Quantitative Measure of Levels of Service

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ABSTRACT

This study was undertaken to accomplish two specific objectives pertaining to the measurement of traffic flow quality: (a) to demonstrate that the internal energy of the traffic stream as determined by the parameter acceleration noise is related to the traffic flow parameters of speed, volume, and density and (b) to demonstrate that acceleration noise can be used as a quantitative measure of the level of service for traffic flow on an urban freeway. Traffic flow data at different levels of service were collected from sections of Interstate 65 in Louisville, Kentucky, using a "floating car" equipped with a Greenshields Traffic Analyzer. The traffic analyzer data were later reduced using an interactive computer program to yield values of acceleration noise. The relationships between acceleration noise and the traffic flow parameters of speed, volume, and density were analyzed using scatter diagrams and plots of the mean values of each parameter for each level of service. The results of F-tests between the variables showed the relationships to be significant and the values of R^2 indicated a high degree of correlation. As a result of this study, it was concluded that acceleration noise due to traffic interaction is a quantitative measure of the level of service for traffic flow. This conclusion is based on the relationships between acceleration noise and the traffic flow parameters of speed, volume, and density. Respectively, these relationships are linear, exponential, and quadratic in nature. Furthermore, acceleration noise increased by a factor of 12.64 as level of service deteriorated from A to E, compared to speed, which decreased by a factor of 1.47, and compared to volume and density, which increased by factors of 2.89 and 4.29, respectively, for the same changes in levels of service.

Researchers and traffic engineers have long recognized the need for methods of comparing the effects of various design options and traffic controls on the quality of traffic flow and levels of service in a quantitative manner. Various parameters, indices, and models have been developed over the years in an effort to solve this problem, yet none has gained wide acceptance as a quantitative measure of traffic flow quality.

Travel time, the "old reliable" of traffic flow parameters, has been used practically every way possible to quantify traffic flow quality (1-3). But travel time is not a good indicator of operating conditions during a trip on a section of highway unless delays are exceedingly long or frequent.

Traffic flow has been compared to heat flow and a traffic flow model based on heat flow has been developed (4). This heat flow analogy assumes that a traffic lane is similar to a long, slender, insulated rod (controlled access and no opportunity for lane change). Heat flow through such a rod is described by a differential equation that relates the variables of temperature, distance, time, and the material properties of conductivity, specific heat, and density. Traffic flow variables are simply substituted for the appropriate heat flow variables in the differential equation and the solution yields the speed-density relationship of the traffic stream. This approach appears to be straightforward and easily understood. However, there is a problem with this analogy. The heat flow equation, when applied to traffic flow, implies that speed might be negative if the change in vehicular density increases with respect to distance. This situation is not realistic and therefore reduces the conceptual appeal of the model as a quantitative measure of traffic flow quality.

A considerable amount of work has been done with regard to fluid flow modeling of the traffic stream (4). A single lane of traffic offers a striking analogue to the flow of a compressible fluid, such as a gas, in a pipe with a constant area. Both systems consist of discrete particles: individual molecules in the case of the fluid and individual vehicles in the case of the traffic stream. In application of fluid flow models to traffic flow problems, a greater concern is implied with the overall statistical behavior of the traffic stream than with the interactions between vehicles because none of the parameters relate to the individual vehicle. Fluid models have certain shortcomings as quantitative measures of traffic flow quality because the sample size associated with traffic problems includes only a small portion of the particles or vehicles (4).

The heat flow model and fluid flow models involve systems that are governed by natural physical laws. The system associated with the traffic stream includes the driver, the road, and the vehicle. Also, traffic conditions, which are related to vehicle behavior and roadway geometry, are important factors associated with the traffic stream. None of these elements of the traffic stream are governed by the natural physical laws that are associated with heat flow or fluid flow. Although these models have been successful on a limited basis, they are not generally likely to reflect the actual traffic flow characteristics associated with the traffic stream.

A parameter that successfully measures the quality of traffic flow on a given highway facility in a quantitative manner must be sensitive to the three basic elements of the traffic stream: the driver, the road, and the vehicle. Also, such a parameter must be sensitive to traffic flow conditions and it must measure the smoothness or the quality of flow within the traffic stream. Acceleration noise is a parameter that is sensitive to the three basic elements of the traffic stream and it is a measure of the quality of flow within the traffic stream. Acceleration noise is defined as the standard deviation of the individual accelerations and decelerations of a vehicle traveling over a section of highway.

