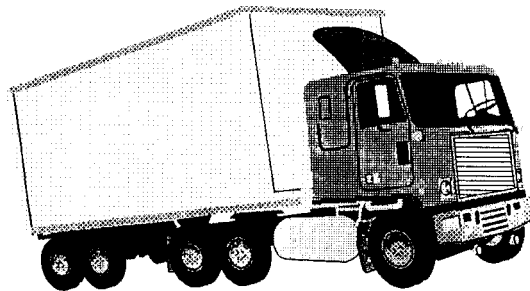


TRUCK NOISE LEVELS ON UPGRADES AND A SIMPLE METHOD FOR NOISE PREDICTION

Supplemental Report (Final)

By

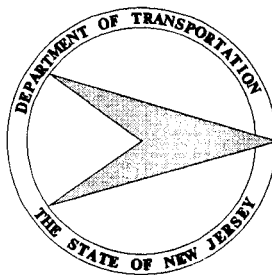
S. Robert Sasor
Principal Engineer



May 1992

Prepared By

New Jersey Department of Transportation
Division of Research and Demonstration
Bureau of Transportation Technology Research



In Cooperation with
U.S. Department of Transportation
Federal Highway Administration

NOTICE

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

DISCLAIMER STATEMENT

The contents of this report reflect the views of the author who is responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the N. J. Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the contributions made by all members of the Bureau of Transportation Technology Research and the Division of Research and Demonstration who worked on this study. Those deserving special mention are the late Joe Flesch, for his work on site selection and data acquisition; Bruno Rembish, Jack Martenak, and Zoltan Zeisky, for their work on data acquisition and data reduction; Tom Fuca who provided guidance as project manager; Jan Furda who prepared the final manuscript; and Bill Crowell who completed the drafting work. The author also gratefully acknowledges the Bureau of Equipment for providing the 6-ton diesel dump truck and a driver for the onboard measurements.

1. Report No. FHWA/NJ-91-004		2. Government Accession No. N.A.		3. Recipient's Catalog No. N.A.	
4. Title and Subtitle Truck Noise Levels on Grades and A Simple Method for Noise Prediction				5. Report Date May 1992	
				6. Performing Organization Code N.A.	
7. Author(s) S. Robert Sasor				8. Performing Organization Report No. 91-004-7910	
9. Performing Organization Name and Address New Jersey Department of Transportation Division of Research and Demonstration 1035 Parkway Avenue, CN612 Trenton, N.J. 08625				10. Work Unit No. (TRAIS) N.A.	
				11. Contract or Grant No. N.J. HPR Study 7910	
12. Sponsoring Agency Name and Address New Jersey Department of Transportation Division of Research and Demonstration 1035 Parkway Avenue, CN612 Trenton, N.J. 08625				13. Type of Report and Period Covered Supplemental Report	
				14. Sponsoring Agency Code	
15. Supplementary Notes Prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration.					
16. Abstract A simple method for predicting the noise due to heavy trucks on interstate upgrades was developed from mathematical modelling, and the findings of passby and onboard measurements. This method provides speed and noise emission level inputs to the STAMINA 2.0 traffic noise computer program. It predicted the noise from heavy trucks on interstate upgrades more accurately than STAMINA 2.0 alone (1.75 dBA more accurately on average). Truck passby noise measurements were made on a 2 mile long, 4% interstate highway upgrade at one location just before the upgrade and at three locations on the upgrade. Truck noise measurements were also made on upgrades and ramps with a microphone on board a test truck. Heavy truck noise levels measured near the top of the 4% upgrade were more than a decibel (dBA) lower than on the preceding level roadway. Also, speeds measured on the upgrade were considerably higher than those given in the 1985 Highway Capacity Manual. The onboard noise measurements on upgrade roadways corroborated the passby measurement results. Onboard measurements on ramps indicated that the medium truck's noise level was always less on the various types of ramps than it was on the mainline roadways they adjoined.					
17. Key Words Highway Traffic Noise Truck Noise, Noise Measurements Pass-by Noise Levels Traffic Noise on Upgrades Traffic Noise Prediction			18. Distribution Statement No Restrictions		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 96	22. Price

TABLE OF CONTENTS

	<u>Page</u>
SUMMARY AND CONCLUSIONS	1
RECOMMENDATIONS	9
INTRODUCTION	11
APPROACH	14
Mathematical Models	14
Onboard Measurements	15
Passby Measurements	16
Simplified Prediction Method for Upgrades	17
PASSBY TRUCK NOISE MEASUREMENTS	20
One Point Measurements	20
Findings	23
Two Point Measurements	28
SIMPLIFIED PREDICTION METHOD FOR UPGRADES	32
New Average Speed Computer Program	34
Adjusted Noise Emission Level Equation	35
Evaluation	37
IMPLEMENTATION OF FINDINGS	45
REFERENCES	47
APPENDIX A: Mathematical Models for Predicting Noise from Trucks on Upgrades and Ramps	49
APPENDIX B: Onboard Truck Noise Measurements	52
APPENDIX C: Passby Truck Noise Measurements	64
Measurement Methodology	64
Data Reduction	74
Data Analysis	78
APPENDIX D: Listing of Average Speed Computer Program	80
APPENDIX E: One Point Passby Measurement Data (Heavy Trucks)	83

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
1	Pass-by Microphone Locations 1-4	21
2	Noise Emission Level Equation	38
B-1	On Board Microphone Location - Medium Dump Truck	53
B-2	On Board Measurement Sites - Interstate 78, Route 173, and Study Ramps	55
B-3	Truck Speed, RPM, and Noise Level Charts - Upgrade	56
B-4	Truck Speed, RPM, and Noise Level Charts - Ramps	57
C-1	Pass-by Microphone Layout - Location 1	65
C-2	Pass-by Microphone Layout - Location 2	66
C-3	Pass-by Microphone Layout - Location 3	67
C-4	Pass-by Microphone Layout - Location 4	68
C-5	Setup for a Typical Measurement Site	71
C-6	Noise Recording System	73
C-7	Data Reduction System	76

LIST OF TABLES

<u>Table</u>		<u>Page</u>
1	Heavy Truck Pass-by Data, Locations 1-4 (One Point Measurements)	25
2	Heavy Truck Pass-by Data for Location 1 (Two Point Measurements)	31
3	Input Conditions for STAMINA 2.0	41
4	STAMINA 2.0 Output: Hourly Leq of a Single Truck (dBA)	42
5	Mean Difference Between Predicted and Measured Leq's (dBA)	44

SUMMARY AND CONCLUSIONS

Federal noise standards require the New Jersey Department of Transportation to estimate the noise impacts of a proposed federal-aid highway on the public. Expected traffic noise impacts are estimated using a Federal Highway Administration (FHWA) approved highway traffic noise prediction computer program [1]. Fundamental to this computer program are vehicle noise emission levels which describe the noise source. National average reference noise emission levels are specified in the program. Because of regional trends in vehicle types, this study was undertaken to accurately determine reference noise emission levels for trucks travelling on New Jersey highways.

For the original study, which was begun in 1976, approximately 4500 truck noise emission levels were measured at 37 sites. The interim report, completed in May 1978, covers the measurement methodology and the sites selected. From analysis of the noise emission level data, two truck classes -- (1) medium trucks and buses, and (2) heavy trucks -- were found to represent all of the truck classes that were studied. Reference noise emission levels were determined for these two classes of trucks operating on level, upgrade, and downgrade roadways and ramps. The final report, completed in July 1980, details data reduction and analysis of the truck noise data and presents a comparison of New Jersey's truck noise emission levels and the FHWA's national average truck noise emission levels [2]. The comparison indicates

that New Jersey's truck noise levels were generally slightly higher than the national averages.

This report describes the work completed for the supplemental study of truck noise on upgrades and ramps. The objectives of the supplemental study were to examine more closely the time-varying noise emission levels of trucks on upgrades and ramps, and to develop a method for adjusting the FHWA highway traffic noise computer program so that predictions of noise due to trucks on upgrades will be more accurate. The original study examined a truck's noise emission level at only one point and time.

SUPPLEMENTAL STUDY APPROACH

The following approach was taken for the supplemental study. Since the current FHWA traffic noise prediction computer model does not rigorously address noise from trucks on upgrades or ramps, preliminary mathematical models to address these situations were developed. These models proved to be very unwieldy in their mathematics because of their assumptions of non-constant noise emission levels and non-constant speeds -- the true conditions which occur for trucks on upgrades or ramps. The mathematical models were too complex to be practicable and a more simple method was sought.

Data for trucks operating on upgrades and ramps was measured to better understand the relationships between truck noise emission

level and speeds for these roadway conditions. This increased understanding guided the development of a simple prediction method for trucks on upgrades. Two types of field measurements were taken -- onboard measurements and passby measurements. For onboard measurements, a microphone was mounted on a boom attached to the truck to be measured. Thus, the microphone was not stationary but moved with the truck; accordingly it provided a continuous -- in some cases more than 5 minutes -- measurement of the truck's noise emission level, speed, and RPM as the truck negotiated various ramps and grades. For passby measurements, stationary microphones were positioned adjacent to an upgrade roadway and the level roadway preceding it. Three microphones were located at various distances along a 2 mile long 4% interstate highway upgrade, and one microphone was located along the level roadway section. Consequently, noise emission levels and speeds were measured for isolated trucks in the normal traffic stream as they passed by the microphones. These passby measurements had a duration of about 5 to 10 seconds, provided data only at the specific microphone locations, and did not produce a continuous data record.

Analysis of these truck noise and speed measurements not only guided the development of the simple prediction method for upgrades but also provided information which was subsequently used to revise this method. The completed simple prediction method for heavy trucks on interstate upgrades was evaluated along with the method presently used by the environmental unit at NJDOT to determine which method was more accurate when compared to measured levels.

PASSBY MEASUREMENTS

The passby measurements resulted in significant findings. As mentioned, these measurements were made at a 4% interstate upgrade of 2 mile length. Four microphone locations were used, one per day, each with microphones positioned at 50 feet from the center of the near and center lanes, respectively. One location was 2,000 feet before the start of the upgrade and the other locations were 3,000, 7,000, and 9,000 feet after the start of the upgrade. The last location was near the top of the upgrade. One point and two point passby measurements were taken. One point data was collected at all four microphone locations but a truck's noise and speed were measured at only one microphone location per passby. For the one point measurements, about 300 heavy truck noise emission levels with corresponding speeds, and about 250 heavy truck Leq's (equivalent sound levels) were obtained.* An analysis of this data resulted in the following findings:

-Median heavy truck noise emission levels were not higher on the upgrade than on the level roadway preceding it for either the near or center lanes. In fact, median heavy truck noise emission levels measured at 1000 feet before the top of the upgrade were more than a decibel lower than those measured on the level roadway at 2000 feet before the start of the upgrade.

-Center lane heavy truck noise emission levels and Leq's were generally more than 2 dB higher than those for the near lane for all microphone locations.

* Insufficient data was collected for medium trucks.

-Median heavy truck speeds fell nearly the same amount on the upgrade for both the center and near lanes (about 15 miles per hour). Center lane heavy truck speeds were on the average about 10 miles per hour higher than near lane speeds.

-Heavy truck speeds measured about 1000 feet before the top of the upgrade were about 13 and 6 miles per hour higher, respectively, than the speeds given in the performance curves for heavy and standard trucks contained in the 1985 Highway Capacity Manual [3] under Basic Freeway Segments for the corresponding grade percentage and length.

NOISE PREDICTION METHOD

The simple method for predicting the noise of heavy trucks on interstate highway upgrades was developed from consideration of the preliminary mathematical models and the noise and speed data obtained from the onboard and passby measurements of heavy trucks on upgrades. The mathematical models for predicting the noise from trucks on upgrades and ramps were so complex that a more simple method was needed. This simple method was proposed based on the assumption that even though a heavy truck on an upgrade has a time-varying speed and noise emission level, use of a truck's average speed for the grade and the noise emission level associated with this average speed will approximately predict the actual noise levels.

Initially, a short computer program was written to calculate the average speed of a heavy truck on upgrades of various lengths and slopes. Heavy truck deceleration rates were taken from performance curves in the 1985 Highway Capacity Manual. Also, the heavy truck noise emission level associated with this average speed was obtained from an equation for upgrade interstate roadways determined for NJDOT's original truck noise study [4]. Thus the original simple prediction method for heavy trucks on upgrades consisted of a computer program to calculate average speed, an equation yielding a reference noise emission level for heavy trucks, and prediction of highway noise levels using this information as input to the FHWA Level 2 Highway Noise Prediction Program (STAMINA 2.0).

Unfortunately this simple method gave results which were much different than the actual heavy truck speeds and noise emission levels measured in 1984 for this supplemental study. The 1984 heavy truck speed data from this study and available truck speed data from other states was reviewed, and a new computer program to calculate average heavy truck speeds on upgrades was written. At the heart of this program was a speed loss on upgrade equation determined by the University of Michigan's Transportation Research Institute (UMTRI) for one of their recent studies [5]. By applying the result of a non-linear regression performed on UMTRI's data, this equation was modified slightly to obtain the speed loss for an average eastern interstate tractor trailer. This modified equation yielded a heavy truck speed in good

agreement with those speeds measured near the top of the upgrade for NJDOT's supplemental truck noise study. In addition, the simple method's equation for reference heavy truck noise emission levels on upgrades was adjusted based on a comparison of truck noise data taken in 1977 (NJDOT's original study) and 1984 (this supplemental study). The comparison indicated that the heavy truck reference level equation should be adjusted downward by about 3 decibels. Therefore, it was adjusted accordingly.

The noise level predictions made by both methods were compared to actual noise levels measured in 1984 on the approximately 4% upgrade of I-78, to determine if the simple prediction method for upgrades results in more accurate noise prediction for heavy trucks on interstate upgrades than the method presently used by the environmental unit at NJDOT. The comparison was done in terms of equivalent sound levels (Leq's) for individual heavy trucks using the FHWA's STAMINA 2.0 computer program. The findings of this comparison are given below:

-The simple prediction method for upgrades predicted the Leq's of individual heavy trucks on average about 0.8 dB more accurately than the present method for the center lane; and 2.6 dB more accurately, for the near lane.

To summarize, this supplemental study, which was undertaken to examine more closely noise emission levels and speeds of trucks on upgrades and ramps, resulted in the following significant

findings. A-weighted heavy truck noise emission levels were not higher on a 2 mile long 4% interstate upgrade than on the level roadway before it. Near the top of this same upgrade, heavy truck speeds were from 6-13 miles per hour higher than the speeds indicated in the performance curves in the 1985 Highway Capacity Manual. The simple prediction method for heavy trucks on interstate upgrades predicts individual heavy truck Leq's on average about 1.75 dBA more accurately than the presently used traffic noise prediction model when both methods are compared to actual heavy truck noise measurements. This more accurate representation of heavy truck Leq's translates into an approximately 1.5dBA lower Leq sound level prediction for sound receivers adjacent to interstate upgrades with significant heavy truck volumes. If the simple prediction method for upgrades is implemented by incorporating it into the FHWA Level 2 Highway Traffic Noise Prediction Program, then the number and severity of expected noise impacts for proposed interstate highways will be reduced. This should provide NJDOT with a cost benefit because fewer and smaller noise barriers to mitigate expected noise impacts will be required.

RECOMMENDATIONS

Based on the results of the passby measurements taken for this study the following recommendations are made:

-The grade adjustment in the FHWA Level 2 Traffic Noise Prediction Program (STAMINA 2.0) should not be used when noise predictions are made for interstate upgrades because in this study heavy truck noise levels were found to be no higher on an interstate upgrade than on the level roadway before it. The STAMINA 2.0 grade adjustment raises the level roadway truck noise emission level by 2 to 5 dBA depending on the slope of the upgrade.

-If the speed loss, crawl speed, or average speed of a heavy truck on an interstate upgrade has to be determined, the average speed computer program (modified University of Michigan study equation) developed for the simple prediction method for upgrades should be used rather than the performance curves in the 1985 Highway Capacity Manual.

It is further recommended that the simple prediction method for upgrades be implemented by incorporating it into STAMINA 2.0, because more accurate noise level predictions will result. As a consequence, noise level predictions for some interstate upgrades will be about 1.5 decibels lower. For these highway sections, NJDOT will achieve a cost benefit because less noise impacts will be

identified and less noise mitigation (i.e., highway noise barriers) will be required. Implementing the simple prediction method for upgrades as recommended, will yield lower noise level predictions for upgrade highway sections only, and will not affect noise level predictions for level roadway sections. Therefore, at least temporarily, noise level predictions for level roadways may be 1-2 dB higher than for upgrade roadways. This situation should be rectified when the research recommended below is performed.

Further study of truck noise emission levels in New Jersey is recommended since the passby measurements made for this study on an upgrade in 1984 showed that truck noise emission levels were significantly lower than in 1977. A measurement study to update the truck noise emission levels measured in New Jersey in 1977 for level, upgrade, and downgrade interstate and non-controlled access roadways is proposed. Federal noise regulations for in-use trucks, which went into effect in January 1986, and for newly manufactured trucks, which went into effect in January 1988, may further lower truck noise emission levels [6].

INTRODUCTION

On proposed federal-aid highway construction projects, NJDOT conforms to federal noise standards contained in the Federal-Aid Highway Program Manual, Volume 7, Chapter 7, Section 3, "Procedures for Abatement of Highway Traffic Noise and Construction Noise" (FHPM-7-7-3) [7]. These standards require that expected traffic noise impacts due to a proposed highway project be determined and analyzed. Prediction of traffic noise levels is required to assess the expected environmental noise impacts of the proposed highway. If expected noise levels approach or exceed the noise abatement criteria in the federal noise standards, or when they substantially exceed the existing noise levels, NJDOT is also required to consider noise abatement measures such as traffic noise barriers. NJDOT determines expected traffic noise levels using highway traffic noise prediction computer programs approved by the Federal Highway Administration (FHWA) pursuant to FHPM 7-7-3. These programs, which utilize national truck noise levels, contain an adjustment to these levels for upgrades which is questionable.

This report covers work which was completed for a research study of truck noise on upgrades and ramps. It includes the findings of passby measurements at various locations along the length of a upgrade; a simple method for predicting the noise due to heavy trucks on interstate upgrades; onboard measurements of a truck operating on grades and ramps; and mathematical modelling of truck

noise levels on upgrades and ramps. Most of the research study was devoted to truck noise levels on upgrades. Time-varying noise emission levels of individual trucks were examined instead of looking at a truck's noise emission level at only one location on a grade, as was done in NJDOT's original truck noise study and studies completed by other states. Since the traffic noise prediction models currently in use are not capable of rigorously dealing with trucks on upgrades and ramps, this study was begun to examine more closely the time-varying noise emission levels of trucks on these roadways, and to develop a method to more accurately predict noise due to trucks on upgrades. This study is a supplement to NJDOT's original truck noise study.

NJDOT's original truck noise study was begun in 1976 when the FHWA approved traffic noise prediction program was not predicting as accurately as needed. The original study's objective was to more accurately predict highway traffic noise levels by improving the program's treatment of trucks with regard to noise. At the time, the program made no allowance for medium trucks and the reference truck noise levels were not representative of N.J. trucks because of regional trends in vehicle types. Truck noise emission levels were determined from direct measurement of the passby noise of individual trucks as they travelled on flat, upgrade, and downgrade roadways and on ramps. More than 4500 truck noise emission levels were obtained from measurements at 37 sites. From analysis of the truck noise level data, two truck classes - (1) medium trucks and buses, and (2) heavy trucks - were found to

satisfactorily represent all the truck classes that were studied. An interim report [8], which covers the measurement methodology, including field procedures and equipment, and measurement sites, including criteria for selection, was prepared. A final report [4] was completed which describes data reduction and analysis of the noise data taken for 2 to 6 axle trucks and 2 and 3 axle buses as they travelled on flat, upgrade, and downgrade highways within New Jersey. It also presents a limited amount of truck noise data for ramps. Reference noise emission levels as a function of speed are presented for the two general truck classes for each type of roadway, and levels are compared between roadway types. In addition, New Jersey's noise emission levels for trucks are compared to the national average truck emission levels contained in the FHWA highway traffic noise prediction method [2].

