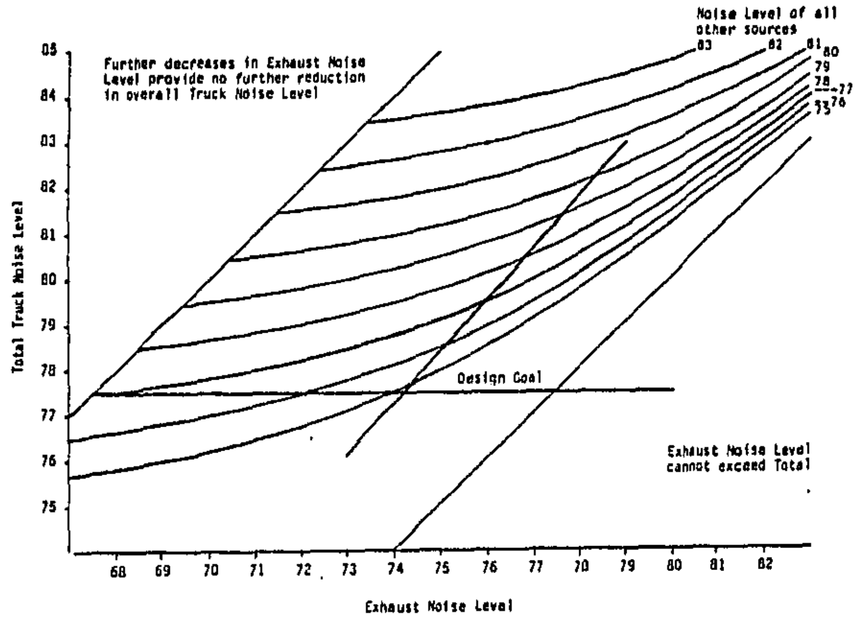

FIG. A-10 NOISE EMISSIONS FROM TRUCKS USING THE DETROIT DIESEL 6V-92 ENGINE.

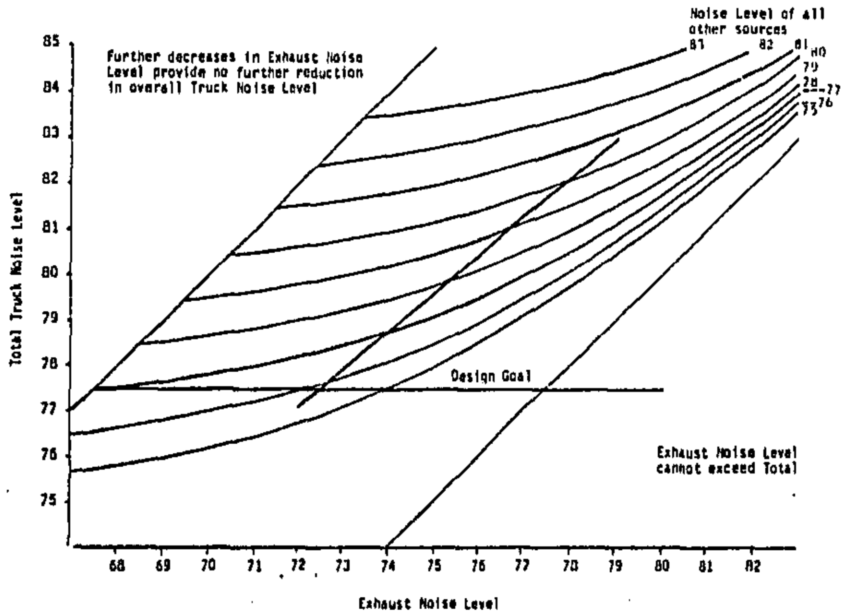

FIG. A-11 NOISE EMISSIONS FROM TRUCKS USING THE DETROIT DIESEL 8V-71 ENGINE.