The quality of traffic flow on a given highway facility affects many features of the traffic stream that are quantitative in nature. For example, vehicle operating costs are directly affected by the quality of traffic flow and are measured quantitatively. To determine the effect that the quality of traffic flow has on these features, a quantitative measure of traffic flow quality is needed. At present, the only parameter that is an accepted measure of traffic flow quality is level of service and it is qualitative not quantitative in nature. Therefore, it is not now possible to relate the quantitative features of the highway environment to traffic flow quality.

PURPOSE AND OBJECTIVES

The purpose of this study is to accomplish two specific objectives. These objectives are to demonstrate

- That acceleration noise is related to the traffic flow parameters of speed, volume, and density and
- That acceleration noise can be used as a quantitative measure of the level of service for traffic flow on an urban freeway.

DATA COLLECTION, ANALYSIS, AND RESULTS

Introduction

Data related to acceleration noise and level of service were collected for this study. Specific attention was given to weather and holiday limitations, highway section selection, use of the test vehicle and research equipment, and traffic count methods. The methods employed in the data-collection effort are discussed.

An attempt was made to identify and exclude those variables that were difficult, if not impossible, to control. Of course, the first of these variables to be considered was weather conditions. Adverse weather conditions can cause variation in traffic flow patterns. Data were not collected during periods of inclement weather. Furthermore, the pavement of each test section was dry and free from moisture before any data-collection runs were made. If adverse weather conditions occurred during a series of test runs, the runs were terminated and not resumed until the pavement was dry.

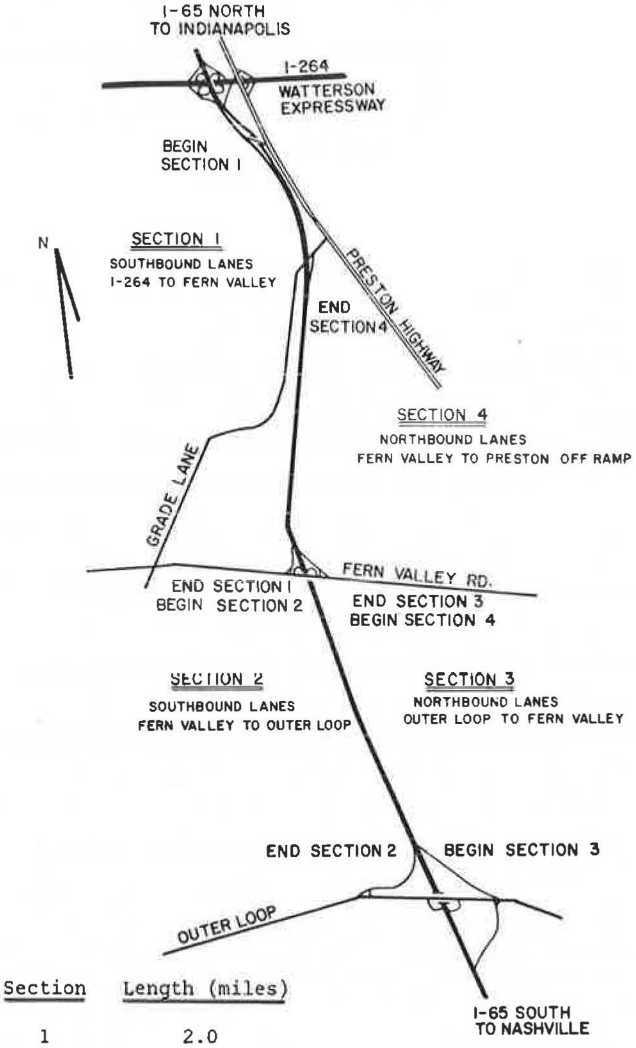
During holiday periods and weekends, the traffic flow characteristics on any highway can change dramatically compared to typical weekday traffic conditions. To eliminate any variance in the data attributable to this variable, data were only collected on weekdays excluding holidays.

Highway Test Section

Four sections of Interstate 65 in Louisville, Kentucky, were selected for study. I-65 is a four-lane urban freeway with 10-ft shoulders and a 20-ft grass median. The horizontal alignment is relatively straight, and the vertical alignment is relatively flat. Preliminary studies showed that a wide range of levels of service existed and that traffic volumes approach capacity during peak periods. These sections are shown in Figure 1. These freeway sections carry heavy traffic volumes in both the morning and afternoon peak periods. The average daily traffic (ADT) volume in 1981 on Sections 1 and 4 was 68,430 vehicles per day. The ADT volume on Sections 2 and 3, for the same year, was 60,700 vehicles per day. Classification counts supplied by the City Traffic Engineer's Office in Louisville, Kentucky, showed the amount of truck traffic to be 15 percent of this ADT volume.