The original truck noise study provided much information about truck noise on flat, upgrade, and downgrade roadways; however, the data for upgrades was taken at only one location along the grade. Thus, it did not provide any information as to how a truck's noise emission level and speed vary in time as the truck travels on a flat roadway and then up a grade. This study was undertaken to discover this important information, and to determine how a truck's changing emission level and speed relate to the prediction of noise levels adjacent to the highway.

APPROACH

The following approach was taken to examine more closely the noise from trucks on upgrades and ramps, and to predict noise from trucks on upgrades more accurately. A preliminary mathematical model for predicting noise from trucks on upgrades and ramps was developed, since the FHWA Traffic Noise Prediction Model [2] assumes constant speed and noise emission level, and does not rigorously address noise from vehicles on upgrades and ramps where speeds and emission levels are not constant. Methodologies for conducting onboard and passby truck noise measurements were developed, and measurements were taken to obtain actual truck noise and speed data for evaluating the mathematical model. A simplified method for predicting noise from heavy trucks on upgrades was developed because the preliminary mathematical model was so complex, and implementation did not appear feasible. This simplified method was revised based on an analysis of the truck noise measurements. Finally the noise levels predicted by the revised simplified method of this study and the method currently used by the environmental noise unit at NJDOT were compared to the levels measured for individual heavy trucks on a 4% interstate upgrade.

MATHEMATICAL MODELS

The FHWA Traffic Noise Prediction Model assumes constant speed vehicles with constant noise emission levels. The mathematical

models addressed situations where vehicle speeds and/or noise emission levels were not constant over time; namely, vehicles operating on upgrades and ramps. Via discussions and correspondence, the FHWA Environmental Sciences Group outlined a general analytical approach for deriving the models for upgrades and ramps. The mathematical models were developed in terms of the equivalent sound levels (Leq) methodology presented in the FHWA Model [2] and thus are compatible with it. These models were developed as adjustments to the FHWA model -- adjustments which took into account the time varying nature of noise emission levels and speeds for vehicles operating on upgrades and ramps. A short document presenting the derivations of the mathematical models with some basic examples of their usage was transmitted to FHWA in 1980. After further study it was decided that these models were too complex to be practical and a more simple method was pursued. For more details on the mathematical models, see Appendix A, Pages 49-51.

ONBOARD MEASUREMENTS

Onboard measurements were conducted to obtain information about the relationships of truck noise emission level, speed, and engine RPM under the operating conditions occurring on grades and ramps. This information was used in evaluating the mathematical models and the simplified prediction method for trucks on upgrades. An NJDOT dump truck (a medium truck) was used for the onboard measurements. A microphone mounted on the truck which moved with the truck provided a different perspective than the customary

stationary microphone used in passby measurements. Instruments which made simultaneous and continuous recordings of noise, speed, and RPM were placed in the cab of the truck. Onboard truck noise measurements are discussed more fully in Appendix B, Pages 52-63.

PASSBY MEASUREMENTS

Passby measurements were taken for individual trucks in the existing traffic stream to obtain data on how noise emission levels and speed change at different locations along an upgrade. This data was used to evaluate the mathematical models and the simplified prediction method for trucks on upgrades.

A two mile long 4% interstate upgrade was selected as the site for the passby measurements. Four microphone locations were used. One location was 2,000 feet before the start of the grade and other locations were 3,000, 7,000 and 9,000 feet after the start of the grade. The last location was near the top of the upgrade. Passby measurements were made with stationary microphones positioned 50 feet from the center of the travelled lane. A measurement methodology was developed for obtaining accurate measurements of the noise emission level, equivalent sound level (Leq), and speed of individual trucks. The methodology specified the extent to which the target truck had to be isolated from other nearby traffic so that its noise emission level and Leq could be accurately measured. The noise level of every sufficiently isolated medium or heavy truck in the near or center lanes was measured.

Two types of measurements were taken -- one point and two point. One point measurements were made for truck passbys at each of the four microphone locations on successive days. For two point measurements, the same truck's noise was measured at two microphone locations per passby. One location was before the upgrade; the other was one of the three locations on the upgrade. Measuring a truck's noise emission level at more than two locations along the upgrade for a single passby was not attempted mainly because the existing traffic volume on the two mile long upgrade was too high to isolate individual trucks at three or four locations. See pages 20-31 for a full discussion of the passby measurements.

SIMPLIFIED PREDICTION METHOD FOR UPGRADES

The simplified method for predicting the noise due to heavy trucks on interstate highway upgrades was developed because all of the preliminary mathematical models were found to be too complex for practical application. The simplified method was developed using information about truck noise emission levels and speeds on upgrades obtained from the onboard and passby measurements, and from other sources.

The simplified method is based on the assumption that even though a heavy truck on an upgrade has a time-varying speed and noise emission level, use of a truck's average speed for the grade and

the noise emission level associated with this average speed will approximately predict actual noise levels. It was felt that even an approximate prediction of actual noise levels would be more accurate than the noise levels predicted by the currently used method [1].

Accordingly, the simplified prediction method for heavy trucks on upgrades originally consisted of (1) a computer program which calculated the average speed of a heavy truck from equations based on the speed versus distance on upgrade curves contained in the 1985 Highway Capacity Manual, and (2) the noise emission level versus speed equation for heavy trucks on greater than 2% interstate upgrades developed for NJDOT's original truck noise study [4]. However, the simplified method was revised because it did not agree well with the results of the passby measurements for this study. Heavy truck speeds yielded by the simplified method were 10-15 mph less than those actually measured. Also the noise emission level versus speed equation yielded noise emission levels significantly higher than those measured.

After reviewing the truck speed data from the passby measurements and truck speed data from other states, a decision was made not to use the 1985 Highway Capacity Manual's speed on grade curves. Therefore, a new computer program for calculating the average speed of heavy trucks on upgrades was written. This program utilizes the University of Michigan Transportation Research Institute's speed loss on grade equation [5]. Heavy truck speeds

estimated by the University of Michigan equation are nearer to those measured in this study.

A new truck noise emission level equation for heavy trucks on upgrades was also determined. Heavy truck noise levels for this study were compared to those measured in 1977 on the same upgrade. This comparison indicated that the 1984 heavy truck noise levels were about 3 dB less than those measured in 1977 for the original truck noise study. Accordingly, the original study's heavy truck noise emission level equation for upgrades was modified to reflect the lower levels measured in 1984. This modified equation was used in the simplified method.

To evaluate the simplified method, predicted noise levels were compared to measured noise levels. NJDOT's environmental noise unit predicts traffic noise levels using the FHWA Level 2 noise prediction computer program (STAMINA 2.0) [1]. Equivalent noise levels (Leq's) were predicted first using STAMINA 2.0, and then using STAMINA 2.0 with heavy truck speed and noise emission level input provided by the simplified prediction method for upgrades. These two sets of predicted levels were compared to the nearly 200 Leq's measured for individual heavy trucks on the 4% upgrade used for the passby measurements of this study. For this two mile long interstate upgrade, STAMINA 2.0, using inputs provided by the simplified prediction method for upgrades, predicted individual heavy truck Leq's about 1.75 decibels more accurately on average than STAMINA 2.0 as it is presently used. For a full discussion of the simplified prediction method for upgrades see pages 32-44.

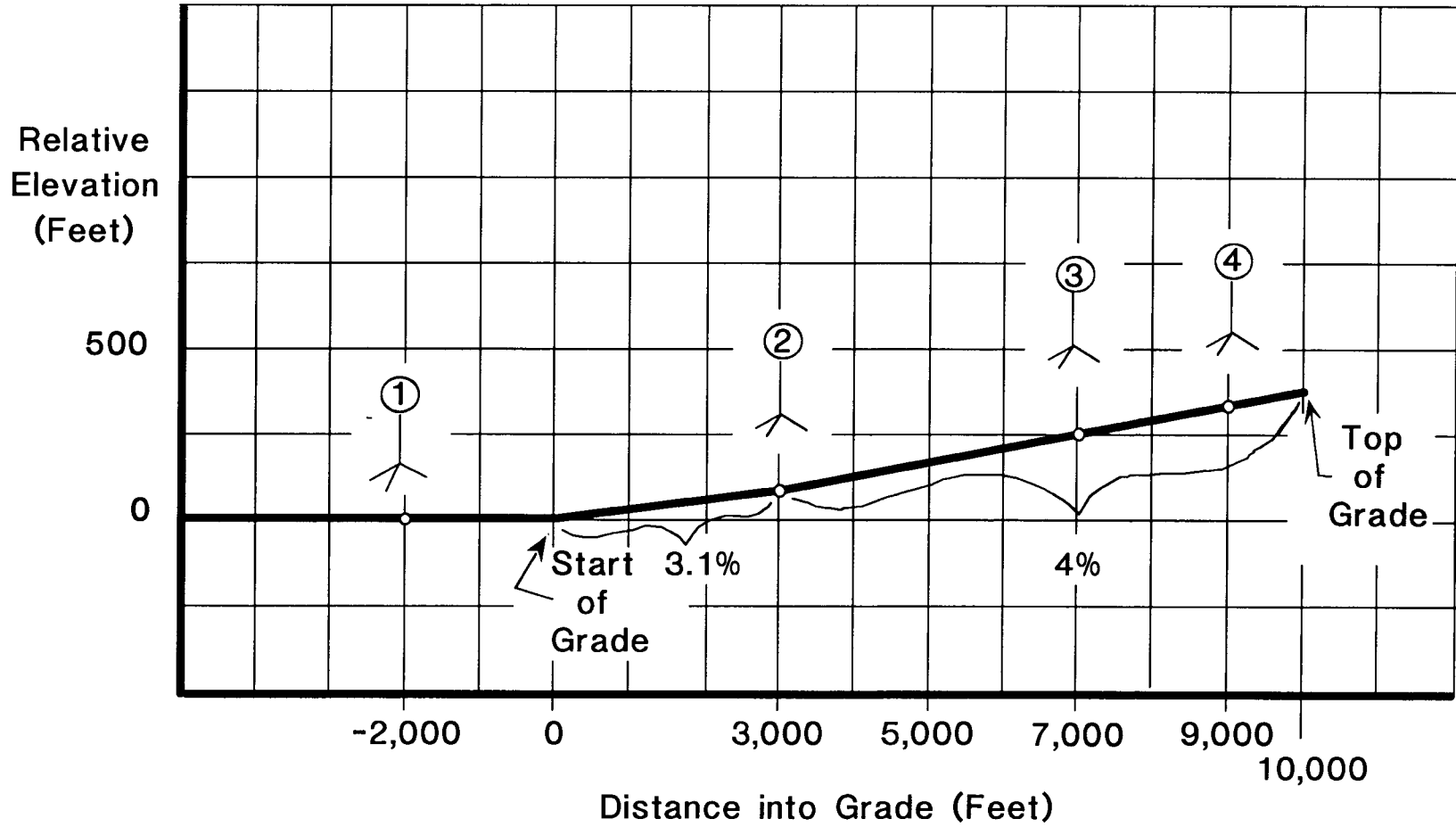
PASSBY TRUCK NOISE MEASUREMENTS

Passby measurements were taken for heavy and medium trucks in the existing traffic stream on a 2 mile long 4% upgrade on Interstate 78 about 5 miles west of Clinton near Pattenburg. Three measurement locations were on the upgrade and one location was before it (Figure 1, Page 21). For these measurements, the noise from the passby of an individual truck was recorded on one channel of a tape recorder while a description of the vehicle was recorded on another channel. A truck's noise emission level and equivalent noise level (Leq) were determined from the recorded noise. A truck's average speed for the measurement interval (400 ft) was determined from the time between annotations on the voice channel. Thus noise and speed data for trucks operating with time-varying noise emission levels and speeds were obtained. This information was used in developing the simplified prediction method for trucks on grades. Two types of measurements were taken, "one point" and "two point". One point measurements were made at one of the four microphone locations for individual truck passbys. Measurements were taken at each location on different days. For two point measurements, the same truck's noise was measured at two locations per truck passby (at one of the three locations on the upgrade and at the location before the upgrade.)

ONE POINT MEASUREMENTS

One point measurements were taken at the three microphone

**Figure 1. PASS-BY MICROPHONE LOCATIONS 1-4
(Interstate 78 Upgrade)**



-21-

Not to Scale

locations along the I-78 upgrade and the single location along a flat roadway section before the upgrade. Measurements were made at one location (one point) per truck passby. Microphone Location 1 was about 2,000 feet before the start of the 4% upgrade and microphone Locations 2, 3 & 4 were about 3,000, 7,000, and 9,000 feet after the start (See Figure 1, Page 21). The I-78 upgrade was selected as the measurement site because it was the longest and steepest of the upgrade sites that were inspected, which met the physical site criteria required for accurate noise measurements at three locations along a grade. The physical site criteria, which are described in the interim report for the original study [8], specify the size and position of sound reflecting objects allowed in the measurement area and the general physical features of a site. Microphone Locations 1 and 2 met these physical site criteria. Location 3 met these criteria with the exception that microphones were placed on a downslope. Location 4 met these criteria with the following exceptions: a 2.5-3 foot high center barrier was present in the roadway median, a stand of trees began 5 feet behind the near lane microphone, and microphones were placed on a slight downslope. See Figures C-1 to C-4, Pages 65-68, for details on physical features and microphone placement at all locations.

A measurement methodology was developed to obtain accurate truck noise levels at the microphone locations. This methodology included a valid measurement criteria and data collection procedures. Procedures for data reduction and data analysis were

also developed. The measurement methodology, and data reduction and analysis procedures are given in Appendix C, Pages 64-79.

For the one point measurements, about 300 valid truck noise emission levels and about 250 valid truck Leq's were obtained. The findings for these measurements are given below.

Findings

Nonparametric statistics were used to determine if there were statistically significant differences between the noise levels and speeds for various lanes and locations. As mentioned under "Data Analysis" in Appendix C, the SAS computer package [9] was used to perform the Wilcoxon Rank Sum and Median nonparametric tests. The Wilcoxon Rank Sum Test (WRST) and the Median Test were done to determine if the truck noise and speed data samples taken for various lanes and locations were from the same populations and from populations with the same medians, respectively.

First, near and center lane data was compared for each location. The WRST and the Median Test indicated that at a 10% significance level, noise emission levels and Leq's for the near and center lanes had different populations with different medians for each location. These tests indicated that speeds for the near and center lanes had different populations with different medians except for Location 2. Second, data for Locations 1,2,3, and 4 were compared for each lane. Thus for each lane, six comparisons

(Locations 1 vs. 2, 1 vs. 3, 1 vs. 4, 2 vs. 3, 2 vs.4, and 3 vs. 4) were made for each of the three variables. The WRST and the Median Test indicated that at a 10% significance level, noise emission levels and Leq's had different populations with different medians except for Locations 2 vs. 4, near lane and Locations 1 vs. 2, center lane. These tests indicated that truck speeds had different populations with different medians except for Locations 1 vs. 3, center lane and Locations 1 vs. 2 and 3 vs. 4 for the near lane. For those instances where data was from normally distributed populations for both of the lanes or locations being compared, the Student t-test was done. For these cases, results of the Student t-test agreed with those of the nonparametric tests.

In summary, in most cases (20 of 24) heavy truck noise emission levels and Leq's were significantly different for each location and lane. Also, for heavy truck speeds, again in most cases (9 of 12), speeds were significantly different for each location and lane.

Table 1, Page 25, indicates the findings for all four microphone locations. Median heavy truck noise emission levels, Leq's, and speeds are presented. In addition, energy means are shown for noise emission levels and Leq's. Mean speed is presented because it may be of interest to some readers. The number of observations in the sample for a particular lane and location is shown in the right hand column of each variable section of the table.

TABLE 1: HEAVY TRUCK PASS-BY DATA
 LOCATIONS 1 - 4 (ONE POINT MEASUREMENTS)

LOCATION	LANE	NOISE EMISSION LEVEL (dBA)			EQUIVALENT SOUND LEVEL [LEQ] (dBA)			SPEED (mph)		
		MEDIAN	ENERGY MEAN	N	MEDIAN	ENERGY MEAN	N	MEDIAN	MEAN	N
1	Center	86.2	86.3	41	81.0	81.8	22	55.7	56.1	45
2	Center	86.7	87.4	53	81.2	82.4	42	48.7	47.8	60
3	Center	82.7	84.1	51	77.6	79.3	45	53.5	51.6	63
4	Center	84.3	84.6	41	79.5	80.0	45	42.0	41.7	59
1	Near	83.4	84.6	51	78.1	78.7	37	47.8	48.6	63
2	Near	82.1	85.6	9	76.6	76.6	8	45.8	46.5	10
3	Near	78.5	79.5	14	72.4	72.6	9	34.7	34.2	16
4	Near	81.6	82.8	45	76.7	77.1	34	31.7	33.2	59

Noise Data - The following findings regarding heavy truck noise are drawn from inspection of Table 1.

-Median and energy mean noise emission levels and Leq's were lower at upgrade Locations 3 & 4 than they were for Location 1 (the flat roadway before the upgrade) for both the near and center lanes.

-Center lane noise emission levels and Leq's were higher than those for the near lane for all locations. Center lane energy mean noise emission levels were more than 1.5 dB higher than those for the near lane; median noise emission levels, more than 2.5 dB higher; energy mean Leq's, more than 2.5 dB higher; and median Leq's, more than 2.5 dB higher. Part of the difference in noise levels between the center and near lanes is probably due to the center lane being a hard site with regard to ground absorption, while the near lane was a soft site.

-Noise emission levels and Leq's measured at Location 4 (about 1,000 feet before the top of the upgrade) were more than a decibel lower than those measured at Location 1 (flat roadway section before upgrade) for both near and center lanes.*

-Noise emission levels and Leq's for Location 3 (about 6,750 feet past the start of the upgrade) were the lowest measured for

* Though heavy truck noise emission levels measured at Location 4 were more than a decibel lower than those measured at Location 1, 5 minute Leq's measured at Locations 4 and 1 (including only heavy trucks) would be nearly the same because heavy truck speeds were significantly less at Location 4.

any location for both the near and center lanes. Less ground reflected noise may partially explain this result since the microphones at Location 3 were positioned farther above the ground than those at the other locations.

As shown in Table 1, sample sizes for Leq data were usually smaller. This occurred because the valid measurement criteria were more stringent for Leq measurements than for noise emission level measurements.

Speed Data - The following findings about heavy truck speeds are drawn from inspection of Table 1.

-Median and mean speeds dropped nearly the same amount between Locations 1 and 4 for both the center and near lanes (about 15 miles per hour).

-Center lane speeds were higher at all locations than near lane speeds (about 10 miles per hour on the average).

-For the center lane, speeds were higher for Location 3 than for Location 2. This was apparently due to heavier trucks in the center lane switching to the near lane after Location 2 and before Location 3, when they found themselves slowing down quickly.

-Final upgrade speeds at Location 4 were higher than those specified in the 1985 Highway Capacity Manual [3] under Basic

Freeway Segments. The average of the near and center lane heavy truck speeds at Location 4 was about 13 and 6 miles per hour higher, respectively, than the speeds indicated in the Highway Capacity Manual's Performance Curves for Heavy Trucks (300 lb/hp) and Performance Curves for Standard Trucks (200 lb/hp) for the appropriate grade percentage and length.

TWO POINT MEASUREMENTS

Two point measurements were taken at the same locations as the one point measurements utilizing the same microphone positioning and the same data collection procedure with the additions and exceptions mentioned in the following paragraphs.

Measurements were made at two microphone locations per truck passby. One location was the single location along a flat roadway section before the upgrade (Location 1); the second location was one of the three locations along the upgrade (Locations 2,3, & 4). Thus two equipment vehicles were used with one operator in each. Each operator had to make the tape recording of the truck noise as well as observe vehicle spacing to decide if the valid measurement criteria were met. The valid measurement criteria were modified slightly to simplify their use since each operator now had to handle the duties previously done by two people when the one point measurements were made.