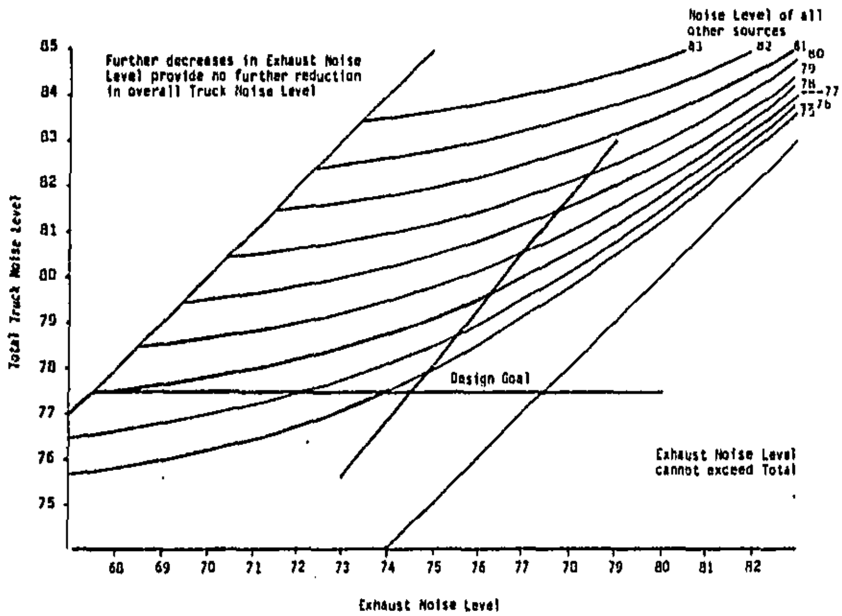

FIG. A-12 NOISE EMISSIONS FROM TRUCKS USING THE DETROIT DIESEL 8V-92 ENGINE.

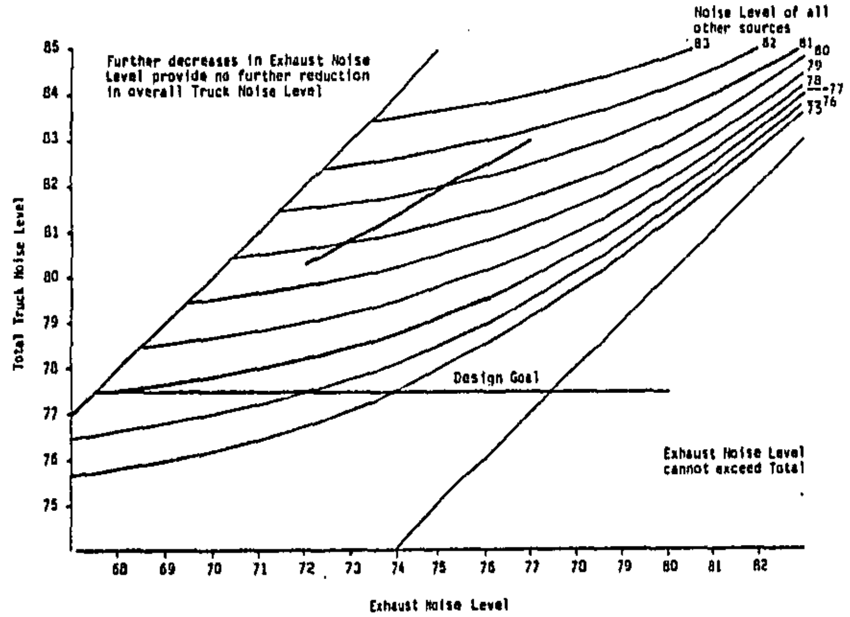

FIG. A-13 NOISE EMISSIONS FROM TRUCKS USING THE DETROIT DIESEL 4-53 ENGINE.