Test Vehicle and Research Equipment

Jones and Potts (5) investigated the variability of acceleration noise with different drivers. They found that acceleration noise did, in fact, vary with drivers, depending on the individual driver's speed. For example, acceleration noise was essentially the same for two drivers driving below the design speed of the highway. However, if both drivers exceeded the design speed, acceleration noise was greater for the faster driver. On the

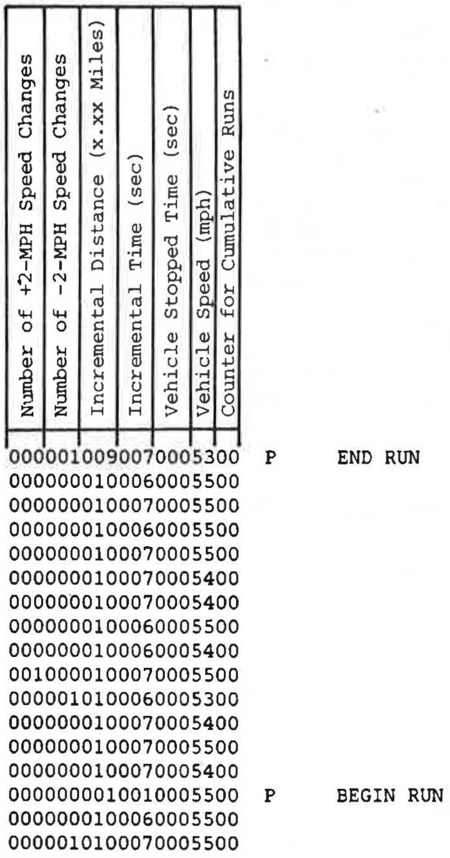


Section	Length (miles)
1	2.0
2	1.0
3	1.0
4	1.4

FIGURE 1 Selected study sections of I-65 in Louisville, Kentucky.

basis of the conclusions of the Jones and Potts study, a decision was made to use a single driver for the test vehicle and thus to avoid variations in the data caused by differences in drivers.

In previous studies of acceleration noise, data were recorded by various instruments including an accelerometer, a tachograph, a recording speedometer, and a traffic analyzer (4,6-8). For this study, a Greenshields Traffic Analyzer was installed in a 1971 Plymouth Fury and used to collect the required data for determination of acceleration noise. The traffic analyzer was cable connected to the test vehicle's transmission where the speedometer cable is located. A special connector was used to allow the speedometer to remain operational. The data recorded included (a) the number of positive and negative 2-mph speed changes over the highway section, (b) the running time of the test vehicle, and (c) the length of each highway section. The traffic analyzer can be set on automatic mode that allows for recording all of these data on a constant-distance (every 0.10 mile) basis. There is also a manual switch that allows the operator to record data at any time during a test run. The data are printed in a digital format on recording tape during each data-collection run and can easily be reduced and analyzed at a later time. The format of the recording tape is shown in Figure 2.



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0000010100060005300
0000000100070005400
0000000100070005500
0000000100070005400
000000001001000550O  P      BEGIN RUN
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FIGURE 2 Format of traffic analyzer recording tape.

The "floating car" technique was used to collect data relating the traffic flow parameters of speed, volume, density, and acceleration noise on the selected freeway sections. This technique has long been established as providing an accurate determination of the average speed of the traffic stream on a given highway section. It is assumed that the acceleration data for a floating car would also represent an average of the accelerations of the vehicles in the traffic stream (4).

Data Collection

Total acceleration noise on a given freeway section is the sum of the natural acceleration noise and the acceleration noise due to traffic interaction. The natural acceleration noise is the acceleration noise of the driver and the vehicle in response to the geometric characteristics of the highway. The natural acceleration noise can be measured by making test runs with the floating car on the highway section in the absence of significant traffic. This can be accomplished by making runs between the hours of 1:00 a.m. and 5:00 a.m. when traffic volume on this urban freeway is low. A total of 65 test runs was made on the selected freeway sections between the hours of 1:00 a.m. and 5:00 a.m. The data were then reduced by an interactive computer program to calculate the acceleration noise.