After the target truck passed Location 1 a detailed description of the truck was relayed by walkie talkie to the equipment operator

at the upgrade location. This was done to insure that noise from the same truck was measured at both locations. In addition, the truck description information recorded on the voice channel was more detailed than for the one point measurements, so that it could be used to check, if necessary, that the same truck was measured at both microphone locations. This description information included cab type and color, body type and color, manufacturer, company name, load condition, truck number, and any unique markings on the truck.

Data was collected for 5 days between November 26 and December 5, 1984. Ninety five noise emission levels and 57 Leq's which met the valid measurement criteria were obtained for heavy trucks. No valid noise data was obtained for medium trucks. Of the 95 heavy truck noise emission levels, 73 were obtained for Location 1. Of the 57 heavy truck Leq's, 43 were obtained for Location 1. Thus, there was not much heavy truck noise data for Locations 2, 3, or 4. Corresponding noise emission levels and Leq's at two locations for the same truck passby were even more limited in number. For Locations 1 and 2 only 5 matchups were obtained; for Locations 1 and 3, 7; and for Locations 1 and 4, 4. The reason for such a small number of corresponding noise levels at two locations was that it was very difficult to achieve isolation of the same truck at two locations, given the volume of traffic on this interstate highway.

There was insufficient data to find any meaningful results about truck noise emission levels and Leq's for Locations 2, 3, & 4 (the

upgrade locations). The two point matchups for particular trucks did not provide any meaningful information either; again due to too small a sample size. The only meaningful results were obtained for Location 1.

For Location 1, statistical analysis indicated that noise emission levels, Leq's, and speeds were significantly different for the near and center lanes. As shown in Table 2, Page 31, noise emission levels were about 2 dBA higher; Leq's, 1.5-2.0 dBA higher; and speeds, 4-5 mph higher for the center lane. These results are similar to those obtained for Location 1 via the one point measurements.

One and two point measurements were not combined for data analysis because it was felt that the two point measurements were not as accurate as the one point measurements, since for the one point measurements it was one person's sole duty to observe vehicle spacing to see if the valid measurement criteria were met. As mentioned, for two point measurements the equipment operator had to record noise and the truck description as well as observe vehicle spacing.

TABLE 2: HEAVY TRUCK PASS-BY DATA
FOR LOCATION 1 (TWO POINT MEASUREMENTS)

LOCATION	LANE	NOISE EMISSION LEVEL (dBA)			EQUIVALENT SOUND LEVEL [LEQ] (dBA)			SPEED (mph)		
		MEDIAN	ENERGY MEAN	N	MEDIAN	ENERGY MEAN	N	MEDIAN	MEAN	N
1	Center	86.0	86.7	34	80.9	81.6	20	55.1	55.4	36
1	Near	84.0	84.8	39	79.4	79.9	23	50.5	51.4	41

SIMPLIFIED PREDICTION METHOD FOR UPGRADES

As mentioned for this supplemental study, mathematical models for predicting the noise from trucks on upgrades and ramps were developed based on an approach outlined by the FHWA. These mathematical models were developed in terms of the equivalent sound levels methodology contained in the FHWA Model [2] and considered the time varying nature of noise emission levels and speeds for vehicles operating on upgrades and ramps (See Appendix A, Pages 49-51). All of the models were very complex mathematically, and it would have taken a major field effort to determine all of the constants for the various equations. Consequently, a simpler method was sought. In light of information obtained from the onboard and passby measurements of trucks on upgrades, a simple method was developed. This method assumes that even though a heavy truck on an upgrade has a time-varying speed and noise emission level, use of a truck's average speed for the grade and the noise emission level associated with this average speed will approximately predict actual noise levels.

For the simple method, it was decided to write a short Fortran computer program to calculate the average speed of a heavy truck on an upgrade for various grade lengths and slopes for a given entry speed. For the program, heavy truck deceleration rates on upgrades were obtained from the Performance Curves for Heavy Trucks (300 lb/hp) which is Figure I.3-4. on page 3-43 of the 1985 Highway Capacity Manual [3]. This graph relates heavy truck speed

to distance on grades of various slopes for an entry speed of 55 miles per hour. SAS procedure NLIN was used to do non-linear regressions to determine equations for the 2-7% upgrade curves in this figure. These equations were incorporated into an iterative computer program which simulated a truck's movement along the upgrade for incremental time periods. The program calculated a heavy truck's average speed by keeping track of how long it took the truck to travel a specified distance.

The noise emission level associated with this average speed was obtained from the findings of New Jersey's original truck noise study [4]. The equation relating energy mean noise emission level to heavy truck speed on controlled access highways of greater than 2% upgrade was used (Roadway Type 2, page 67). The average speed given by the computer program and the noise emission level from the original truck noise equation were used as input to the FHWA Level 2 Highway Noise Prediction Program (STAMINA 2.0) which predicted the Leq for the specified sound receivers.

The heavy truck noise data collected for this supplemental study in 1984 on the 4% interstate upgrade was used to evaluate the accuracy of this simple prediction method for upgrades. The simple method gave results which were very different than the actual heavy truck speeds and noise emission levels measured in 1984. The simple method computer program for heavy truck speeds yielded speeds which were about 10 and 20 miles per hour lower than those measured near the top of the upgrade (Location 4) for the

near lanes and center lanes, respectively. In addition, heavy truck noise emission levels yielded by the simple method were significantly higher than those measured.

NEW AVERAGE SPEED COMPUTER PROGRAM

The 1984 heavy truck speed data from this study and available truck speed data from other states was reviewed. Based on this review, it was decided to abandon the computer program based on the 1985 Highway Capacity Manual heavy truck speed versus distance on upgrade curves. The standard truck (200 lb/hp) performance on upgrade curves (Figure I.3-2., page 3-41, of the 1985 Highway Capacity Manual), though yielding speeds nearer to the actual measured speeds (about 3 and 12 mph lower near the top of the upgrade for the near and center lanes, respectively), were still judged to be inadequate.

A literature search for other information about heavy truck speed losses on upgrades was undertaken. A study conducted by the University of Michigan Transportation Research Institute (UMTRI) [5] provided an equation which more nearly matched the heavy truck speeds measured in this study. A new Fortran computer program, which incorporated the UMTRI equation, was written to calculate average speed for heavy trucks on interstate upgrades. The program was similar to the previous one except that incremental distances were the basis of the iterative process. The program used UMTRI's equation essentially as presented in Reference 5,

however, the weight to power ratios were modified. (See Appendix D, Page 80, for a listing of the computer program.)

A non-linear regression was done on UMTRI's data for eastern interstate tractor trailers to determine these weight to power ratios at 25 mph(200 lb/hp) and 50 mph(350 lb/hp) as required by the equation. Near the top of the upgrade, the modified equation yielded a heavy truck speed in good agreement with those measured for this study -- it fell midway between the speeds measured for the near and center lanes (4 mph higher than the near lane speed and 5 mph lower than the center lane speed).

ADJUSTED NOISE EMISSION LEVEL EQUATION

As mentioned, the heavy truck noise emission levels predicted by the simple method were significantly higher than those measured for this study in 1984. The decision was made to adjust the heavy truck noise emission level equation of the simple method based on a comparison of truck noise data taken in 1977 (the original study) and 1984 (this supplemental study). Truck noise measurements were taken in 1977 on the same upgrade of I-78 where measurements were taken in 1984. The distance between microphone locations for the two years was about 500 feet. 1977 truck noise data for Site 6 was reanalyzed for the comparison. Using SAS procedure Univariate [9], noise emission level and speed data were both found to be from not normally distributed populations.

Accordingly, nonparametric statistical methods were used for the 1977 vs. 1984 comparison. SAS procedure NPAR1WAY, which performs the Wilcoxon Rank Sum Test and the Median Test, indicated that both heavy truck noise emission levels and speeds were from different populations when the 1977 and 1984 data were compared. An estimator associated with Wilcoxon's rank sum statistic [10] was used to find the median difference between the noise emission levels measured in 1977 and 1984 (143 and 45 observations, respectively). Using all data for both years, the median difference in heavy truck noise emission levels was about 4 decibels.

Since the speed ranges for the two years varied significantly, linear regressions of noise emission level versus speed were completed for the 1977 and 1984 data so that the median difference in noise emission level could be determined over the same range of speeds. Using speeds ranging from 18 through 52 miles per hour in increments of 1 mile per hour, the regressions for 1977 and 1984 were used to generate data sets of an equal number of noise emission levels for the same speeds. SAS procedure NPAR1WAY was run on these equal size data sets, and it once again indicated that heavy truck noise emission levels were from different populations. Using the estimator associated with the Wilcoxon rank sum statistic mentioned above, the median difference between the heavy truck noise emission levels generated from the regression lines was found once again to be 4 decibels.

Based on the preceding comparison, an adjustment was made to the heavy truck noise emission level equation used in the simple prediction method for upgrades. As mentioned, this heavy truck noise emission level equation was obtained from New Jersey's original truck noise study [4] and related energy mean noise emission level to heavy truck speed on controlled access highways of greater than 2% upgrade (Roadway Type 2, page 67). To be on the conservative side, this equation was adjusted downward by 3 decibels. This new equation, which is shown below, yields the truck noise emission levels corresponding to the average speeds calculated by the new Fortran computer program.

$$(\overline{L}_O)_E = 71.70 + 7.46 \log_{10} (V)$$

Where $(\overline{L}_O)_E$ = energy mean noise emission level, and

V = speed in miles per hour.

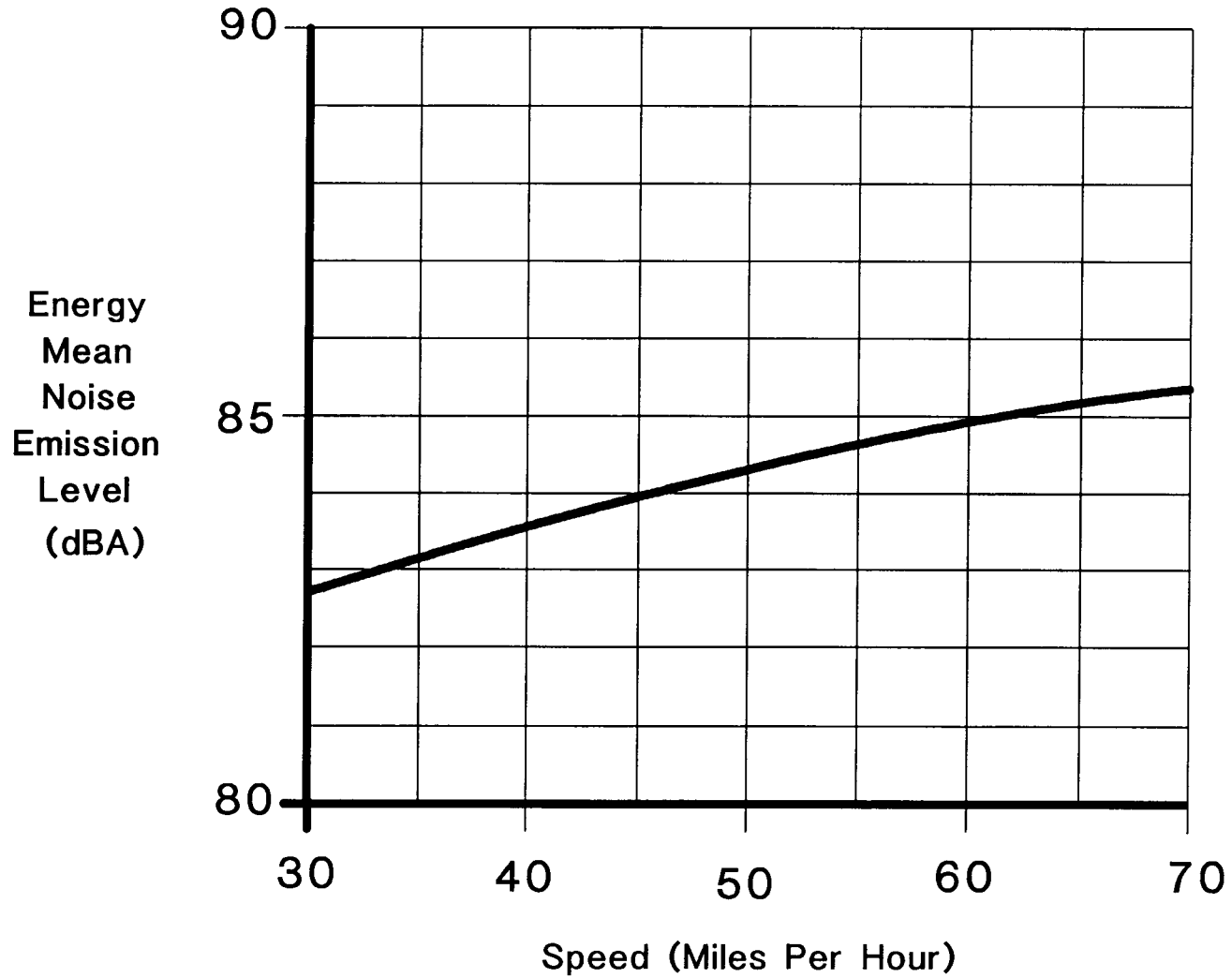
Figure 2, Page 38, is a graphical representation of this equation for speeds from 30 to 70 miles per hour.

Thus the simple prediction method for upgrades provides input to the FHWA Level 2 Noise Prediction Computer Program (STAMINA 2.0) based on the equation shown above and the computer program which calculates average heavy truck speeds for upgrades of various slopes and lengths.

EVALUATION

To determine if the simple prediction method for upgrades results

Figure 2. NOISE EMISSION LEVEL EQUATION



in more accurate noise prediction for heavy trucks on interstate upgrades than the method presently used by the environmental unit at NJDOT, the noise level predictions made by both methods were compared to actual noise levels measured in 1984 on the approximately 4% upgrade of I-78.

For these predictions the I-78 interstate upgrade was modelled as a 3% upgrade for 3130 feet and a 4% upgrade for 6700 feet for a total length of 9,830 feet (about 1.9 miles). The heavy truck was assumed to enter the upgrade at a speed of 55 miles per hour. The STAMINA 2.0 traffic noise prediction computer program was utilized for the comparison. Noise predictions were made for both near and center lane heavy trucks. Sound receivers were placed at 50 feet from the near and center lanes (the distance at which field measurements were made). With regard to ground absorption, the sound path from near lane traffic to receiver was considered a soft site ($\alpha = 0.5$); from center lane traffic to receiver, a hard site ($\alpha = 0$).

The comparison was done in terms of equivalent sound levels (Leq's) for individual heavy trucks. STAMINA 2.0 was used to predict the Leq due to one heavy truck. This hourly Leq had to be adjusted for the time period over which the Leq of each individual heavy truck was measured in order to make a valid comparison between predicted and actual noise levels. Note that all of the individual heavy truck Leq's obtained in 1984 were measured over a 400 foot distance interval. Consequently, because speed was

different for each truck, the time period over which Leq was measured was also different for each truck.

For noise predictions done with the present method used by NJDOT's environmental unit, STAMINA 2.0 alone was used. For noise predictions done with the simple prediction method for upgrades, the simple method provided the heavy truck speed and heavy truck energy mean noise emission level inputs to STAMINA 2.0. Noise barriers were not modelled for any of the predictions.

Table 3, Page 41, shows the input conditions for the noise predictions using the present method and the simple prediction method for upgrades. Note that heavy truck speed and noise emission level, and STAMINA 2.0 grade adjustment were different for the two methods. The national average heavy truck noise emission level is given on Page 4 of Reference 2. Table 4, Page 42, shows the output from STAMINA 2.0 for sound receivers with a height of 5 feet above the roadway elevation at a distance of 50 feet from the center of both the near and center lanes. The output is in terms of the hourly Leq of a single truck. Notice that the noise levels predicted by the simplified prediction method for upgrades are about 2.5 dB lower than those predicted by the method presently used by NJDOT's environmental unit. The equivalent noise levels (Leq's) predicted by the two methods were then compared to the actual Leq's measured for individual heavy trucks on the approximately 4% interstate upgrade in 1984.

TABLE 3
INPUT CONDITIONS FOR STAMINA 2.0

LOCATION 2

	PRESENT METHOD	SIMPLE METHOD
Roadway Segment Length (ft)	400	400
Segment Slope	3%	3%
Speed (mph)	55	50
Stamina Grade Adjustment	Yes	No
Heavy Truck Noise Emission Level (dBA)	87.3 (national avg. + 1)	84.4

LOCATIONS 3 & 4

	PRESENT METHOD	SIMPLE METHOD
Roadway Segment Length (ft)	400	400
Segment Slope	4%	4%
Speed (mph)	50	40
Stamina Grade Adjustment	Yes	No
Heavy Truck Noise Emission Level (dBA)	87.3 (national avg. + 2)	83.7

TABLE 4
 STAMINA 2.0 OUTPUT: HOURLY LEQ OF A SINGLE TRUCK (dBA)

LOCATION	LANE	SITE GROUND ABSORPTION	PRESENT METHOD	SIMPLE PREDICTION METHOD	DIFFERENCE
2	Center	Hard	53.9	51.4	2.5
2	Near	Soft	53.1	50.6	2.5
3	Center	Hard	54.3	51.6	2.7
3	Near	Soft	53.5	50.9	2.6
4	Center	Hard	54.3	51.6	2.7
4	Near	Soft	53.5	50.9	2.6

For this comparison, a computer program was written to adjust the single heavy truck hourly Leq's predicted by STAMINA 2.0 to the time periods over which each of the individual heavy truck Leq's was measured. Program output was the mean difference between the predicted Leq and the measured Leq for all of the trucks in any given class specified by a location and lane. This output is shown in Table 5, Page 44.

This table indicates that in five of the six cases specified by a location and lane -- Location 2, center lane being the exception -- the simplified prediction method for upgrades predicted more accurately than the present method. Thus, based on the foregoing comparison with heavy truck Leq's measured in 1984 on the 4th interstate upgrade, the simplified prediction method for upgrades predicted the Leq's of individual heavy trucks on average about 0.8 dB more accurately than the present method for the center lane; and 2.6 dB more accurately than the present method, for the near lane.

Note: The present method (STAMINA 2.0 computer program) used by NJDOT's environmental unit predicts higher Leq's adjacent to an upgrade than adjacent to a level roadway -- in the case of the I-78 upgrade, about 1-2 dB higher. For the I-78 upgrade, however, the simplified prediction method for upgrades predicts Leq's up to 1.5 dB lower than the present method's predictions for level roadways. Thus, if the simplified prediction method for upgrades is implemented by incorporating it into STAMINA 2.0 without any adjustments being made to STAMINA 2.0's heavy truck noise levels for level roadways, then Leq noise predictions for upgrades, though they will be more accurate, will in some cases be lower than the Leq's predicted for level roadways. This situation will be rectified when the recommended research to update truck noise levels on level roadways is completed.

TABLE 5
 MEAN DIFFERENCE BETWEEN PREDICTED AND
 MEASURED LEQ'S (dBA)

LOCATION	LANE	NUMBER OF MEASUREMENTS	PRESENT METHOD	SIMPLE PREDICTION METHOD
2	Center	42	0.30	-2.2
3	Center	45	4.6	1.9
4	Center	45	2.1	-0.6
2	Near	8	4.6	2.1
3	Near	9	7.8	5.2
4	Near	34	3.4	0.8

IMPLEMENTATION OF FINDINGS

The simplified prediction method for upgrades can be utilized at NJDOT by the Bureau of Environmental Analysis (BEA), which does highway noise predictions. The simplified prediction method will improve the accuracy of noise predictions done for the upgrade sections of interstate highways with a significant number of heavy trucks.

This report, which documents this study and presents information required for implementation, will be forwarded to BEA. Meeting(s) will be held between Division of Research personnel and BEA to review and clarify the findings of this study to facilitate implementation.