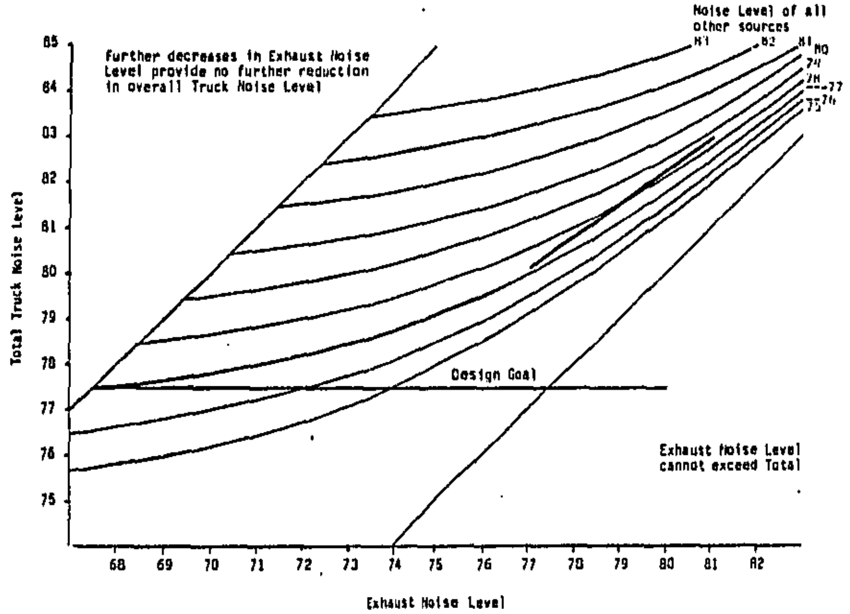

FIG A-14 NOISE EMISSIONS FROM TRUCKS USING THE DETROIT DIESEL 6V-53 ENGINE.

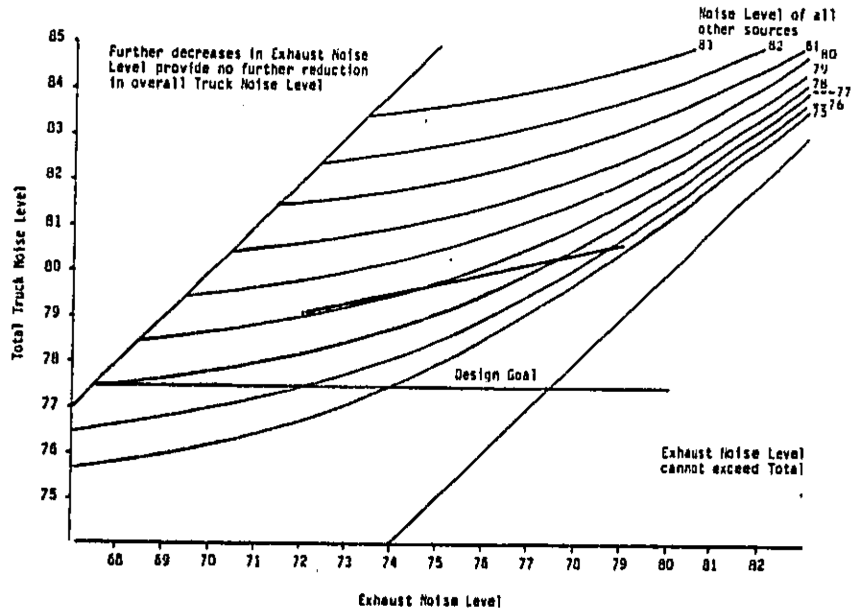

FIG. A-15 NOISE EMISSIONS FROM TRUCKS USING THE DETROIT DIESEL 8.2L ENGINE.

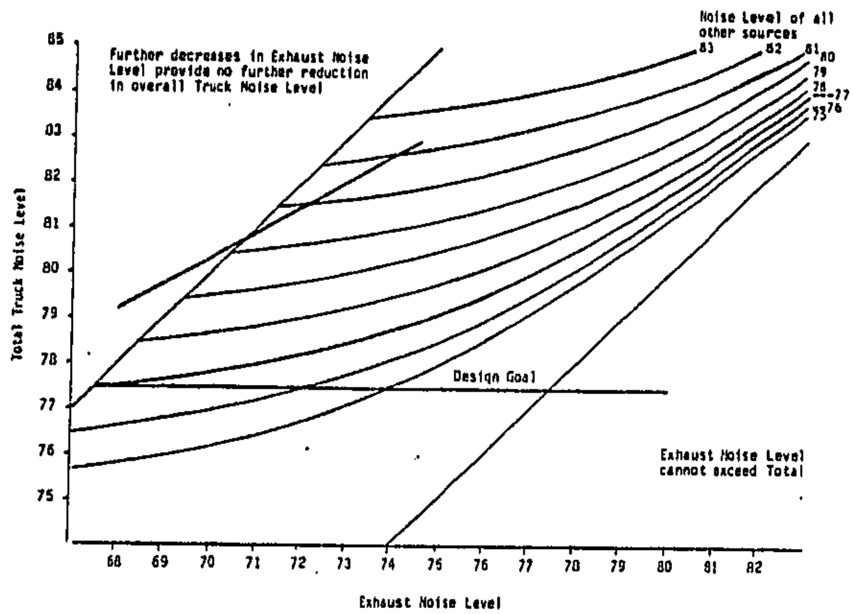

FIG. A-16 NOISE EMISSIONS FROM TRUCKS USING THE INTERNATIONAL HARVESTER 9.0L ENGINE.