Acceleration noise due to traffic interaction can be determined by making test runs with the floating car at various times of the day when traffic volume is considered to be low, moderate, and high. During the peak hours (7:00 a.m. to 9:00 a.m. and 3:00 p.m. to 6:00 p.m.), traffic volumes are directional. Inbound traffic volume in the morning is generally high, while outbound traffic volume is relatively low. Conversely, outbound traffic volume in the afternoon is generally high, while inbound traffic is relatively low. A single round trip yields data with regard to high and low traffic volumes. Test runs during the morning and afternoon peak periods yielded data over a wide range of speeds and densities compatible with levels of service A through E. Traffic flow during the test runs was never stopped; however, at level of service E, traffic flow was generally slow-and-go.

Approximately 100 test runs that generated more than 488 vehicle-miles of travel were made on the selected freeway sections to collect the data required to calculate acceleration noise due to traffic interaction. During these test runs 346 data points were collected at various levels of service. A single data point reflects the acceleration noise measured over the length of a test section. A single test run over the four freeway sections generated four data points.

Traffic volumes during test runs were determined using the manual count method at two count station locations along the test sections. Two observers were located at each count station with instructions to record the vehicle count during each 15-min period listed on the volume data sheets. One observer was responsible for recording the traffic count in the northbound lanes while the other was responsible for recording the traffic count in the southbound lanes. It was extremely important that the traffic counts be coordinated with the data-collection runs of the test vehicle. Before going into the field, the driver of the test vehicle and the observers conducting the traffic counts synchronized their watches. The format of the traffic count field sheet is shown in Figure 3.

Data Reduction

The values of acceleration noise, speed, volume, and density were reduced from data collected during the test runs on the designated sections of I-65. The test runs were conducted when traffic flow condi-

Date: 6-16-82
Southbound I-65
Fern Valley Road to Outer Loop Road--Afternoon Peak

Time Period	15 Minute Count
3:00 - 3:15	741
3:15 - 3:30	792
3:30 - 3:45	862
3:45 - 4:00	874
4:00 - 4:15	908
4:15 - 4:30	899
4:30 - 4:45	801
4:45 - 5:00	946
5:00 - 5:15	896
5:15 - 5:30	917
5:30 - 5:45	742
5:45 - 6:00	657

FIGURE 3 Format of typical traffic count field sheet.

tions ranged from level of service A to level of service E. The numbers of test runs associated with each level of service were 76 for level of service A, 111 for level of service B, 79 for level of service C, 57 for level of service D, and 23 for level of service E. There are 346 sets of data points in the data base.

Two computer systems were used in the reduction and analysis of the data collected for this study. The DECsystem10 computer, at the University of Louisville, was used to calculate acceleration noise, average speed, and traffic density using an interactive program developed for this study. The IBM 3081-K computer at Clemson University was used to statistically analyze the reduced data and generate a major portion of the graphic information related to this study.

Level of service criteria for freeway sections are given in The Highway Capacity Manual (HCM), Table 9.1 (9), where the maximum allowable volume for each level (or maximum allowable volume-to-capacity ratio) is tabulated against speed. The use of the HCM table implies a correlation between the volumes and speeds shown, when, in fact, no such relationship exists. Meeting one criterion (either speed or volume) does not guarantee that the other has been met.

Roess et al. (10) under a research contract from the FHWA and the National Cooperative Highway Research Program revised the criteria for establishing level of service for freeway sections. They considered it critical that any revised criteria be based on correlated values of volume and speed. Figure 4 shows the speed-volume relationship for freeway capacity.

These curves are based on limited amounts of data available in the literature as well as three pilot studies conducted specifically by Roess et al. (10). The curves show two major characteristics of freeway sections. First, there is a significant range of volumes over which speed is insensitive to volume. Second, as volume approaches capacity, speed decreases rapidly (10).

The use of the HCM table to determine level of service is impractical because speed is insensitive to volume over a large range. A more reliable parameter is density. Therefore, in this study, speed and density were used to define level of service. Table 1 gives the level of service recommendations based on speed and density for basic freeway sections (10). This table was used to determine levels of service associated with this research.