The simplified prediction method for upgrades is a modification of existing FHWA approved noise prediction methods, and as such, is subject to approval by the FHWA's Office of Environmental Policy before implementation. Once this approval is obtained and with the concurrence of BEA, the FHWA Level 2 Highway Traffic Noise Prediction Program (STAMINA 2.0) will be modified by the Office of Telecommunications and Information Services (OTIS) to include the simplified prediction method for upgrades. Thus the modification will add the average speed calculating program for heavy trucks on upgrades, and the adjusted heavy truck noise emission level equation for interstate highway upgrades, to STAMINA 2.0. Based

on measurements made in New Jersey in 1984, the average speed program and the adjusted heavy truck noise level equation more accurately represent the heavy truck speeds and noise emission levels occurring on upgrades in this state, than national averages do.* Proper operation of the modified program will be verified before it is used by BEA.

After BEA begins using the modified highway prediction program, the Division of Research will continue to maintain a liaison, and if requested, will assist in the resolution of any problems arising with the use of the simplified prediction method for upgrades or the modified program.

* See Note on bottom of Page 43.

REFERENCES

- [1] Bowlby, W., Higgins, J., and Reagan, J., Noise Barrier Cost Reduction Procedure, STAMINA 2.0/OPTIMA: User's Manual, Report No. FHWA-DP-58-1, Federal Highway Administration, U.S. Dept. of Transportation, April 1982.
- [2] Barry, T.M., and Reagan, J.A., FHWA Highway Traffic Noise Prediction Model, Report No. FHWA-RD-77-108, Federal Highway Administration, U.S. Dept. of Transportation, Final Report, December 1978.
- [3] Highway Capacity Manual, Special Report 209, Transportation Research Board, National Research Council, Washington, D.C., 1985.
- [4] Sasor, S.R., Determination of Truck Noise Levels for New Jersey, Report No. FHWA/NJ-81-006, New Jersey Dept. of Transportation, Final Report, July 1980.
- [5] Gillespie, T.D., Methods for Predicting Truck Speed Loss on Grades, Report No. UMTRI-85-39/2, Contract No. DTFH61-83-C-00046, University of Michigan Transportation Research Institute, Final Report, November 1985.
- [6] "Noise Abatement Programs", Part IV, Environmental Protection Agency, 40 CFR Parts 202 and 205, Final Rule, Federal Register, Vol. 51, No. 5, Wednesday Jan. 8, 1986, Rules and Regulations.
- [7] "Procedures for Abatement of Highway Traffic Noise and Construction Noise", Federal Aid Highway Program Manual, Volume 7, Chapter 7, Section 3, Federal Highway Administration, U.S. Dept. of Transportation, circa 1980.
- [8] Sasor, S.R., Determination of Truck Noise Levels for New Jersey, Report No. 78-008-7791, New Jersey Dept. of Transportation, Interim Report, May 1978.
- [9] SAS User's Guide: Statistics, Version 5 Edition, SAS Institute, Cary, No. Carolina, SAS Institute Inc., 1985, 956 pages.
- [10] Hollander, M., and Wolfe, D.A., Nonparametric Statistical Methods, John Wiley & Sons, New York, 1973, pp. 75-78.
- [11] Lehmann, E.L., Nonparametrics: Statistical Methods Based on Ranks, Holden-Day, San Francisco, 1975, pp. 13-18.

APPENDICES

	<u>Page</u>
APPENDIX A - Mathematical Models for Predicting Noise from Trucks on UpGrades and Ramps	49
APPENDIX B - Onboard Truck Noise Measurements	52
APPENDIX C - Passby Truck Noise Measurements	64
APPENDIX D - Average Speed Computer Program	80
APPENDIX E - One Point Passby Measurement Data (Heavy Trucks)	83

APPENDIX A

MATHEMATICAL MODELS FOR PREDICTING NOISE

FROM TRUCKS ON UPGRADES AND RAMPS

This appendix describes the preliminary work that was done on an equivalent sound level (Leq) methodology for predicting the noise from trucks on upgrades and ramps. This methodology, which consists of mathematical models, is compatible with the FHWA Highway Traffic Noise Prediction Model [2]. A short document presenting the derivations of these models was prepared for FHWA. This appendix describes briefly the work presented in that document.

Current noise prediction models are based on the assumption of constant speed motor vehicles with constant noise emission levels. These conditions are essentially met on a straight, flat, and long roadway. However, development of a prediction model for ramps and upgrades required consideration of time-varying noise emission levels and non-constant speed.

Several time varying noise emission levels were considered. For non-constant speed, only the constant acceleration situation was analyzed. The combined effect of both a time-varying noise emission level and constant acceleration was also examined. For most cases, given the stated assumptions, an expression for predicting the equivalent sound level (Leq) was derived. All of

the expressions which were derived were developed for a single vehicle traveling on a straight and finite roadway segment. Geometric spreading of the sound waves was assumed; thus, excess attenuation due to ground cover or atmospheric absorption was not considered.

The following list outlines the material which was presented in the document submitted to FHWA. The document presents derivations of the equations for predicting L_{eq} for the various cases, as well as some example problems which illustrate the results of their application.

Case 1. Noise emission level is a function of the logarithm of a linear function of time. Reference mean square pressure (sound intensity) varies linearly in time. Speed is constant. Example problems included.

Case 2. Noise emission level is a function of the logarithm of a hyperbolic function of time. Reference mean square pressure varies hyperbolically in time. Speed is constant. Example problems included.

Case 3. Noise emission level is constant. Acceleration is constant. A derivation in terms of velocities and another in terms of the angles defining the roadway segment are presented. Example problems included.

Case 4. Noise emission level is a function of the logarithm of a linear function of time. Reference mean square pressure

varies linearly in time. Constant acceleration.
Example problems included.

Case 5. Noise emission level is a function of the logarithm of the change in velocity. Constant acceleration. No example problems.

Case 6. Noise emission level is a function of the logarithm of the distance travelled in a roadway segment. Reference mean square pressure varies according to the distance into the segment. Constant acceleration. No example problems.

Case 7. Noise emission level is a function of the logarithm of a hyperbolic function of time. Reference mean square pressure varies hyperbolically in time. Constant acceleration. No solution was obtained.

Case 8. In an attempt to derive simpler Leq equations, we considered using the average reference mean square pressure (sound intensity) from a roadway segment having a time varying noise emission level.

APPENDIX B

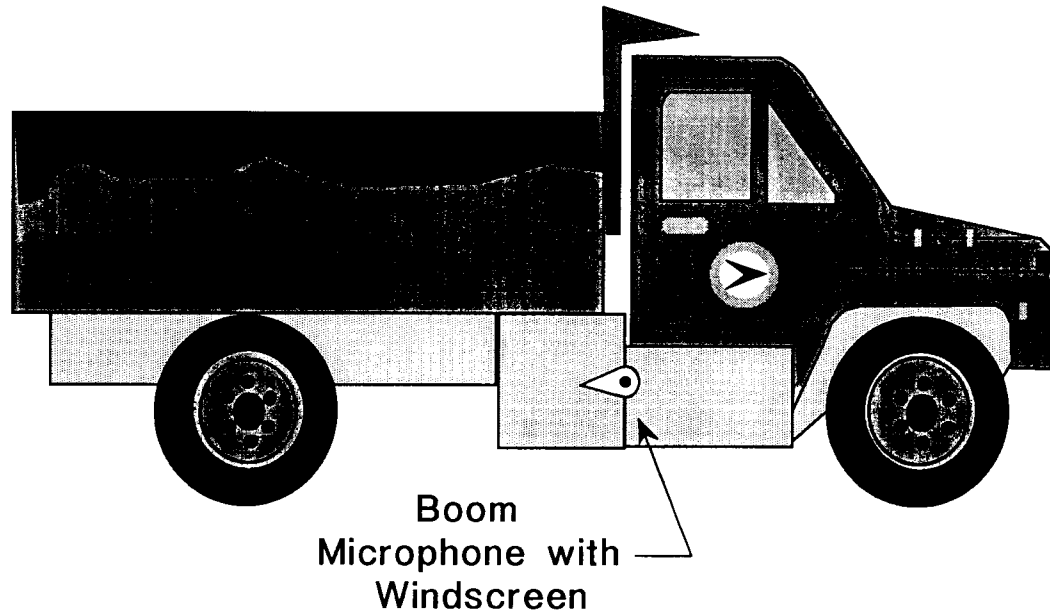
ONBOARD TRUCK NOISE MEASUREMENTS

In the late summer of 1983, onboard measurements were taken to obtain simultaneous and continuous recordings of a truck's noise, speed, and RPM on grades and ramps. Instruments to record this data were set up in the cab of a 1983 NJDOT 6-ton diesel dump truck. The truck's noise was recorded with a Nagra magnetic tape recorder, speed was measured with a K-55 radar unit, and RPM was taken from a tachometer cable to the engine. Truck speed and RPM were recorded on strip charts. The dump truck was a medium truck with two axles and dual rear wheels with a weight of 30,600 lbs.* The truck, which had an automatic transmission, was new, with less than 1000 miles on the odometer; it had ribbed tires in the front and cross-bar tires in the rear. The exhaust was horizontal. The truck was operated with the transmission in the "2-5" range position, so it started in 2nd gear and upshifted to 3rd, 4th, and 5th automatically.

A microphone was mounted on a boom which was fastened to the passenger side of the truck, opposite the back of the cab, midway between the wheels (See Figure B-1, Page 53). The microphone was pointed inward towards the side of the truck, at a distance of four

* Measurements were planned but not taken for several heavy trucks (3 axle dump & 5 axle tractor trailer) because these types of trucks were in near constant use during seasonal paving operations, and they were not available for a time period long enough to instrument the vehicles and take measurements.

Figure B-1. ON BOARD MICROPHONE LOCATION
Medium Dump Truck

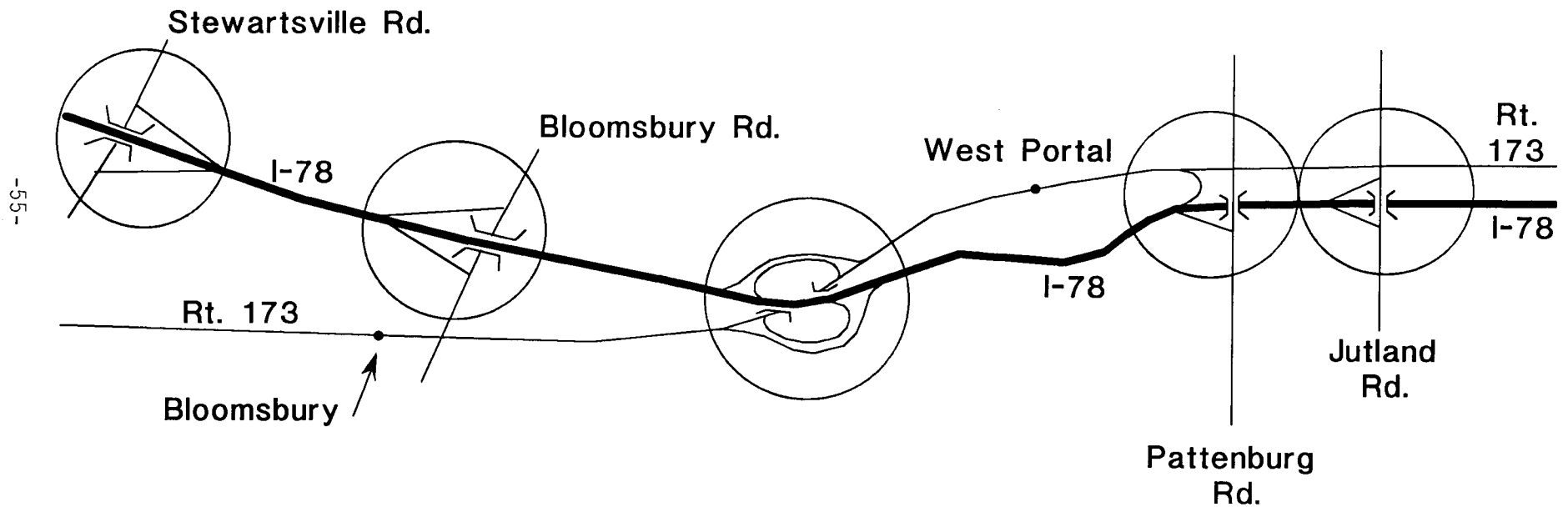


feet from the truck and several feet above the road surface. To reduce the wind noise at the microphone a special, teardrop shaped windscreen, obtained from the Polytechnic Institute of N.Y., was used. The microphone moved along with the vehicle; this is in contrast to standard passby measurements where the microphone is stationary.

Continuous recordings, some as long as 10 minutes, of speed, RPM, and noise level were made as the truck travelled on level, upgrade, and downgrade roadway sections of controlled and non-controlled access highways and on ramps. These measurements were taken about 10 miles west of Clinton on Interstate 78, Route 173, exit and entrance ramps connecting the two, and other exit and entrance ramps of I-78 (See Figure B-2, Page 55). This location was selected primarily because of the size of the upgrades on I-78 and Rte. 173; 2 miles long and 4%, and 1 mile long and 7%, respectively. Other factors in site selection were the volume of traffic, which was light enough so the truck with boom could be isolated from other vehicles, and the close proximity of a variety of different types of ramps. Measurements were taken on 2 outer connecting, 2 inner loop, and 8 diagonal ramps with lengths from 800-1700 feet and grades ranging from -6% to +6%.

Graphs showing simultaneous readings of speed, RPM, and truck noise level were prepared (See Figures B-3 & B-4, Pages 56 & 57). More than 45 minutes of usable data was obtained. Following are the findings of the onboard truck noise measurements.

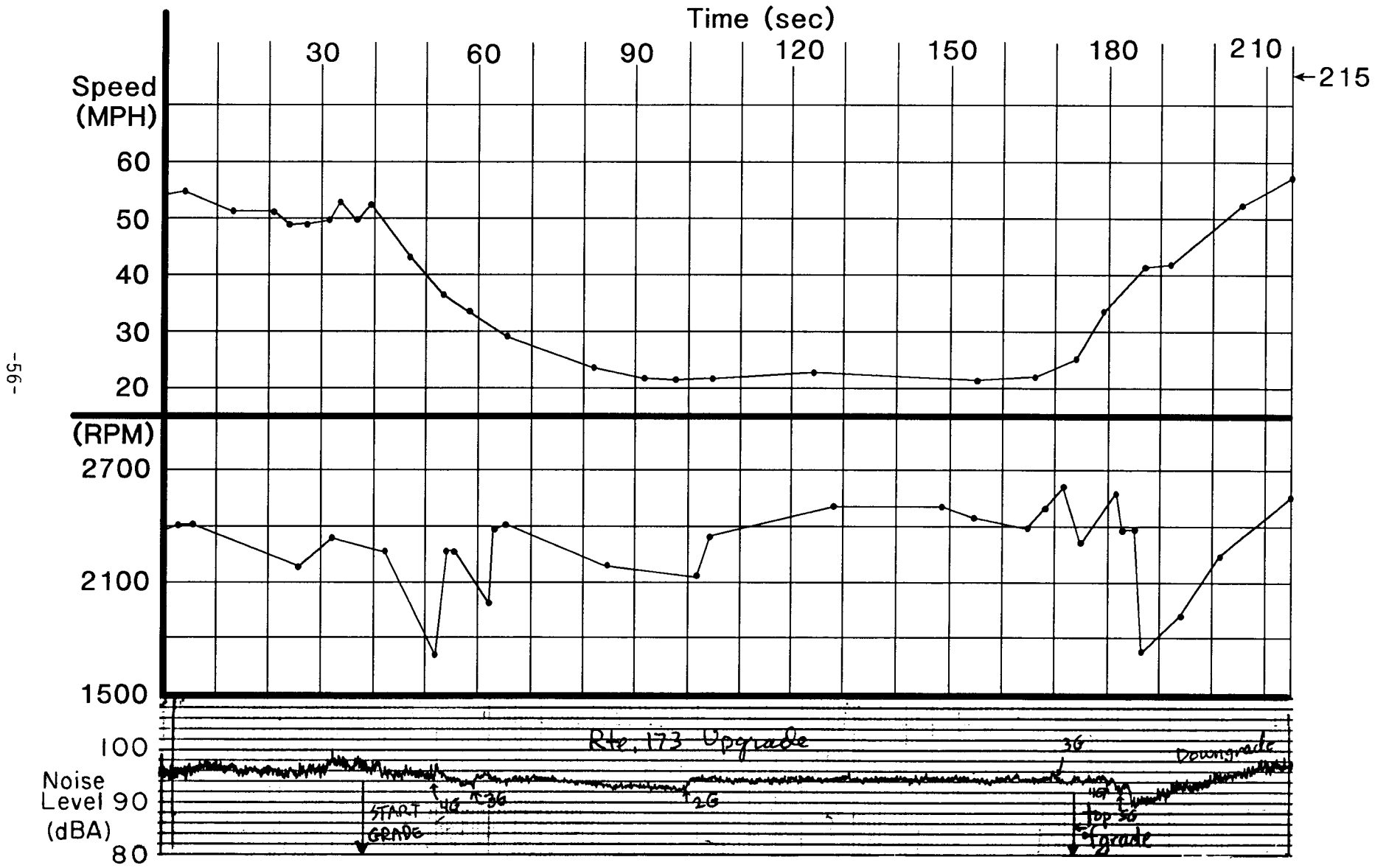
**Figure B-2. ON BOARD MEASUREMENT SITES
(Interstate 78, Route 173, & Study Ramps)***



Not To Scale

*Circled Areas Show Study Ramps

**Figure B-3. TRUCK SPEED, RPM, & NOISE LEVEL CHARTS
(Rt.173 Upgrade - 1 Mile, 7%)**

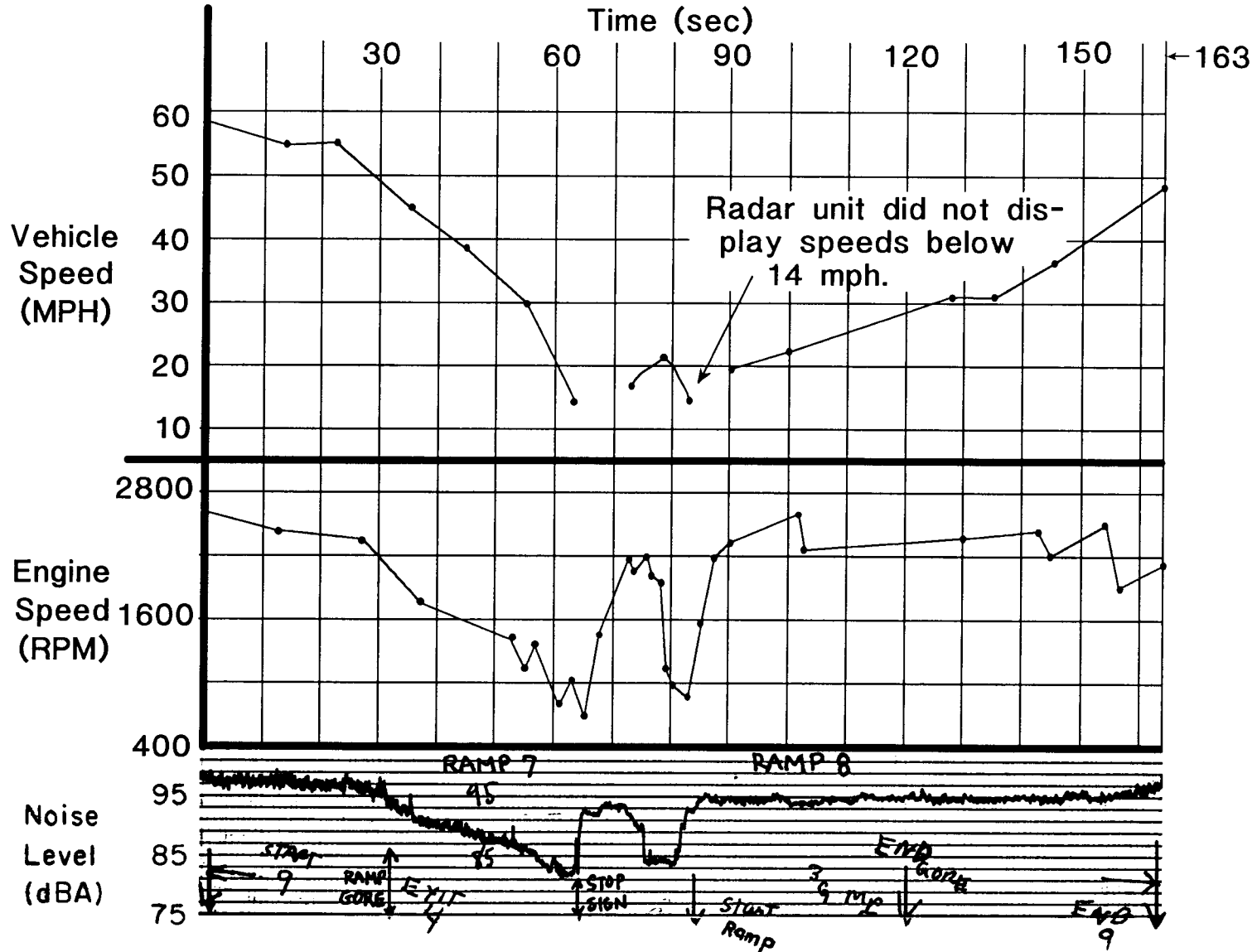


-56-

Figure B-4. TRUCK SPEED, RPM, & NOISE LEVEL CHARTS

Ramp 7 - Stewartville Road Off Ramp (Diagonal, Exit)

Ramp 8 - Stewartville Road On Ramp (Diagonal, Entrance)



UPGRADE ROADWAYS

The medium truck's noise level on the upgrade roadways was on the average 2-3 dBA less than on the level roadways before them. At times, its noise level on the upgrades was as much as 4 dBA less than on the level road sections. The finding of lower truck noise levels on upgrades is in agreement with the results of the passby measurements taken for this study (See pages 23-27). Thus, the same trend was found from the onboard measurements of a medium truck on a non-controlled access highway (Route 173), as was found from the passby measurements of heavy trucks on a controlled access highway.