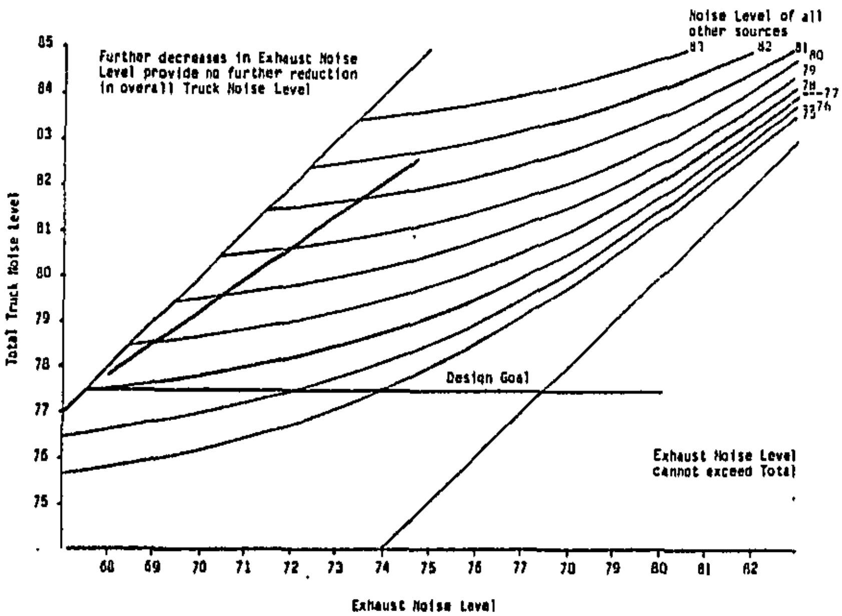

FIG. A-17 NOISE EMISSIONS FROM TRUCKS USING THE INTERNATIONAL HARVESTER 466 ENGINE.

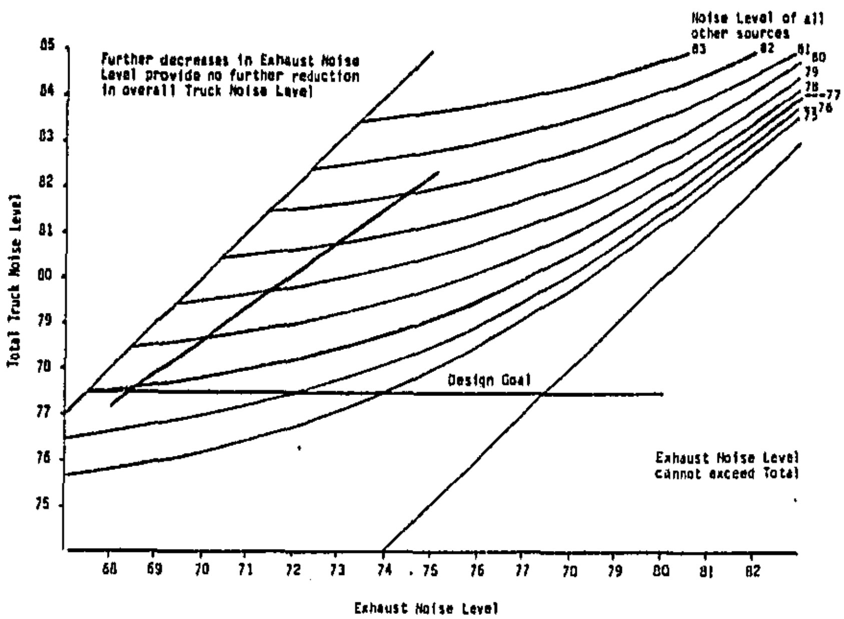

FIG. A-18 NOISE EMISSIONS FROM TRUCKS USING THE MACK ENGINE.