Acceleration noise can be expressed mathematically as

$$\sigma = \left[(1/T) \int_{[0,T]} (a(t))^{1/2} dt\right]^{1/2} \tag{1}$$

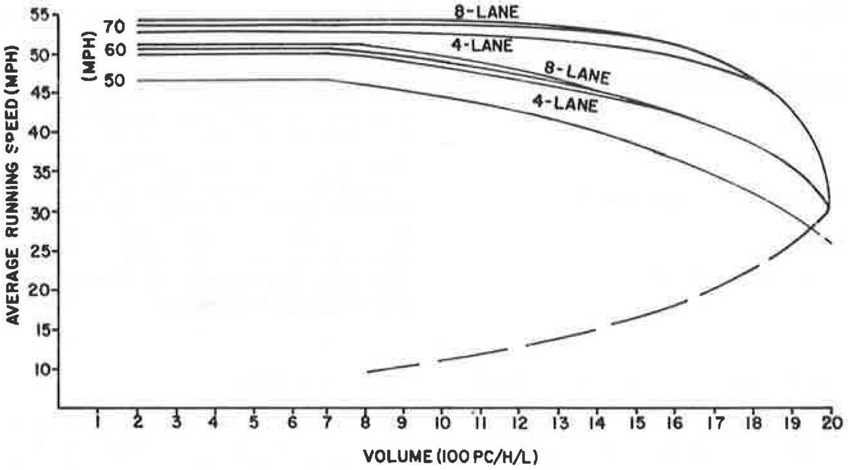

FIGURE 4 Recommended speed-flow curves for freeway capacity *(10)*.

TABLE 1 Levels of Service for Basic Freeway Sections *(10)*

Performance Criteria for Levels of Service			Maximum Service Volumes (one direction) for Levels of Service During Uniform Periods of Flow (passenger cars/hour)			
Level of Service	Speed (mph)	Density (passenger cars/mile/lane)	4 Lanes	6 Lanes	8 Lanes	Each Additional Lane
Average Highway Speed = 70 mph						
A	≥ 50	≤ 15	1,600	2,400	3,280	820
B	≥ 50	≤ 25	2,500	3,900	5,400	1,350
C	≥ 48	≤ 35	3,400	5,100	6,800	1,700
D	≥ 40	≤ 47	3,850	5,775	7,700	1,925
E	≥ 30	≤ 67	4,000	6,000	8,000	2,000
F	< 30	> 67	highly variable			
Average Highway Speed = 60 mph						
A	–	–	–	–	–	–
B	≥ 45	≤ 25	2,300	3,525	4,800	1,200
C	≥ 43	≤ 35	3,050	4,575	6,100	1,525
D	≥ 38	≤ 47	3,600	5,400	7,200	1,800
E	≥ 30	≤ 67	4,000	6,000	8,000	2,000
F	< 30	> 67	highly variable			
Average Highway Speed = 50 mph						
A	–	–	–	–	–	–
B	–	–	–	–	–	–
C	≥ 40(64)	≤ 35	2,800	4,200	5,600	1,400
D	≥ 35(56)	≤ 47	3,300	4,950	4,950	1,650
E	≥ 30(48)	≤ 67	4,000	6,000	6,000	2,000
F	< 30(48)	> 67	highly variable			

Note: Dashes indicate level of service not achievable due to restricted average highway speed.

where

σ = acceleration noise (ft/sec^2),
$a(t)$ = acceleration (positive or negative) at time t(ft/sec^2), and
T = total time in motion (sec).

Because this equation (4,11-13) is difficult to evaluate precisely using field data, the following equation can be used to approximate acceleration noise from parameters that can easily be collected in field studies (4,13,14). The equation is

$$\sigma = \left\{[(\Delta V)^2/T] \sum_{i=0}^{k} (n_i^2/\Delta T_i) - [(V_t - V_o)/T]^2\right\}^{1/2} \qquad (2)$$

where

σ = acceleration noise (ft/sec^2),
T = total time in motion (sec),
ΔV = constant increment of velocity change (mph),
n_i = integer denoting the number of speed changes at the constant increment (ΔV) that have occurred over time Δt_i,
V_t = velocity at trip start, and
V_o = velocity at trip end.

The natural acceleration noise (σ_n) on a given highway facility is the acceleration noise during a vehicle trip on the facility that can be ascribed to a driver's natural speed changes in the absence of significant traffic (4,12). The natural acceleration noise for each section of I-65 was determined by averaging the values of acceleration noise calculated from data collected during 65 test runs made in the absence of a significant volume of traffic. Table 2 gives the value of the natural acceleration noise for each section of I-65 and the 95 percent confidence limits on each mean value.