Route 173

Noise levels for the medium truck on the Route 173 upgrade (1 mile, 7%) were on average about 2 dBA lower than on the level roadway before it. At a speed of 21 mph, just before the truck downshifted to 2nd gear, the truck's noise level was 4 dBA below that measured on the level roadway. As the truck downshifted to a lower gear, there was a 1-2 dBA increase in noise level. The medium truck's noise level was both speed and RPM dependent. For example, for the same RPM (2450), the truck's noise level was 2 dBA louder at a speed of 50 mph than at a speed of 20 mph. For the same speed (21 mph), the truck's noise level was 2 dBA higher for 2,360 RPM than for 2,125 RPM. Thus, where the microphone was placed, it apparently detected a combination of both tire noise

and engine-exhaust noise. The highest truck noise levels occurred for the combination of the highest speed and the highest RPM which happened in 5th gear on the level and downgrade road sections before and after the upgrade.

On the upgrade, the medium truck downshifted from 5th to 2nd gear, and speed dropped from 50 mph to a constant 20 mph crawl speed which was reached one minute into the grade. Engine speed varied from 1600 to 2600 RPM.

Interstate 78

The upgrades on I-78 were longer (2 miles) but not as steep (4%) as the one on Route 173. The medium truck did not decelerate as quickly, and it never attained crawl speed. The truck entered the upgrades at speeds of 50-54 mph and reached a minimum speed of 32-36 mph while downshifting from 5th to 3rd gear.

Truck noise levels on the upgrades were on average about 2-3 dBA less than on the level road sections before them. At speeds of 33-37 mph, truck noise levels were about 4 dBA below those measured on the level roadways. Noise levels rose about 1 dBA when the truck downshifted to a lower gear. Once again, the loudest noise levels were measured when truck speed and RPM were at their highest, which occurred on the level roadways and downgrade roadways before and after the upgrades, respectively.

With regard to the downgrade road sections of Route 173 and I-78, the medium truck's noise level was approximately the same on them, as it was on the level road sections.

RAMPS

As mentioned, measurements were taken on 12 ramps -- 8 diagonal, 2 inner loop, and 2 outer connecting with lengths from 800-1700 feet and grades ranging from -6% to +6% (See Figure B-2, Page 55). Noise levels for the medium truck were always less on the ramps than on the mainline roadways they serviced. For the exit ramps, the medium truck's average noise level was generally 9-10 dBA less than it was on the mainline road; for the entrance ramps, 3-4 dBA less. Speeds ranged from about 45 mph to zero, and engine speed from just below 600 RPM at idle, to 2600 RPM during acceleration. Ramps are referred to as exit or entrance based on how they functioned with regard to Interstate 78. Since truck noise measurements were continuous, they were taken on the acceleration and deceleration lanes between the ramps and the mainline roadways. Results for these lanes are given at the end of this section.

Diagonal Ramps

Exit Ramps - All of the exit ramps started from deceleration lanes of I-78 and ended in "STOP" signs on side roads. The medium truck decelerated to a stop on these ramps. Levels for the medium truck dropped an average of 10 dBA between the start and end of the ramps

(from about 92 at the start of the ramp, to about 82 when idling at the stop signs). The medium truck's average noise level on the ramps was 10 dBA less than on the mainline roadway. The truck's speed ranged from about 45 mph at the start of these ramps, to 0 mph at the end. RPM on the mainline was about 2500 (@ 55mph), at the start of the ramps it was about 1900, and at the end, just below 600 at idle at the stop signs.

Entrance Ramps - The entrance ramps started off of side roads and ended at acceleration lanes to I-78. The medium truck accelerated on these ramps, some of which had upgrade sections of 5-6%. The medium truck's noise level increased on average about 3.75 dBA between the start and end of these ramps. The highest noise level was 2 dBA below that measured on the mainline. The medium truck's average noise level on these entrance ramps was about 3 dBA below its level when travelling on the mainline. The truck's noise level dropped 1-2 dBA when the truck upshifted. On acceleration, the medium truck shifted from 2nd gear thru 4th on ramps with a shallow upgrade, and from 2nd gear to 3rd on the steeper ramps. Engine speed ranged from 1,000 RPM at the start of the ramps, to a maximum of 2600 RPM in 2nd gear. Speeds ranged from less than 15 mph (the limit of the radar unit) at the start of the ramps, to 33 mph on average at the end of the ramps.

Outer Connecting Ramps

These two ramps were both entrance ramps connecting Route 173 with

I-78. The medium truck accelerated, then cruised, and then accelerated again on these types of ramps. The noise level of the truck increased an average of 3.5 dBA from the start till the end of the ramps. The truck's noise level on these entrance ramps was always below its level on the mainline roadway; on the average, about 4 dBA below. There was a 1-2 dBA drop in noise level when the truck upshifted. Speeds ranged from less than 15 mph at the start of the ramps to 38 mph at the end. On the nearly level outer connecting ramp, the truck shifted from 3rd thru 5th gear, and RPM ranged from 1200 to 2575. On the upgrade outer connecting ramp, the truck upshifted only to 3rd gear by the end; RPM ranged from 1000 to 2500.

Inner Loop Ramps

These two ramps were both exit ramps connecting I-78 with Route 173. Sometimes the truck drove by a "YIELD" sign, at other times, the truck stopped at a "STOP" sign. For the yield sign case, the truck decelerated, accelerated slightly, decelerated again, and finally accelerated again as it passed by the sign. For the stop sign case, the truck decelerated, accelerated slightly, and decelerated again to a complete stop. The medium truck's noise level on these ramps was always lower than it was on the mainline roadway. Brake noise spikes of 4-6 dBA above the usual truck levels occurred, and were 1-3 dBA below main road levels. The average truck noise level on these ramps was about 9.5 dBA less than on the main road. For the yield sign case, speeds ranged

from 40-21 mph, the gear range was 5th to 3rd, and the RPM range was 850-2200. For the stop sign case, speeds ranged from 42-0 mph, the gear range was 5th to 3rd, and the RPM range was 560-1850.

Acceleration & Deceleration Lanes

These lanes lay between the exit and entrance ramps and Interstate 78. Upshifting occurred in the acceleration lanes, and noise levels increased by 2-3 dBA between the start and end of the lanes. Between the start and end of the deceleration lanes, noise levels decreased by about 5 dBA before a diagonal exit ramp, and 8 dBA before an inner loop exit ramp. The medium truck's noise level was significantly less on the acceleration and deceleration lanes than it was on the main road.

APPENDIX C

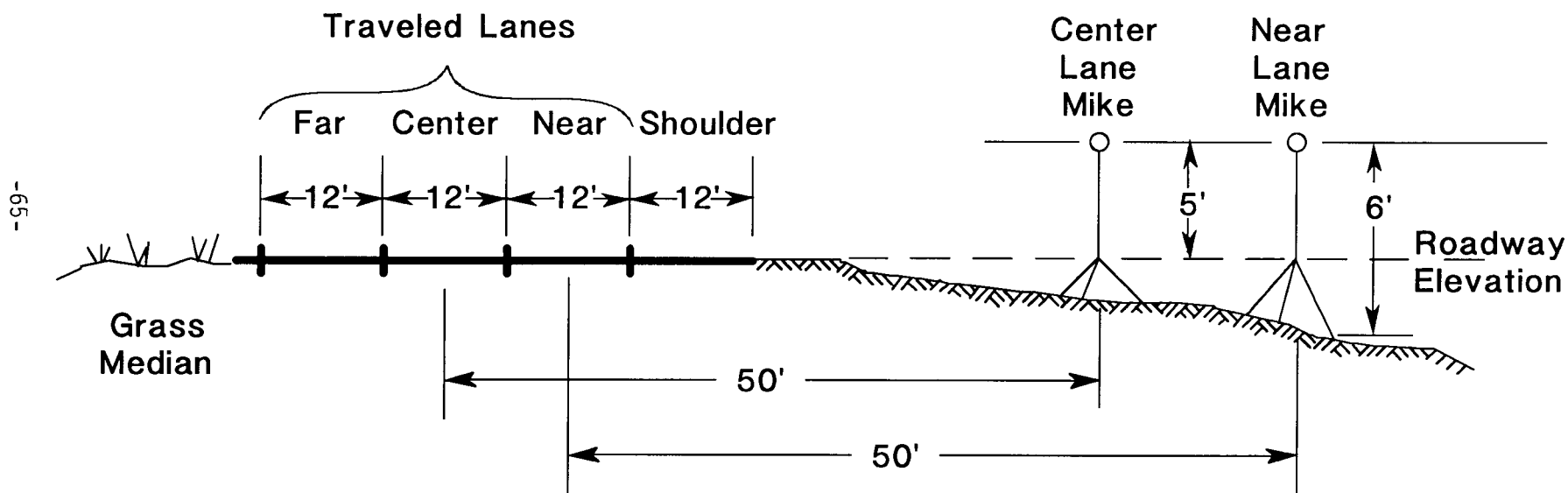
PASSBY TRUCK NOISE MEASUREMENTS

This appendix contains the measurement methodology, and the data reduction and analysis procedures developed to obtain truck noise levels by the one point measurement passby method. The methodology and procedures for the two point measurements are essentially the same as these with the exceptions mentioned on pages 28-30. Measurements of truck noise emission level and Leq were made on the Interstate 78 upgrade in the late fall of 1984.

MEASUREMENT METHODOLOGY

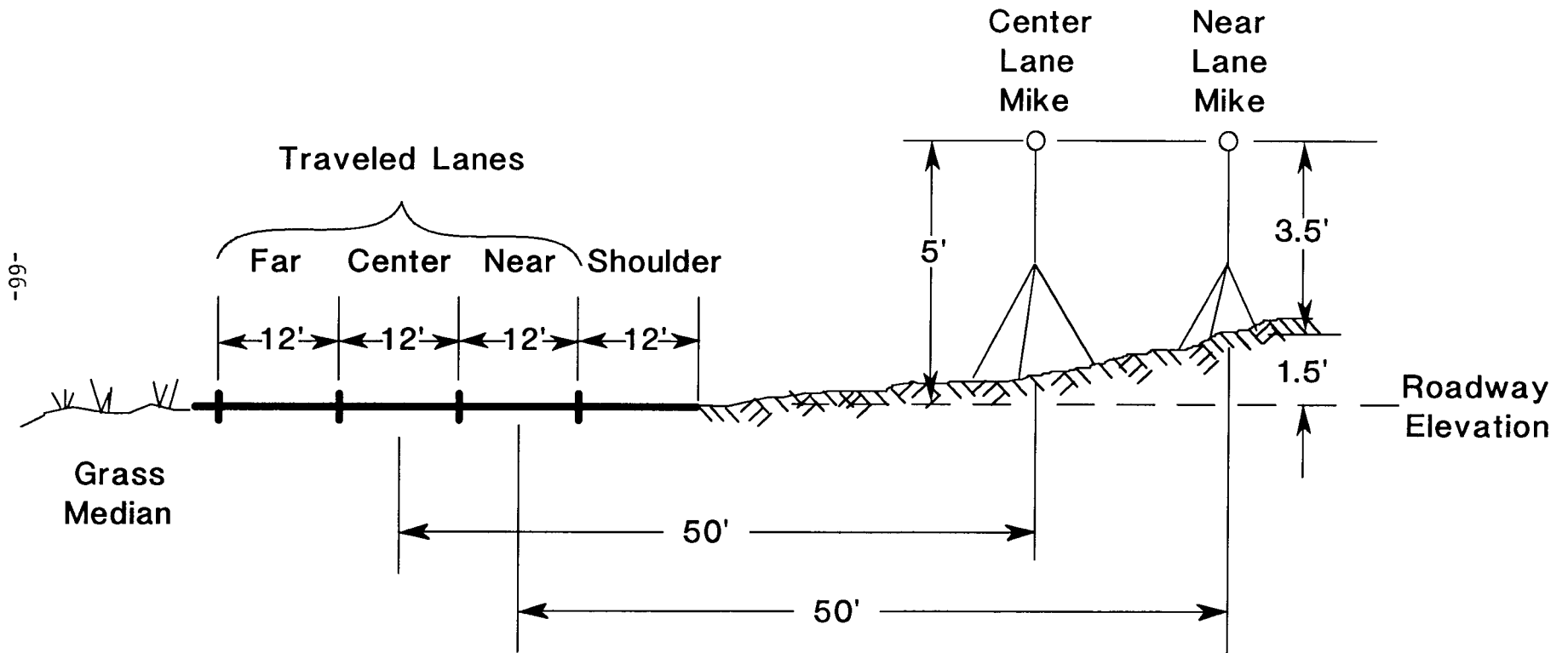
Measurements of truck noise were made for all qualifying medium (2 axles, dual rear wheels) and heavy (3 or more axles) trucks in both the center and near lanes of the near side of the 6-lane highway. To qualify for measurement, a particular truck had to be sufficiently isolated from other nearby vehicles so that its noise emission level and equivalent sound level (Leq) could be accurately measured. The extent of this isolation is specified in the valid measurement criteria which are described below. Two microphones were used at each location -- one 50 feet from the center of the center lane; the other, 50 feet from the center of the near lane. Microphone height at a location was always 5 feet above the surface of the travelled lane and consequently ranged from 3.5 feet to 12.8 feet above the ground when all four locations are considered (See Figures C-1 to C-4, Pages 65-68).

**Figure C-1. PASSBY MICROPHONE LAYOUT - LOCATION 1
(2,000 ft. before upgrade)**



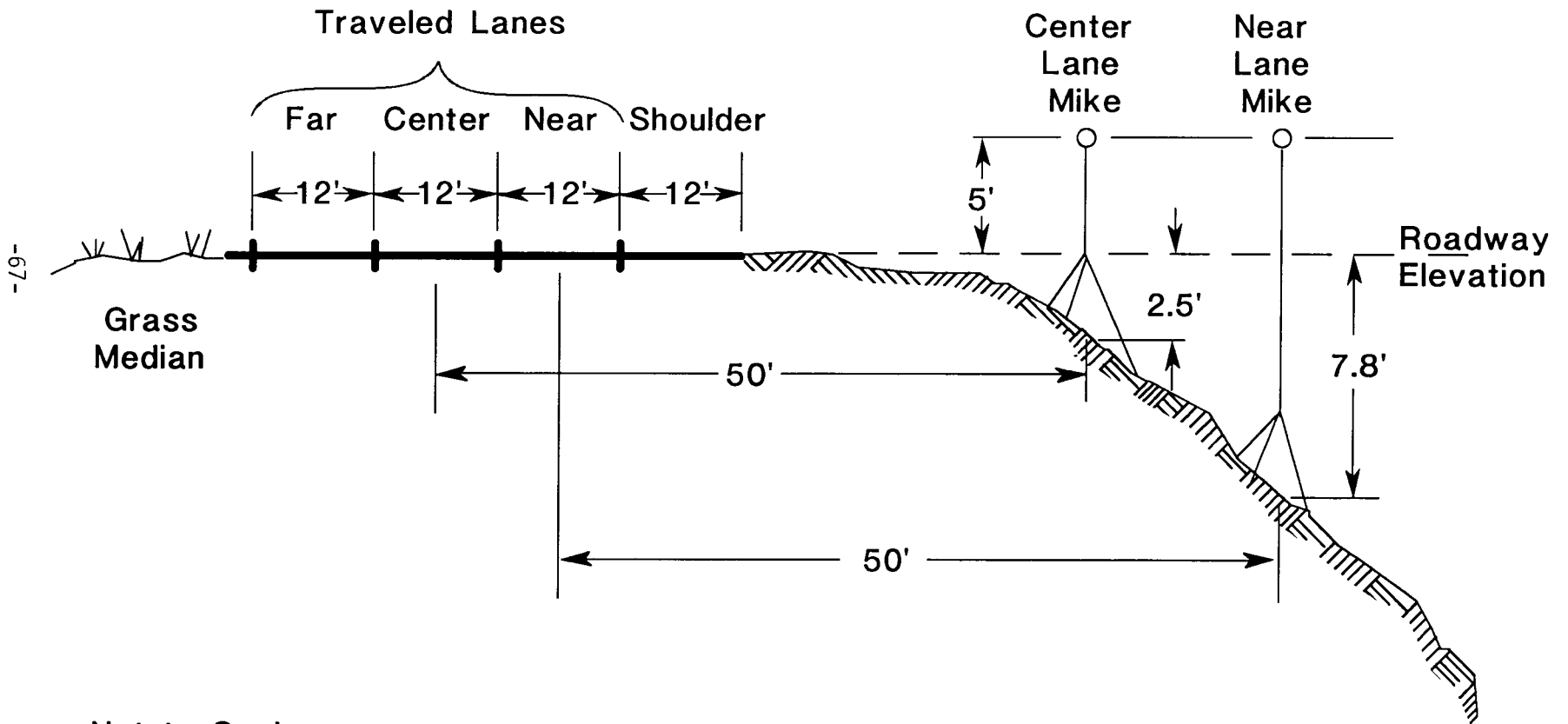
Not to Scale

**Figure C-2. PASSBY MICROPHONE LAYOUT - LOCATION 2
(3,000 ft. into upgrade)**



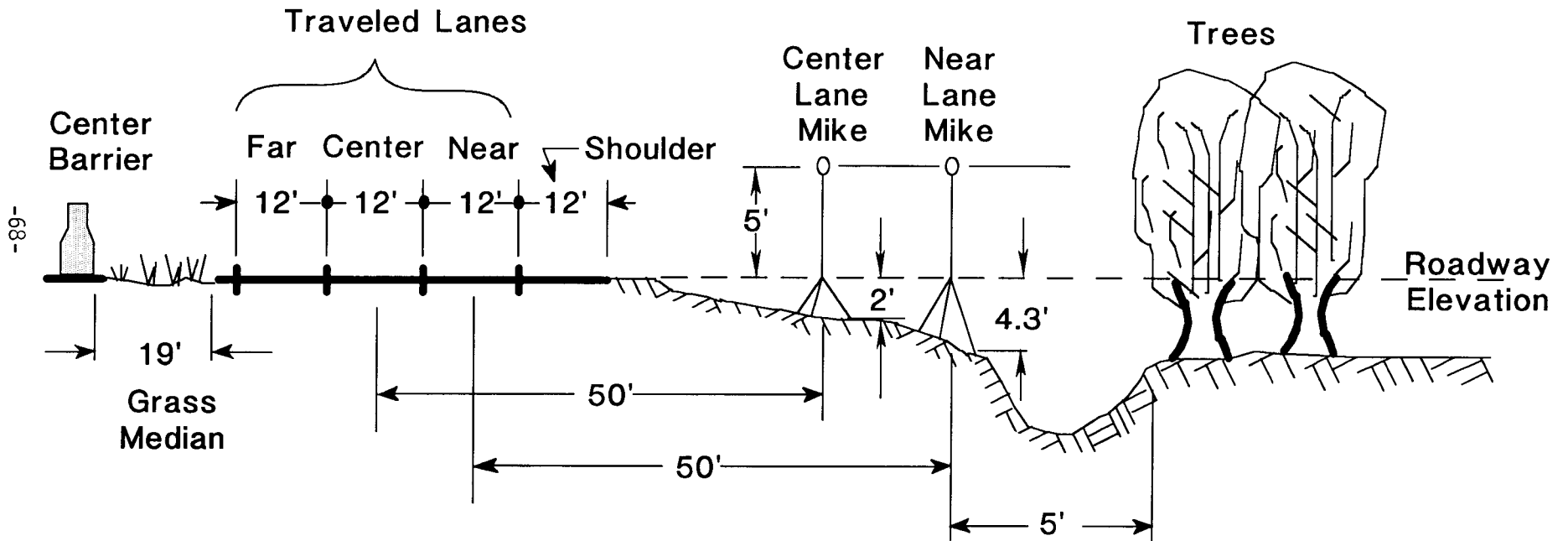
Not to Scale

**Figure C-3. PASSBY MICROPHONE LAYOUT - LOCATION 3
(7,000 ft. into upgrade)**



Not to Scale

**Figure C-4. PASSBY MICROPHONE LAYOUT - LOCATION 4
(9,000 ft. into upgrade)**



Not to Scale

Valid Measurement Criteria

The valid measurement criteria specified the extent to which a target truck had to be isolated from nearby traffic to obtain an accurate measurement of the truck's noise emission level and Leq. Thus the valid measurement criteria established the vehicle spacing requirements that were used for the field passby measurements at the I-78 sites. Each medium and heavy truck in the traffic stream which met the valid measurement criteria was measured. In general terms, the valid measurement criteria for measuring a heavy truck's noise emission level were as follows:

- trucks must be at least 200 feet from the target truck for both near side and far side traffic,
- cars must be at least 100 feet from the target truck for near side traffic,
- cars on the far side of the roadway can be any distance from the target truck,
- a time history of the noise level is checked later in the lab to see if a 6 dB rise and fall has occurred around the target truck's peak level. This ensures that the target truck was isolated from the noise of other vehicles. (See Reference 4 for a detailed explanation.)

In general, the valid measurement criteria for measuring a heavy truck's equivalent sound level (Leq) were as follows:

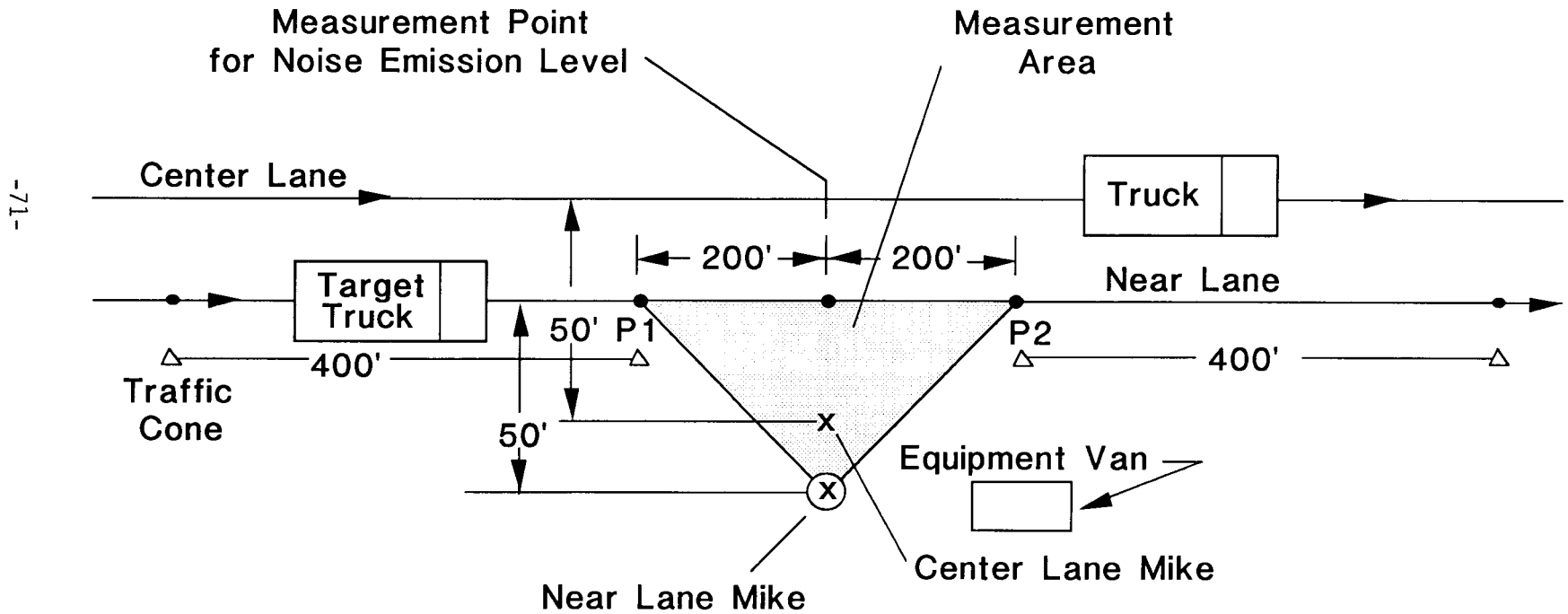
- when the target truck is by itself or with one car in the measurement interval (200 feet to each side of the microphone), other trucks must be at least 400 feet from the target truck for both near and far side traffic,
- the target truck can have up to 5 cars with it in the measurement interval if other trucks are at least 800 feet from the target truck for both near and far side traffic. However, none of the cars in the near lane can block the noise from center lane trucks.

The valid measurement criteria were more stringent for medium trucks for both noise emission level measurement and Leq measurement. The valid measurement criteria for heavy and medium trucks were decided upon after running computer simulations. A computer program, which was based on the FHWA Model [2], was run to simulate the effect that the noise from nearby vehicles had on the measurement of a target truck's noise emission level and Leq for various vehicle spacings. Many situations were simulated with vehicles having a wide range of noise emission levels. The accuracy of an individual measurement under the valid measurement criteria mentioned above is about 0.5 dB worst case for noise emission level. For Leq, the accuracy of an individual heavy truck measurement was about 1.5 dB worst case for the amount of traffic on Interstate 78.

Data Collection

One point measurements were made on 10 days between October 15, 1984 and November 21, 1984. About 300 noise emission levels and about 250 truck Leq's were obtained which met the valid measurement criteria. Measurement locations had been previously surveyed for elevations so that microphones could be accurately positioned at a height of 5 feet above the level of the travelled lane. The layout of a typical measurement location is shown in Figure C-5, Page 71.

Figure C-5. SETUP FOR A TYPICAL MEASUREMENT SITE



-71-

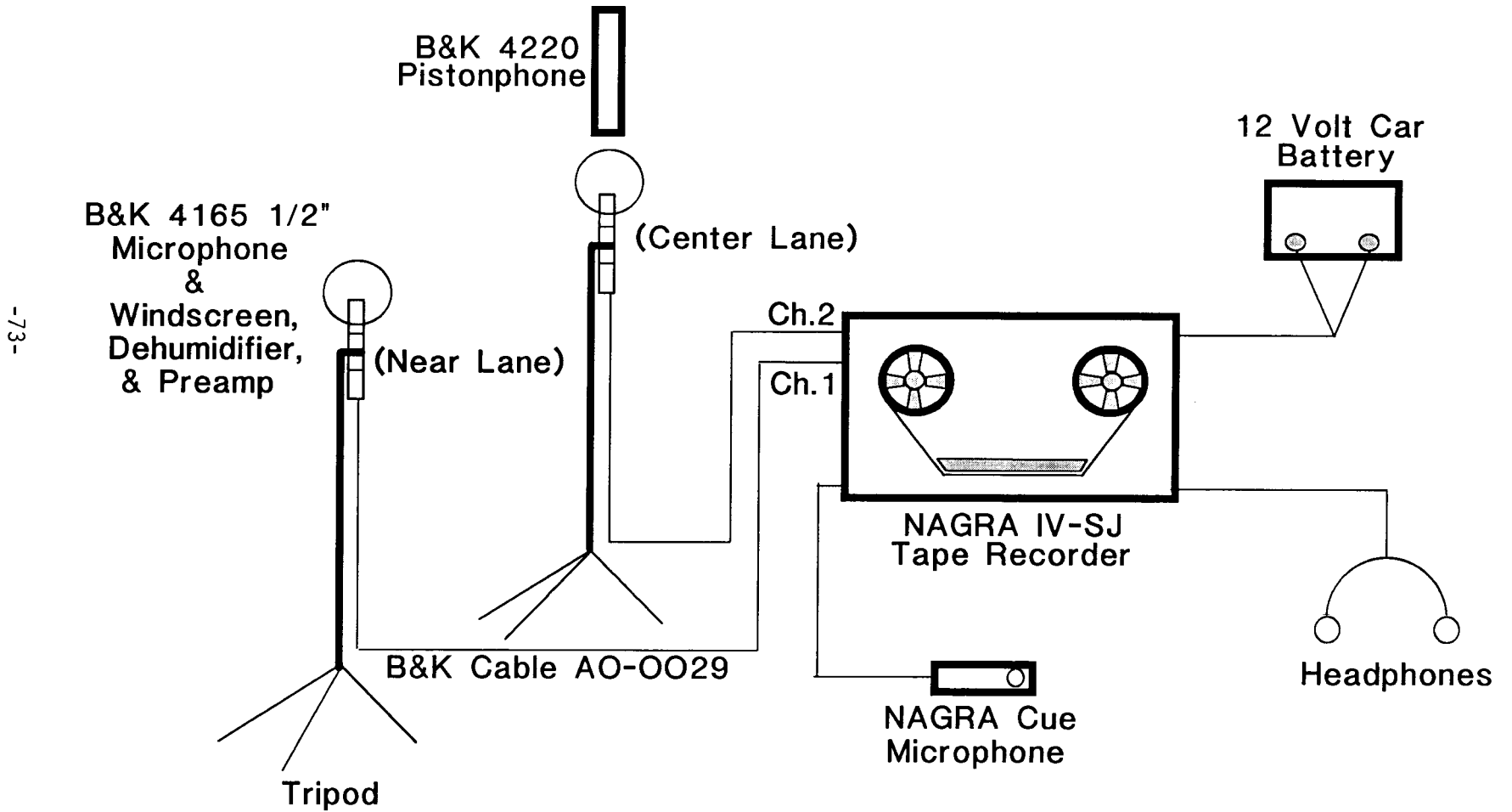
Not to Scale

As shown there were two microphone positions at each measurement location for measuring the noise for near and center lane trucks. The measurement area is the shaded portion of the figure and consists of the triangular area between the near lane microphone and the points 200 feet downstream and upstream from the measurement point for noise emission level. Traffic cones were placed at these two points (P1 & P2), at the measurement point, and at other locations on the roadway shoulder outside of the measurement area. The traffic cones at points P1 and P2 defined the beginning and end of the measurement interval for an individual truck passby, and the more distant traffic cones were used to judge vehicle spacing for determining if the valid measurement criteria were met.

The equipment used for measuring truck noise was located in a van which was parked outside the measurement area. It was manned by two bureau personnel, one whose main function was to tape record the truck noise; the other, to observe nearby vehicles and decide if the valid measurement criteria were met. Noise from trucks in the near and center lane was recorded in linear mode on tape recorder Channels 1 & 2 and comments were recorded on Channel 3 (cue channel). See Figure C-6, Page 73, for details on the data collection equipment.

The noise from every truck in the near or center lane that qualified, by virtue of its isolation, for accurate measurement

Figure C-6. NOISE RECORDING SYSTEM



under the valid measurement criteria was tape recorded. The vehicle spacing observer would sometimes reject recordings, if during the course of measurement, nearby vehicles approached the target vehicle too closely. Comments recorded on the voice channel consisted of "start" when the front of the truck passed the traffic cone at P1, "end" when the front of the truck passed the traffic cone at P2, a description of the truck (axle configuration, body type, exhaust location, load condition), lane of travel, and accuracy of measurement (good for noise emission level and/or Leq, or rejection). The "start" and "end" on the voice channel were used to calculate the average speed of the truck and also defined the time period over which the Leq of an individual truck was measured.

The measurement system was calibrated with a 124dB pistonphone at the start and end of every tape and at additional times if required due to long breaks in measurements. Weather conditions, including wind speed and direction, temperature, and barometric pressure, were monitored at the measurement location throughout the day. Measurements were not taken if it was raining, if the pavement was wet, or if wind gusts approached or exceeded 10 knots.

DATA REDUCTION

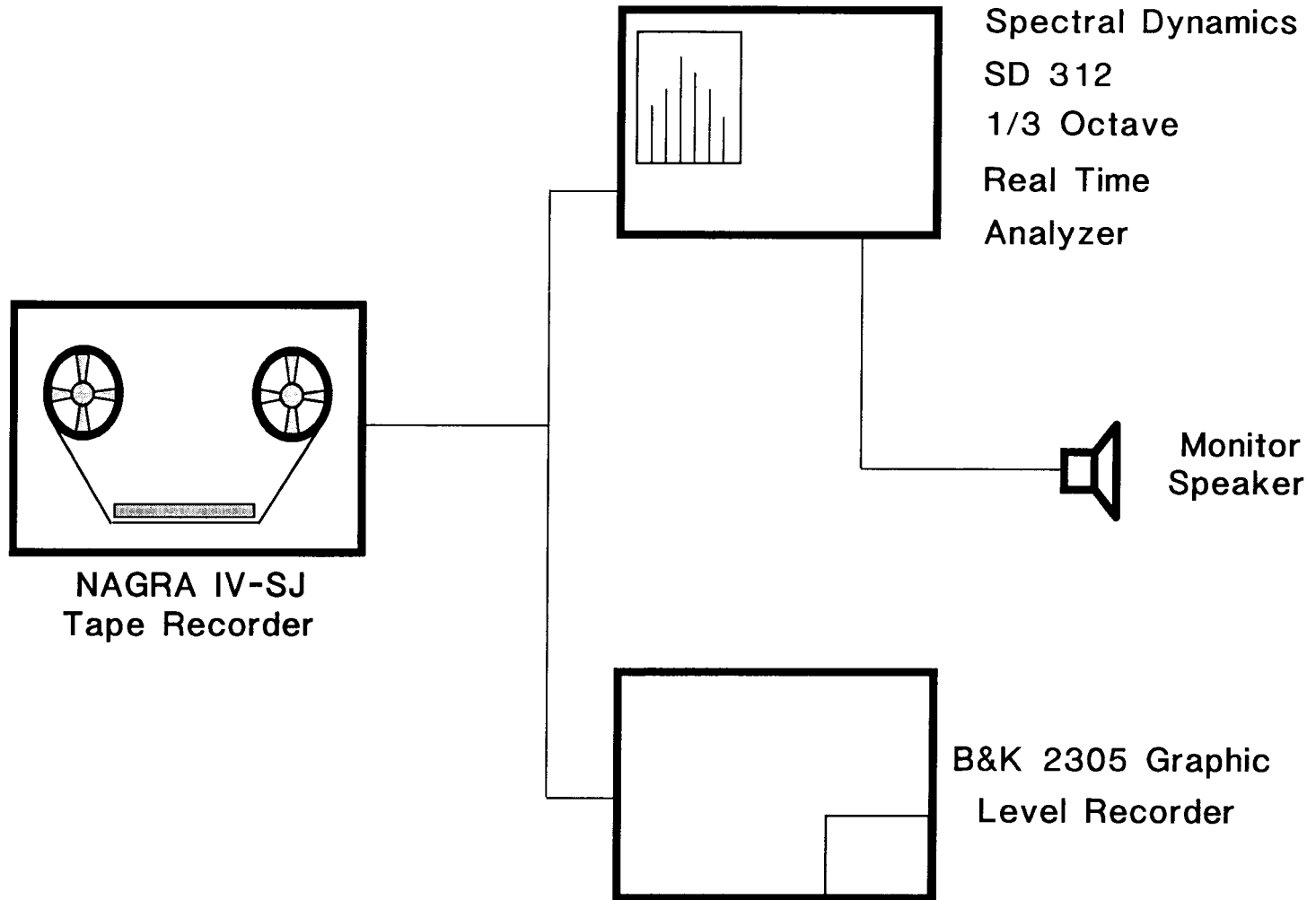
Data tape recorded in the field at the 4% upgrade site was reduced to obtain noise emission levels, equivalent sound levels (Leq's), average speeds, and descriptions of individual medium and heavy

trucks. The equipment used for data reduction was a tape recorder, 1/3 octave real time analyzer, and a graphic level recorder. The equipment setup is shown in Figure C-7, Page 76. Truck noise which was tape recorded on "linear" was A-weighted with the 1/3 octave real time analyzer.

Truck noise emission levels were reduced using the same procedure as in the original study (Reference 4) with the exception that frequency analysis was not performed. The graphic level recorder's lower limiting frequency and writing speed were selected to provide "fast" response, and a 25 dB potentiometer was used to increase resolution. The level recorder produced a time history chart of the noise generated by a truck. A truck's noise emission level was read directly off of this chart as the peak level on the trace. The trace was examined to insure that the 6 dB rise and fall specified in the valid measurement criteria was met. Measurements which did not meet this criteria were excluded from further analysis.

Equivalent sound levels (Leq's) for individual trucks were determined using a new procedure with the 1/3 octave real time analyzer. The analyzer was started when "start" was heard on the voice channel and stopped when "end" was heard. Thus, Leq was determined for the time period between when the target truck was 200 feet before the measurement point and 200 feet past the measurement point. In other words, it was determined over a distance interval of 400 feet with the measurement point (see Figure C-5, Page 71) in the center of the interval. Accordingly,

Figure C-7. DATA REDUCTION SYSTEM



the time period over which the Leq was determined was different for each truck and varied from about 4.5 to 11 seconds depending on speed. Like for noise emission levels, Leq was determined for only the overall sound level (no frequency analysis) and was A-weighted.

Each truck passby noise recording was played through speakers and monitored for interference from nearby vehicles, airplanes, wind, etc., or ambient noise.

Data on the voice channel was reduced to obtain the following information. This channel was monitored to obtain a description of each truck (axle configuration, body type, etc.) which was entered on prepared forms. Any other comments regarding such things as ambient non-highway noise, noise due to traffic on side roads, etc. were also written on the prepared forms. In addition, the voice channel stated whether a truck was in the near or center lane of travel and whether the vehicle spacing valid measurement criteria were met for noise emission level and/or Leq. This information was checked against notes made in the field. The average speed of the target truck was also obtained from the voice channel using a stopwatch. The watch was started on "start" and stopped on "end." This yielded the time for the truck to travel 400 feet from which average speed in miles per hour was calculated.

Microphone location, date, truck description, noise emission level, speed and Leq information were entered on data code sheets

and keypunched to a computer data file for subsequent analysis.