TABLE 2 Natural Acceleration Noise of Four Sections of I-65

Section	Natural Acceleration Noise, σ (ft/sec^2)^n	95 Percent Confidence Limit
1	0.2650	±0.0116
2	0.3180	±0.0192
3	0.2990	±0.0160
4	0.2440	±0.0176

The total acceleration noise (σ_T) of a given highway section is simply the value of acceleration noise measured during various traffic flow conditions. Total acceleration noise combines the effects of geometry and traffic interaction. An equation that represents the total acceleration noise is

$$\sigma_T = \sigma_n + \sigma_t \qquad (3)$$

where

σ_T = total acceleration noise (ft/sec^2),
σ_n = natural acceleration noise (ft/sec^2), and
σ_t = acceleration noise due to traffic interaction (ft/sec^2).

Equation 3 is an expression for total acceleration noise based on the definition of acceleration noise as the standard deviation of the accelerations of a vehicle in the traffic stream. It is recognized that addition and subtraction of standard deviations is not possible in a statistical sense. However, acceleration noise is not being used in a statistical sense; therefore, addition and subtraction of the acceleration noise values (standard deviations) is acceptable. Solving Equation 3 for σ_t yields an expression for the acceleration noise due to traffic interaction. This expression is simply

$$\sigma_t = \sigma_T - \sigma_n \qquad (4)$$

TABLE 3 Mean Values of Traffic Flow Parameters

	Level of Service				
	A	B	C	D	E
No. of data points	76.0	111.0	79.0	57.0	23.0
Mean speed (mph)	57.03	56.13	54.13	49.26	38.80
Mean 15-min volume	323.0	488.0	739.0	868.0	932.0
Mean density (veh/mile)	22.69	34.80	54.70	70.64	97.43
Mean acceleration noise (ft/sec^2)[a]	0.0517	0.0908	0.1825	0.3307	0.6536

[a] This parameter is the value due to traffic interaction.

The value of the acceleration noise due to traffic interaction (σ_t) is independent of the freeway section because the effects of geometry are removed by subtracting the natural acceleration noise (σ_n) from the total acceleration noise (σ_T). Acceleration noise due to traffic interaction is the parameter used to quantify level of service in this study. In the remaining portions of this study, the term acceleration noise (σ) will be used to denote acceleration noise due to traffic interaction unless otherwise noted.

The average speed for each test run was calculated using total elapsed time and total distance data from the traffic analyzer tape. The average speed calculated from this time and distance data is called the space-mean speed. The data associated with the time and distance were input into the computer program developed for this study and the average speed was calculated and printed.

For each level of service, the mean value of speed, 15-min traffic volume, density, and acceleration noise was calculated. These values were determined by averaging each parameter at each level of service. For example, the space-mean speed for each run at level of service A was summed and divided by 76. These values are given in Table 3.

Data Analysis

The specific relationship between acceleration noise and level of service was analyzed. SAS was used to analyze each of the relationships, and SAS/GRAPH was used to develop the graphic displays for each relationship. SAS and SAS/GRAPHIC are statistical analysis programs developed by the Statistical Analysis System Institute (15-17).

As a first step in the analysis process, a scatter diagram was developed describing the relationship between each of the dependent and independent variables. Each relationship was then analyzed using an F-test to determine the significance of the relationship between the variables. The value of F and the probability that a larger value of F exists by chance alone (PR > F) were calculated for each relationship. If the value of PR > F is 0.05 or less, the relationship between the dependent variable and the independent variable is considered significant. The 0.05 level of significance is generally accepted for most engineering work. The value of the square of the correlation coefficient (R^2) was calculated for each relationship.

The relationship between acceleration noise and each of the three traffic flow parameters was investigated and analyzed. Figures 5-7 are scatter diagrams that show the relationship of acceleration noise to speed, volume, and density, respectively. Acceleration noise is considered the dependent variable, and the three traffic flow parameters are considered the independent variables. Included in each figure is the regression equation that describes the relationship between the variables and the values of F, PR > F, and R^2, which describe the statistical

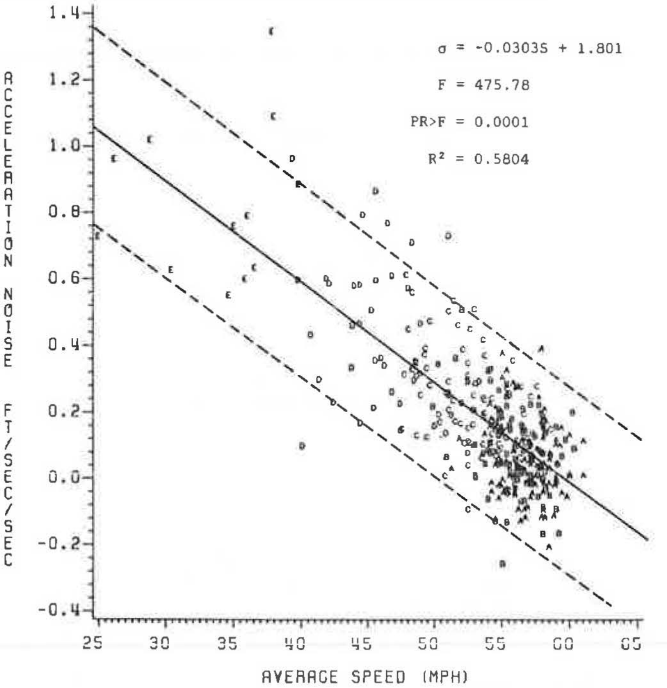

FIGURE 5 Scatter diagram of acceleration noise versus speed.

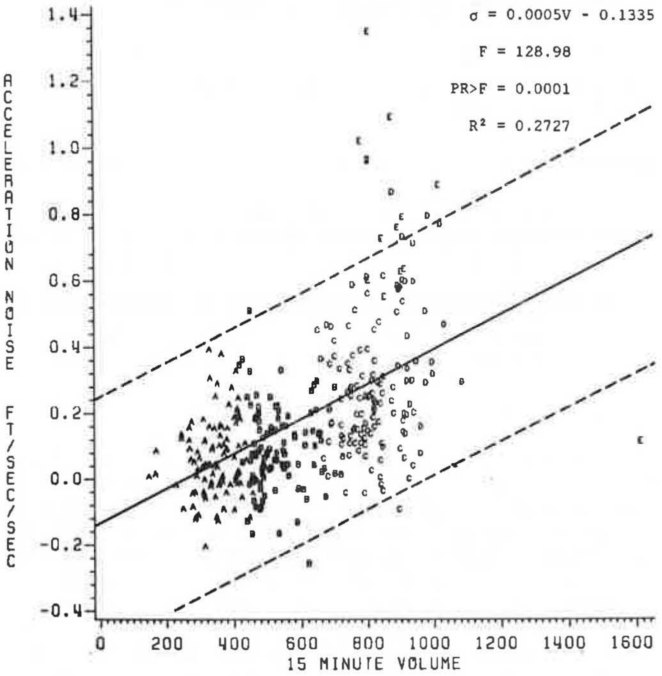

FIGURE 6 Scatter diagram of acceleration noise versus 15-min volume.

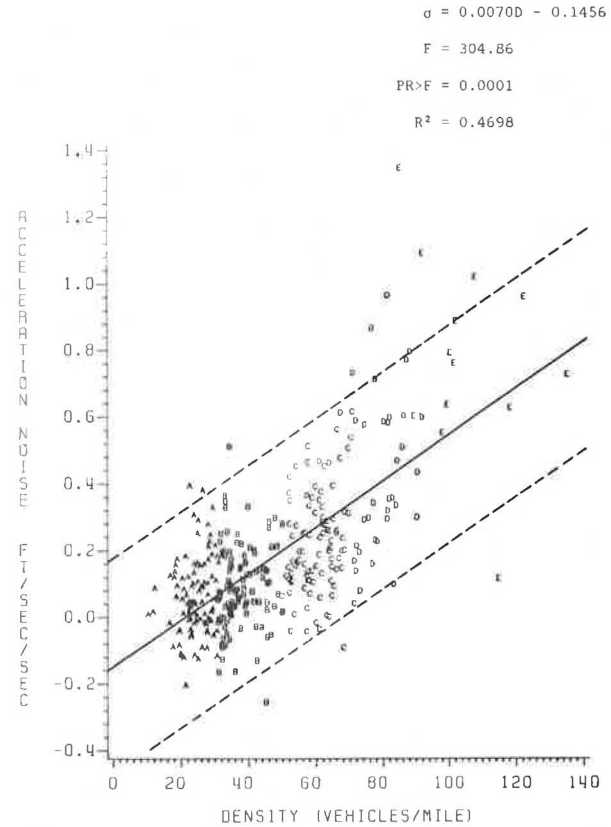

FIGURE 7 Scatter diagram of acceleration noise versus density.

significance of the relationship between the variables. The solid line through the data represents a linear regression fit and the dashed lines represent the upper and lower 95 percent confidence limits.

There is a significant amount of scatter present in Figures 5-7. This scatter is due to the high degree of variability in the traffic flow data. The amount of scatter present masks the significance of the relationship between the variables.