DATA ANALYSIS

The truck noise and speed data which was collected on the I-78 upgrade was analyzed to test for statistically significant differences in noise emission levels, Leq's, and speeds between locations and lanes. Only heavy truck data was analyzed because the amount of data obtained for medium trucks was too limited. Analysis was done on all the noise data meeting the valid measurement criteria.

The Statistical Analysis System (SAS) computer software package was used to perform the statistical analysis [9]. The first step in the analysis was to determine if noise and speed data for various locations and lanes could be compared using the Student t-test. The SAS procedure UNIVARIATE was used to determine if the data was normally distributed as is required for the Student t-test. Procedure Univariate indicated that at a 10% significance level nearly 45% of the noise emission level and Leq noise data for various locations and lanes was not from normally distributed populations.

Accordingly, it was decided to use distribution free (nonparametric) methods for location and lane comparisons. SAS procedure NPAR1WAY was selected for these comparisons; it performs the Wilcoxon Rank Sum Test and the Median Test. Procedure

NPAR1WAY uses a normal approximation for the Wilcoxon Rank Sum and Median tests. This approximation requires a sample size of greater than 10 for a particular class [11]. Sample sizes for noise data classifications by location and lane were considerably higher than this except for Location 3, Near Lane (9) and Location 2, Near Lane (8). Data analysis by these nonparametric methods yielded the findings presented under "Passby Measurements" in the body of the report on pages 23 to 27.

APPENDIX D

LISTING OF AVERAGE SPEED COMPUTER PROGRAM

```

C PROGRAM CALCULATES THE AVERAGE SPEED OVER A GIVEN LENGTH OF GRADE.
C ENTRY SPEED IS 55 MPH.
C DEFINE GRADE BY DISTANCE-ELEVATION VALUES IN FILE GRADE1 STATS.
C BY GILLESPIE,MODIFIED BY SASOR 28DEC87.
C
C SET DISTANCE INTERVALS AT WHICH VALUES PRINT OUT.
REAL*8 DELU,U,A,B
PI= 100.
TOTT= 0.
NDELTA= 0
GRADE= 0.
C SET ENTRY SPEED TO DESIRED VALUE.
ENTSPD= 46.8
U= ENTSPD
C VALUES FOR W/P RATIOS DETERMINED FROM NLIN REGRESSION FOR 50
C PERCENTILE TRACTOR TRAILERS ON EASTERN INTERSTATES.
WP25= 200.
WP50= 350.
B= (1/WP50 - 1/WP25)/25.
A= (1/WP25) - B*25.
READ(1,22) DIST,ELEV
22 FORMAT(F6.0,1X,F4.0)
C READ GRADE ON INITIAL SEGMENT.
GR= (ELEV/DIST)
XL= DIST
YL= ELEV
WRITE(2,5) X,U,TOTT,NDELTA,GRADE
5 FORMAT(/,4 PERCENT UPGRADE - 50 PERCENTILE TRACTOR TRAILERS',/, 'S
*RS REGRESSION VALUES FOR W/P RATIOS FOR EASTERN INTERSTATES',/, 'DI
*STANCE(FT) SPEED(MPH) TIME(SECS) NDELTS GRADE(%)',/,T3.
*F6.0,10X,F5.2,5X,F6.2,3X,18,7X,F5.2)
C DELTA TIME TO TRAVEL EACH 10 FT SEGMENT IS CALCULATED FROM THE
C INITIAL SPEED FOR THE SEGMENT.
155 DELTA= (10./U)*(3600./5280.)
GRADE= GR*100.
160 DELU= ((0.464876*((375.*(A+B*U)/U)-GR)*32.2)/U)*10
U= U + DELU
X= X + 10.
IF(X .GE. XL) GO TO 200
GO TO 220
200 READ(1,22,END=999) DIST,ELEV
GR= (ELEV-YL)/(DIST-XL)
XL= DIST
YL= ELEV
220 XM= (X/PI)
M= (X/PI)
C DELTA TIMES FOR EACH 10 FT SEGMENT ARE SUMMED.
TOTT= TOTT + DELTA
NDELTA= NDELTA + 1
IF((XM - M) .EQ. 0.) GO TO 230
GO TO 155
230 WRITE(2,4) X,U,TOTT,NDELTA,GRADE
4 FORMAT(T3,F6.0,10X,F5.2,5X,F6.2,3X,18,7X,F5.2)
GO TO 155

```

C ADDING DELTA TIME FOR THE LAST 10 FOOT SEGMENT.

999 TOTT = TOTT + DELT

NDELTA = NDELTA + 1

WRITE(2,4) X,U,TOTT,NDELTA,GRADE

AVGSPD = (X/TOTT)*(3600./5280.)

WRITE(2,7) X,TOTT,AVGSPD,NDELTA

7 FORMAT(/, 'DISTANCE(FT)', 3X, 'TOTAL TIME(SECS)', 3X, 'AVG. SPEED(MPH)'

*, 3X, 'NDELTA', /, T3.F6.0, 10X, F6.2, 15X, F5.2, 5X, I8)

END

APPENDIX E

ONE POINT PASSBY MEASUREMENT DATA

(HEAVY TRUCKS)

O B S	D A T E	L O C	L A N E	A X E	T Y P E	E X H	L O A D	T I M E	S P E D	N E L	L E Q
20	10/25/84	1	N	3-2	V	V	.	6.1	44.7	83.3	76.9
22	10/25/84	1	N	3-2	V	V	.	5.5	49.6	82.6	.
30	10/25/84	1	N	3-2	V	V	.	6.4	42.6	84.0	.
32	10/25/84	1	N	3-2	FB	V	L	4.6	59.3	82.3	78.1
38	10/25/84	1	N	3-2	T	V	.	5.8	47.0	83.0	76.6
39	10/25/84	1	N	3-2	D	V	.	5.6	48.7	.	77.8
41	10/25/84	1	N	3-2	V	V	.	6.1	44.7	83.0	77.4
42	10/25/84	1	N	3-2	FB	V	U	5.4	50.5	86.0	80.5
44	10/25/84	1	N	3-2	D	V	U	6.6	41.3	90.3	83.3
45	10/25/84	1	N	3-2	V	V	.	6.1	44.7	.	77.1
47	10/25/84	1	N	3-2	V	V	.	6.7	40.7	.	78.0
50	10/25/84	1	N	3-2	T	V	.	5.5	49.6	.	78.8
51	10/25/84	1	N	3-2	CC	V	L	5.6	48.7	83.0	77.8
54	10/25/84	1	N	3-2	V	V	.	6.3	43.3	84.3	.
62	10/25/84	1	N	3-2	V	V	.	5.9	46.2	83.3	.
64	10/25/84	1	N	3-2	H	V	.	6.4	42.6	80.0	74.2
65	10/25/84	1	N	3-2	V	V	.	5.9	46.2	81.9	.
69	10/25/84	1	N	2-2	V	V	.	5.5	49.6	81.3	76.6
70	10/25/84	1	N	3-2	FB	V	L	5.9	46.2	.	78.1
71	10/25/84	1	N	3-2	FB	V	L	7.3	37.4	.	81.0
73	10/25/84	1	N	3-2	V	V	.	5.3	51.5	85.1	79.9
78	10/25/84	1	N	3-2	V	V	.	5.4	50.5	81.0	76.6
81	10/25/84	1	N	3-2	D	V	U	5.1	53.5	85.9	.
82	10/25/84	1	N	3-2	V	V	.	6.6	41.3	82.2	.
83	10/25/84	1	N	3-2	V	V	.	5.9	46.2	82.6	.
86	10/25/84	1	N	3-2	T	V	.	5.1	53.5	83.3	78.8
87	10/25/84	1	N	3-2	V	V	.	5.6	48.7	85.2	.
94	10/25/84	1	N	3	D	H	.	6.5	42.0	82.2	75.7
100	10/25/84	1	N	3-2	V	V	.	5.4	50.5	.	79.4
102	10/25/84	1	N	3-2	V	V	.	5.4	50.5	.	79.3
103	10/25/84	1	N	3-2	H	V	.	4.9	55.7	82.0	77.5
104	10/25/84	1	N	3-2	V	V	.	4.4	62.0	84.4	.
108	10/25/84	1	N	3-2	V	V	.	5.4	50.5	81.8	76.9
110	10/25/84	1	N	3-2	T	V	.	6.3	43.3	83.7	79.2
114	10/25/84	1	N	3-2	V	V	.	5.4	50.5	85.6	.
119	10/25/84	1	N	3-2	V	V	.	6.2	44.0	82.8	.
121	10/25/84	1	N	3-2	V	V	.	5.7	47.8	84.2	.
123	10/25/84	1	N	3-2	V	V	.	5.8	47.0	86.8	.
124	10/25/84	1	N	2-2	V	V	.	4.3	63.4	81.5	.
127	10/25/84	1	N	3-2	FB	V	.	5.6	48.7	.	78.8
130	10/25/84	1	N	3-2	D	V	.	5.3	51.5	82.9	78.2
139	10/25/84	1	N	3-2	V	V	.	6.1	44.7	83.2	78.1
141	10/25/84	1	N	3-2	V	V	.	6.4	42.6	82.4	77.8
143	10/25/84	1	N	3-2	V	V	.	6.4	42.6	82.3	76.8
146	10/25/84	1	N	3-2	V	V	.	5.2	52.4	87.7	.
147	10/25/84	1	N	3-2	FB	V	.	6.0	45.5	89.4	82.5
148	10/25/84	1	N	3-2	D	V	.	6.4	42.6	83.4	77.8
150	10/25/84	1	N	3-2	V	V	.	5.7	47.8	88.4	81.4
153	10/25/84	1	N	3-2	V	V	.	6.1	44.7	82.6	.
161	11/01/84	1	N	3-2	FB	.	L	6.3	43.3	.	78.9
162	11/01/84	1	N	3-2	D	V	L	5.8	47.0	88.0	.
165	11/01/84	1	N	3-2	V	V	.	5.6	48.7	83.5	78.5
166	11/01/84	1	N	3-2	FB	V	L	4.9	55.7	83.5	.
168	11/01/84	1	N	3-2	V	V	.	4.6	59.3	83.8	.
171	11/01/84	1	N	3-2	FB	V	.	5.1	53.5	83.8	.
176	11/01/84	1	N	3-2	FB	V	U	5.6	48.7	84.0	78.0

OBS	D A T E	L O C	L A N E	A X E E	T Y P E	E X H	L O A D	T I M E	S P E D	N E L	L E Q
177	11/01/84	1	N	3-2	H	V	.	6.1	44.7	83.2	.
184	11/01/84	1	N	3-2	V	V	.	5.1	53.5	.	78.4
187	11/01/84	1	N	3-2	V	V	U	5.2	52.4	87.0	78.4
204	11/01/84	1	N	3-2	V	V	.	5.1	53.5	.	.
211	11/01/84	1	N	3-2	V	V	.	4.8	56.8	84.8	.
217	11/01/84	1	N	3-2	V	V	.	5.3	51.5	84.4	.
223	11/01/84	1	N	3-2	V	V	.	5.8	47.0	86.3	.
23	10/30/84	2	N	3-2	T	V	.	5.6	48.7	82.1	77.1
35	10/30/84	2	N	3-2	V	V	.	5.6	48.7	82.2	76.0
43	10/30/84	2	N	3-2	CC	.	L	7.4	36.9	84.3	77.9
46	10/30/84	2	N	3-2	V	V	.	7.6	35.9	79.8	.
51	10/30/84	2	N	3-2	FB	V	U	3.9	69.9	82.8	77.3
74	10/30/84	2	N	3-2	T	V	.	6.1	44.7	79.6	74.4
83	10/30/84	2	N	3-2	V	V	.	6.9	39.5	81.1	75.9
114	10/30/84	2	N	3-2	V	V	.	5.6	48.7	82.0	76.5
123	10/30/84	2	N	3-2	FB	.	U	6.1	44.7	93.0	.
133	10/30/84	2	N	3-2	V	V	.	5.9	46.2	.	76.6
19	10/31/84	3	N	3-2	V	V	.	6.9	39.5	83.0	.
27	10/31/84	3	N	2-2	V	V	.	6.6	41.3	77.0	72.8
31	10/31/84	3	N	3-2	V	V	.	8.6	31.7	79.8	74.8
32	10/31/84	3	N	2-2	V	V	.	8.9	30.6	75.9	71.4
33	10/31/84	3	N	3-2	V	V	.	10.8	25.3	75.6	.
35	10/31/84	3	N	2-2	V	.	.	5.5	49.6	.	69.5
41	10/31/84	3	N	3-2	V	V	.	6.8	40.1	73.6	.
43	10/31/84	3	N	3-2	V	V	.	10.9	25.0	77.8	72.6
53	10/31/84	3	N	3-2	FB	V	.	6.4	42.6	81.6	.
62	10/31/84	3	N	3-2	V	V	.	7.6	35.9	.	72.4
77	10/31/84	3	N	3-2	V	V	.	12.5	21.8	79.1	.
89	10/31/84	3	N	3-2	V	V	.	11.6	23.5	84.1	.
93	10/31/84	3	N	3-2	V	V	.	10.4	26.2	76.5	74.2
98	10/31/84	3	N	3-2	V	V	.	7.9	34.5	79.3	.
99	10/31/84	3	N	3-2	FB	V	U	6.8	40.1	76.2	72.2
105	10/31/84	3	N	3-2	V	V	.	7.0	39.0	79.6	70.9
32	10/17/84	4	N	3-2	V	V	.	7.3	37.4	80.1	75.0
33	10/17/84	4	N	3-2	V	V	.	9.4	29.0	76.7	72.6
38	10/17/84	4	N	3-2	V	V	.	7.3	37.4	79.5	75.6
42	10/17/84	4	N	3-2	V	V	.	9.0	30.3	78.5	.
43	10/17/84	4	N	3-2	V	V	.	6.8	40.1	.	77.7
46	10/17/84	4	N	3-2	V	V	.	9.9	27.5	.	76.3
47	10/17/84	4	N	3-2	V	V	.	7.3	37.4	84.0	.
48	10/17/84	4	N	3-2	FB	V	L	8.0	34.1	81.5	.
50	10/17/84	4	N	3-2	V	V	.	8.1	33.7	82.0	76.1
53	10/17/84	4	N	3-2	V	V	.	6.9	39.5	79.2	75.3
54	10/17/84	4	N	3-2	V	V	.	5.8	47.0	83.8	77.5
55	10/17/84	4	N	3-2	V	V	.	7.4	36.9	80.0	75.1
62	10/17/84	4	N	3-2	V	V	.	9.0	30.3	85.0	.
66	10/17/84	4	N	3-2	FB	.	L	8.8	31.0	.	.
67	10/17/84	4	N	3-2	H	V	.	12.8	21.3	80.6	.
68	10/17/84	4	N	3-2	D	.	.	8.0	34.1	83.5	.
70	10/17/84	4	N	3-2	V	V	.	11.1	24.6	79.0	.
71	10/17/84	4	N	3-2	FB	V	L	7.8	35.0	83.6	.
72	10/17/84	4	N	3-2	V	V	.	6.9	39.5	.	.
75	10/17/84	4	N	3-2	V	V	.	9.8	27.8	78.0	.
76	10/17/84	4	N	2-2	V	V	.	6.8	40.1	79.0	.
77	10/17/84	4	N	3-2	V	V	.	8.8	31.0	83.5	77.6
78	10/17/84	4	N	3-2	V	V	.	6.6	41.3	85.0	79.2

OBS	D A T E	L O C	L A N E	A X L E	T Y P E	E X H	L O A D	T I M E	S P E D	N E L	L E Q
84	10/17/84	4	N	3-2	FB	.	L	6.9	39.5	80.0	75.3
85	10/17/84	4	N	3-2	D	V	L	13.7	19.9	.	.
88	10/17/84	4	N	3-2	T	V	.	12.2	22.4	86.5	.
90	10/17/84	4	N	3-2	V	V	.	7.8	35.0	.	77.2
91	10/17/84	4	N	3-2	D	.	L	8.9	30.6	82.2	.
92	10/17/84	4	N	3-2	V	V	.	5.7	47.8	81.9	.
96	10/17/84	4	N	3-2	V	V	.	8.9	30.6	77.4	73.4
103	10/17/84	4	N	3-2	V	V	.	9.3	29.3	79.2	.
108	10/17/84	4	N	3-2	V	V	.	10.1	27.0	79.5	.
112	10/18/84	4	N	3-2	V	V	.	9.8	27.8	79.5	73.8
117	10/18/84	4	N	2-2	V	V	.	10.8	25.3	82.0	.
133	10/18/84	4	N	3-2	V	V	.	11.3	24.1	81.1	.
137	10/18/84	4	N	3-2	FB	V	U	6.3	43.3	85.1	79.9
138	10/18/84	4	N	3-2	V	V	.	6.8	40.1	.	77.5
147	10/18/84	4	N	3-2	V	V	.	6.9	39.5	81.5	76.0
157	10/18/84	4	N	3-2	V	V	.	10.3	26.5	81.6	.
158	10/18/84	4	N	3-2	H	V	.	5.9	46.2	84.5	79.2
168	10/18/84	4	N	3-2	FB	V	U	5.2	52.4	.	80.5
169	10/18/84	4	N	3-2	FB	V	L	7.1	38.4	.	76.9
173	10/19/84	4	N	2-2	V	V	.	10.1	27.0	91.3	.
175	10/19/84	4	N	3-2	FB	V	L	8.6	31.7	84.0	78.5
178	10/19/84	4	N	3-2	V	V	.	7.5	36.4	.	77.3
188	10/19/84	4	N	3-2	T	V	.	10.0	27.3	84.1	78.6
197	10/19/84	4	N	3-2	V	V	.	8.8	31.0	79.7	75.3
210	10/19/84	4	N	3-2	V	V	.	12.0	22.7	.	74.3
218	10/19/84	4	N	3-2	V	V	.	10.3	26.5	80.8	75.5
226	10/19/84	4	N	3-2	V	V	.	7.9	34.5	81.6	76.3
233	10/19/84	4	N	3-2	V	V	.	7.6	35.9	84.0	.
235	10/19/84	4	N	3-2	V	V	.	6.3	43.3	81.2	77.0
241	10/19/84	4	N	2-2	V	V	.	9.5	28.7	.	76.8
242	10/19/84	4	N	3-2	V	V	.	9.7	28.1	83.8	.
253	10/19/84	4	N	2-2	V	V	.	6.7	40.7	82.5	.
259	10/19/84	4	N	3-2	V	V	.	10.9	25.0	.	80.6
263	10/19/84	4	N	3-2	V	V	.	9.9	27.5	.	76.6
267	10/19/84	4	N	3-2	V	V	.	10.3	26.5	79.9	74.8
269	10/19/84	4	N	3-2	FB	V	L	7.1	38.4	82.7	77.7
156	11/01/84	1	C	3-2	FB	V	U	5.4	50.5	85.5	.
157	11/01/84	1	C	3-2	FB	V	U	5.7	47.8	86.5	.
164	11/01/84	1	C	3-2	FB	V	U	5.1	53.5	87.2	.
170	11/01/84	1	C	3-2	T	V	.	6.1	44.7	86.5	81.0
172	11/01/84	1	C	3-2	FB	V	U	3.6	75.8	86.0	.
175	11/01/84	1	C	4	V	H	.	5.4	50.5	87.1	.
179	11/01/84	1	C	3-2	V	V	.	5.1	53.5	83.5	80.7
181	11/01/84	1	C	3-2	T	V	.	5.4	50.5	88.2	82.3
190	11/01/84	1	C	3-2	V	V	.	6.0	45.5	84.8	79.4
195	11/01/84	1	C	3-2	V	V	.	5.8	47.0	84.0	.
197	11/01/84	1	C	3-2	D	V	.	5.1	53.5	85.0	.
198	11/01/84	1	C	3-2	V	V	.	5.1	53.5	.	86.5
200	11/01/84	1	C	3-2	H	V	.	5.4	50.5	86.5	80.8
205	11/01/84	1	C	3	V	.	.	5.9	46.2	82.4	.
206	11/01/84	1	C	3-2	T	V	.	4.8	56.8	86.5	.
207	11/01/84	1	C	3-2	V	V	.	4.8	56.8	87.0	.
208	11/01/84	1	C	3-2	D	V	.	5.6	48.7	.	80.6
213	11/01/84	1	C	3-2	V	V	.	5.8	47.0	87.0	82.0
218	11/01/84	1	C	3-2	V	V	.	4.9	55.7	84.4	.
221	11/01/84	1	C	3-2	CC	V	U	4.8	56.8	89.0	83.0

OBS	D A T E	L O C	L A N E	A X L E	T Y P E	E X H	L O A D	T I M E	S P E D	N E L	L E Q
222	11/01/84	1	C	3-2	V	V	.	5.1	53.5	86.2	81.5
225	11/01/84	1	C	3-2	V	V	.	7.6	35.9	86.2	.
228	11/07/84	1	C	3-2	V	V	.	4.7	58.0	86.0	81.0
229	11/07/84	1	C	3-2	H	V	.	5.8	47.0	84.7	78.1
230	11/07/84	1	C	3-2	V	V	.	4.3	63.4	.	82.8
231	11/07/84	1	C	3-2	V	V	.	4.5	60.6	85.4	80.9
232	11/07/84	1	C	3-2	V	V	.	4.8	56.8	85.2	79.3
233	11/07/84	1	C	2-2	V	V	.	4.9	55.7	84.5	81.2
234	11/07/84	1	C	2-1	V	H	.	4.5	60.6	86.3	.
236	11/07/84	1	C	3-2	T	V	.	4.3	63.4	90.8	.
237	11/07/84	1	C	3-2	V	V	.	4.1	66.5	81.1	82.2
238	11/07/84	1	C	3	FB	.	.	6.0	45.5	87.0	80.3
241	11/07/84	1	C	3-2	H	V	.	3.9	69.9	87.4	.
243	11/07/84	1	C	3-2	H	V	.	5.0	54.5	83.5	.
244	11/07/84	1	C	3-2	FB	V	.	5.1	53.5	86.7	81.7
248	11/07/84	1	C	3-2	V	V	.	4.8	56.8	.	84.8
249	11/07/84	1	C	3-2	H	V	.	4.1	66.5	84.7	.
250	11/07/84	1	C	3-2	H	V	.	4.1	66.5	87.8	.
253	11/07/84	1	C	3-2	T	V	.	3.8	71.8	87.1	.
258	11/07/84	1	C	3-2	H	V	.	5.3	51.5	84.4	.
259	11/07/84	1	C	3-2	T	V	.	4.4	62.0	87.3	.
260	11/07/84	1	C	3-2	H	V	.	3.7	73.7	86.5	.
261	11/07/84	1	C	3-2	D	V	U	4.9	55.7	86.2	80.7
267	11/07/84	1	C	3	FB	.	.	4.4	62.0	85.0	.
268	11/07/84	1	C	3-2	V	V	.	4.8	56.8	85.5	80.5
6	10/30/84	2	C	3-2	FB	V	U	4.7	58.0	87.0	81.8
7	10/30/84	2	C	3-2	H	V	.	5.3	51.5	84.5	81.9
8	10/30/84	2	C	3-2	H	V	.	5.7	47.8	83.7	78.1
9	10/30/84	2	C	3-2	H	V	.	5.3	51.5	88.6	83.0
12	10/30/84	2	C	3-2	V	V	.	5.6	48.7	84.0	.
13	10/30/84	2	C	3-2	D	V	.	6.3	43.3	87.2	.
16	10/30/84	2	C	3-2	V	V	.	5.7	47.8	85.8	.
21	10/30/84	2	C	3-2	V	V	.	5.5	49.6	85.1	.
25	10/30/84	2	C	3-2	D	V	U	5.9	46.2	90.0	83.8
26	10/30/84	2	C	3-2	FB	V	U	4.8	56.8	90.0	84.5
27	10/30/84	2	C	3-2	V	V	.	5.3	51.5	85.8	.
30	10/30/84	2	C	3-2	H	V	.	4.4	62.0	86.6	.
31	10/30/84	2	C	3-2	V	V	.	6.2	44.0	88.5	81.3
36	10/30/84	2	C	3-2	FB	V	.	5.8	47.0	85.2	.
37	10/30/84	2	C	3-2	V	V	.	6.5	42.0	.	79.6
41	10/30/84	2	C	3-2	V	V	.	5.8	47.0	85.7	80.3
42	10/30/84	2	C	3-2	D	V	L	5.2	52.4	90.4	85.1
44	10/30/84	2	C	3-2	H	V	.	5.6	48.7	88.0	82.0
45	10/30/84	2	C	3-2	FB	V	L	6.6	41.3	92.3	86.0
48	10/30/84	2	C	3-2	V	V	.	7.4	36.9	84.6	.
50	10/30/84	2	C	3-2	V	V	.	5.5	49.6	88.0	.
52	10/30/84	2	C	3-2	V	V	.	5.1	53.5	86.1	80.6
54	10/30/84	2	C	3-2	V	V	.	5.3	51.5	86.7	81.6
59	10/30/84	2	C	3-2	V	V	.	5.6	48.7	86.9	.
65	10/30/84	2	C	3-2	V	V	.	4.9	55.7	86.5	81.8
70	10/30/84	2	C	3-2	V	V	.	6.2	44.0	86.7	81.2
72	10/30/84	2	C	3-2	T	V	.	6.5	42.0	85.4	80.0
73	10/30/84	2	C	3-2	D	V	U	5.3	51.5	92.5	87.1
75	10/30/84	2	C	3-2	H	V	.	5.9	46.2	86.7	.
77	10/30/84	2	C	3-2	V	V	.	5.9	46.2	84.1	.
79	10/30/84	2	C	3-2	V	V	.	5.3	51.5	87.3	81.8

OBS	D A T E	L O C	L A N E	A X L E	T Y P E	E X H	L O A D	T I M E	S P E D	N E L	L E Q
80	10/30/84	2	C	3-2	H	V	.	5.4	50.5	86.5	81.5
86	10/30/84	2	C	3-2	V	V	.	7.0	39.0	.	79.7
88	10/30/84	2	C	3-2	V	V	.	5.4	50.5	.	78.9
93	10/30/84	2	C	3-2	V	V	.	5.3	51.5	85.8	79.9
95	10/30/84	2	C	3-2	V	V	.	5.9	46.2	85.0	79.7
96	10/30/84	2	C	3-2	T	V	.	6.1	44.7	83.8	.
100	10/30/84	2	C	3-2	H	V	.	5.4	50.5	.	80.7
101	10/30/84	2	C	3-2	H	V	.	5.8	47.0	88.6	82.3
103	10/30/84	2	C	3-2	D	V	U	5.3	51.5	87.2	.
105	10/30/84	2	C	3-2	V	V	.	6.2	44.0	.	88.4
107	10/30/84	2	C	3-2	V	V	.	5.3	51.5	92.5	86.5
108	10/30/84	2	C	3-2	V	V	.	5.8	47.0	83.5	.
110	10/30/84	2	C	3-2	V	V	.	5.6	48.7	88.0	.
111	10/30/84	2	C	3-2	V	V	.	5.4	50.5	89.2	84.4
115	10/30/84	2	C	2-2	V	V	.	6.3	43.3	87.2	.
116	10/30/84	2	C	3-2	V	V	.	5.6	48.7	87.8	80.6
117	10/30/84	2	C	3-2	H	V	.	5.6	48.7	86.7	81.1
118	10/30/84	2	C	3-2	V	V	.	5.6	48.7	85.1	80.1
120	10/30/84	2	C	3-2	T	V	.	6.8	40.1	84.3	78.4
122	10/30/84	2	C	3-2	H	V	.	5.8	47.0	86.9	80.9
124	10/30/84	2	C	3-2	V	V	.	6.9	39.5	83.1	.
125	10/30/84	2	C	3-2	FB	V	U	5.1	53.5	86.3	81.2
129	10/30/84	2	C	3-2	FB	V	L	6.9	39.5	87.0	81.7
130	10/30/84	2	C	3-2	V	V	.	6.1	44.7	.	79.7
132	10/30/84	2	C	2-2	V	V	.	6.0	45.5	84.0	79.2
137	10/30/84	2	C	3-2	V	V	.	6.4	42.6	82.0	76.9
139	10/30/84	2	C	3-2	V	V	.	5.2	52.4	88.7	84.0
140	10/30/84	2	C	2-2	V	V	.	7.6	35.9	.	79.2
141	10/30/84	2	C	3-2	V	V	.	5.1	53.5	85.8	80.5
1	10/31/84	3	C	3-2	V	V	.	4.8	56.8	84.2	79.3
3	10/31/84	3	C	3-2	V	V	.	5.1	53.5	82.7	.
4	10/31/84	3	C	3-2	V	.	.	5.3	51.5	83.0	.
6	10/31/84	3	C	3-2	V	V	.	4.7	58.0	.	78.6
7	10/31/84	3	C	3-2	FB	.	U	4.3	63.4	84.0	79.1
9	10/31/84	3	C	3-2	V	V	.	4.4	62.0	82.1	78.4
10	10/31/84	3	C	3-2	V	V	.	5.2	52.4	81.8	77.4
11	10/31/84	3	C	3-2	V	V	.	4.5	60.6	84.4	80.2
13	10/31/84	3	C	3-2	H	V	.	4.4	62.0	84.1	.
14	10/31/84	3	C	3-2	FB	V	.	4.6	59.3	81.0	77.3
15	10/31/84	3	C	3-2	H	V	.	4.8	56.8	83.4	.
16	10/31/84	3	C	3-2	H	V	.	5.1	53.5	.	79.0
17	10/31/84	3	C	3-2	V	V	.	5.0	54.5	84.8	79.8
18	10/31/84	3	C	3-2	V	V	.	4.8	56.8	81.8	77.6
20	10/31/84	3	C	3-2	V	V	.	7.7	35.4	.	74.1
21	10/31/84	3	C	3-2	V	V	.	4.8	56.8	82.8	.
22	10/31/84	3	C	2-2	V	V	.	4.5	60.6	.	77.5
25	10/31/84	3	C	3-2	V	V	.	5.3	51.5	79.2	75.7
28	10/31/84	3	C	3-2	V	V	.	4.5	60.6	90.0	.
29	10/31/84	3	C	3-2	V	V	.	5.0	54.5	81.0	77.0
36	10/31/84	3	C	2-2	V	V	.	6.2	44.0	79.0	.
37	10/31/84	3	C	3-2	V	V	.	6.5	42.0	79.3	.
38	10/31/84	3	C	3-2	H	V	.	4.9	55.7	.	77.7
39	10/31/84	3	C	3-2	V	V	.	5.6	48.7	79.9	76.0
44	10/31/84	3	C	3-2	H	V	.	5.8	47.0	84.6	.
46	10/31/84	3	C	3-2	T	V	.	4.8	56.8	82.0	78.0
49	10/31/84	3	C	3	D	H	.	4.7	58.0	78.0	76.8

OBS	D A T E	L O C	L A N E	A X L E	T Y P E	E X H	L O A D	T I M E	S P E D	N E L	L E Q
50	10/31/84	3	C	3-2	V	V	.	7.8	35.0	78.5	74.5
52	10/31/84	3	C	3-2	H	V	.	4.1	66.5	86.5	.
54	10/31/84	3	C	3-2	V	V	.	7.8	35.0	79.4	73.7
56	10/31/84	3	C	3-2	V	V	.	6.8	40.1	79.0	75.5
57	10/31/84	3	C	3-2	V	V	.	3.9	69.9	95.5	90.0
58	10/31/84	3	C	3-2	V	V	.	9.6	28.4	.	75.8
60	10/31/84	3	C	3-2	FB	V	.	5.6	48.7	79.3	.
61	10/31/84	3	C	3-2	V	V	.	5.6	48.7	.	77.4
64	10/31/84	3	C	2-2	V	V	.	5.8	47.0	79.6	.
65	10/31/84	3	C	3-2	V	V	.	5.1	53.5	84.3	79.3
67	10/31/84	3	C	2-1	V	H	.	6.3	43.3	78.5	.
68	10/31/84	3	C	3-2	V	V	.	8.4	32.5	78.5	73.3
70	10/31/84	3	C	3-2	FB	V	U	5.3	51.5	82.8	78.0
71	10/31/84	3	C	3-2	V	V	.	7.0	39.0	86.0	.
72	10/31/84	3	C	3-2	V	V	.	6.1	44.7	80.8	76.0
73	10/31/84	3	C	3-2	V	V	.	6.2	44.0	78.2	74.2
76	10/31/84	3	C	3-2	V	V	.	8.4	32.5	83.2	77.7
79	10/31/84	3	C	3-2	V	V	.	4.3	63.4	81.2	77.3
81	10/31/84	3	C	3-2	FB	V	.	6.5	42.0	84.1	80.2
84	10/31/84	3	C	3-2	FB	V	.	4.8	56.8	.	83.3
87	10/31/84	3	C	3-2	V	V	.	4.8	56.8	.	77.5
90	10/31/84	3	C	3-2	V	V	.	4.9	55.7	84.1	.
92	10/31/84	3	C	2-2	V	V	.	4.5	60.6	85.0	80.9
95	10/31/84	3	C	3-2	V	V	.	4.5	60.6	83.4	.
96	10/31/84	3	C	3-2	V	V	.	6.1	44.7	83.6	79.0
97	10/31/84	3	C	3-2	CC	V	L	11.6	23.5	.	77.6
100	10/31/84	3	C	3-2	D	V	U	5.6	48.7	83.0	78.8
101	10/31/84	3	C	3-2	V	V	.	6.6	41.3	81.0	.
102	10/31/84	3	C	3-2	V	V	.	4.8	56.8	82.4	78.1
103	10/31/84	3	C	2-1	V	V	.	4.6	59.3	.	78.5
107	10/31/84	3	C	3-2	FB	V	.	4.3	63.4	83.0	.
108	10/31/84	3	C	3-2	H	V	.	4.6	59.3	83.2	78.7
109	10/31/84	3	C	2-2	V	V	.	5.2	52.4	80.2	77.0
110	10/31/84	3	C	3-2	D	V	L	4.1	66.5	.	79.2
113	10/31/84	3	C	3-2	V	V	.	6.1	44.7	80.5	77.0
114	10/31/84	3	C	3	D	V	.	4.6	59.3	82.7	77.5
111	10/18/84	4	C	3-2	V	V	.	7.8	35.0	85.3	.
113	10/18/84	4	C	3-2	V	V	.	7.8	35.0	.	77.1
116	10/18/84	4	C	3-2	V	.	U	5.9	46.2	88.0	.
118	10/18/84	4	C	3-2	FB	V	.	6.4	42.6	82.8	.
119	10/18/84	4	C	3-2	H	V	.	5.0	54.5	84.1	79.6
121	10/18/84	4	C	3-2	FB	V	U	6.3	43.3	85.2	.
123	10/18/84	4	C	3-2	V	V	.	7.8	35.0	82.7	78.0
125	10/18/84	4	C	3-2	V	V	.	4.8	56.8	84.6	80.7
128	10/18/84	4	C	3-2	T	V	.	7.9	34.5	81.1	76.4
130	10/18/84	4	C	2-2	V	V	.	6.1	44.7	84.8	79.9
131	10/18/84	4	C	3-2	V	V	.	7.8	35.0	83.0	77.4
132	10/18/84	4	C	3-2	V	V	.	9.6	28.4	.	80.0
134	10/18/84	4	C	3-2	D	V	.	6.9	39.5	84.5	80.0
148	10/18/84	4	C	3-2	V	V	.	6.0	45.5	.	78.1
151	10/18/84	4	C	3-2	FB	V	.	6.3	43.3	83.0	78.5
155	10/18/84	4	C	3-2	V	V	.	9.6	28.4	.	76.3
156	10/18/84	4	C	2-1	V	V	.	5.8	47.0	.	81.2
160	10/18/84	4	C	3-2	D	V	U	6.7	40.7	85.2	.
161	10/18/84	4	C	3-2	T	V	.	8.1	33.7	82.1	.
165	10/18/84	4	C	3-2	V	V	.	6.3	43.3	87.3	82.9

O B S	D A T E	L O C	L A N E	A X L E	T Y P E	E X H	L O A D	T I M E	S P E D	N E L	L E Q
166	10/18/84	4	C	3-2	V	V	.	5.4	50.5	85.6	.
167	10/18/84	4	C	3-2	FB	V	.	6.0	45.5	83.7	78.6
170	10/19/84	4	C	3-2	FB	V	.	6.1	44.7	83.5	77.9
172	10/19/84	4	C	3-2	V	V	.	11.0	24.8	80.5	74.8
174	10/19/84	4	C	3-2	V	V	.	5.9	46.2	84.0	79.0
177	10/19/84	4	C	3-2	V	V	.	6.1	44.7	85.0	79.6
182	10/19/84	4	C	3-2	D	V	U	5.9	46.2	87.6	83.5
186	10/19/84	4	C	2-2	V	V	.	7.5	36.4	84.0	78.7
187	10/19/84	4	C	3-2	D	V	L	5.5	49.6	86.1	.
189	10/19/84	4	C	3-3	H	V	.	5.9	46.2	85.1	80.9
190	10/19/84	4	C	3-2	H	V	.	4.8	56.8	.	83.7
192	10/19/84	4	C	3-2	V	V	.	6.5	42.0	.	79.8
194	10/19/84	4	C	3-2	T	V	.	6.8	40.1	81.0	76.3
203	10/19/84	4	C	3-2	FB	.	U	5.8	47.0	86.0	.
204	10/19/84	4	C	3-2	V	V	.	9.1	30.0	.	79.2
211	10/19/84	4	C	3-2	FB	.	U	6.6	41.3	85.7	80.5
212	10/19/84	4	C	2-2	V	V	.	8.0	34.1	.	80.4
213	10/19/84	4	C	3-2	V	V	.	7.1	38.4	.	79.5
215	10/19/84	4	C	3-2	T	V	.	6.9	39.5	83.9	78.6
220	10/19/84	4	C	3-2	V	V	.	5.3	51.5	84.7	.
223	10/19/84	4	C	2-2	V	V	.	6.3	43.3	.	79.1
224	10/19/84	4	C	3-2	T	V	.	4.6	59.3	.	80.9
229	10/19/84	4	C	3-2	FB	V	.	4.4	62.0	.	81.7
230	10/19/84	4	C	3-2	V	V	.	5.6	48.7	85.3	80.6
231	10/19/84	4	C	3-2	V	V	.	8.3	32.9	82.4	.
237	10/19/84	4	C	3-2	V	V	.	8.5	32.1	83.8	.
238	10/19/84	4	C	3-2	V	V	.	7.6	35.9	83.5	78.2
240	10/19/84	4	C	3-2	V	V	.	5.8	47.0	83.4	78.9
243	10/19/84	4	C	3-1	V	.	.	6.8	40.1	85.8	.
245	10/19/84	4	C	3-2	V	V	.	7.3	37.4	.	82.1
247	10/19/84	4	C	3-2	V	V	.	7.1	38.4	.	83.4
248	10/19/84	4	C	3-2	V	V	.	9.3	29.3	81.2	.
250	10/19/84	4	C	2-2	V	V	.	6.6	41.3	83.1	78.4
255	10/19/84	4	C	3-2	V	V	.	10.0	27.3	.	78.2
256	10/19/84	4	C	3-2	V	V	.	6.1	44.7	86.5	81.2
260	10/19/84	4	C	3-2	FB	V	.	5.3	51.5	.	81.0
261	10/19/84	4	C	2-1	V	V	.	6.5	42.0	86.0	80.2
264	10/19/84	4	C	2-2	V	V	.	6.6	41.3	84.3	79.4
270	10/19/84	4	C	3-2	V	V	.	5.8	47.0	.	78.9