To gain a better understanding of the relationship between acceleration noise and the three traffic flow parameters, plots showing the average value of acceleration noise at each level of service versus the average value of speed, volume, and density, respectively, at each level of service were developed. These plots are shown in Figures 8-10. Included in each figure, as in the case of the scatter diagrams, is the regression equation that relates the variables and the values of F, PR > F, and R^2.

Results

Table 3 gives the relationship between level of service and the mean values of the parameters of speed, volume, density, and acceleration noise. The table shows that speed decreases by a factor of 1.47 as level of service deteriorates from A to E, whereas volume and density increase by factors of 2.89 and 4.29, respectively, for the same changes in level of service. Acceleration noise increases by a factor of 12.64 over this range of level of service. The data given in Table 3 suggest that acceleration noise is more sensitive to levels of service than are the traditional parameters of speed, volume, and density.

To understand the relationship between acceleration noise and level of service, an analysis of the relationships between acceleration noise and each of the traffic flow parameters of speed, volume, and density was performed. The results of the analysis are discussed in the following paragraphs.

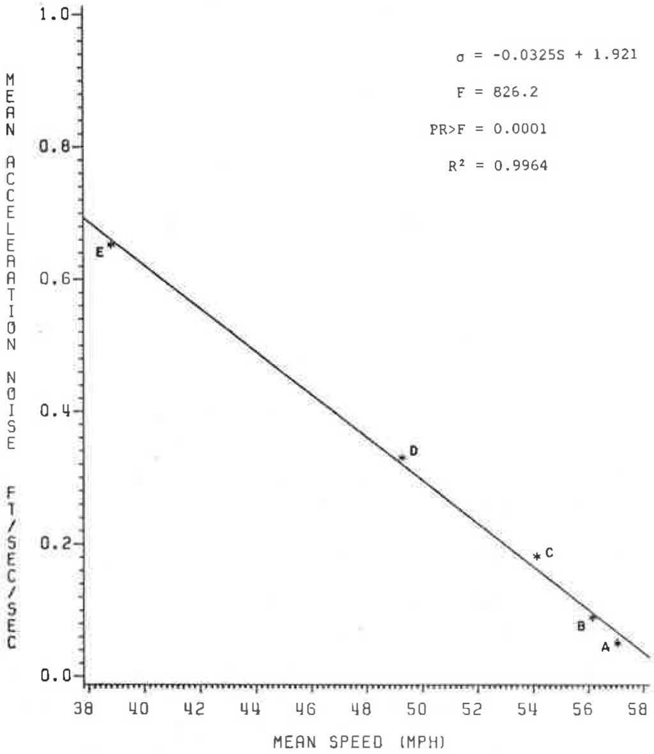

FIGURE 8 Average acceleration noise versus average speed at each level of service.

Figure 5 shows the relationship between acceleration noise and speed. The results of the F-test, which determines if a significant relationship

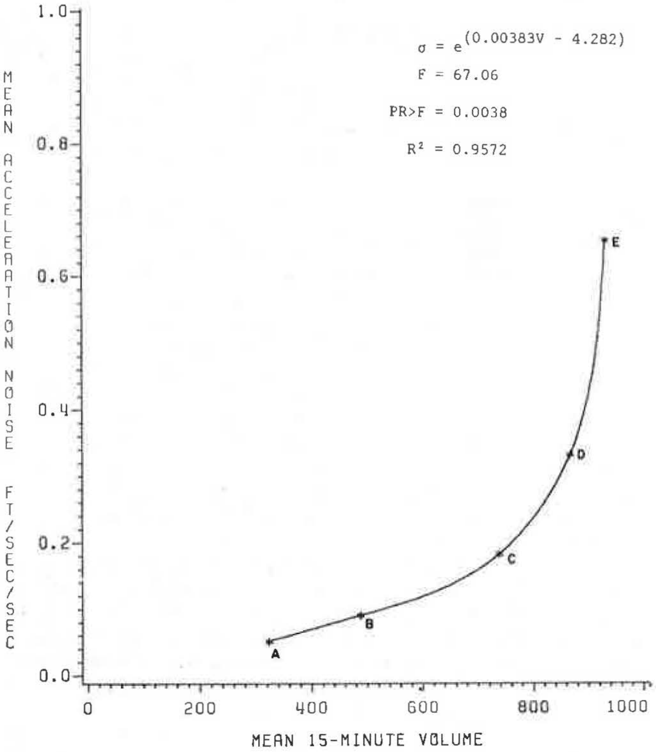

FIGURE 9 Average acceleration noise versus average 15-min volume at each level of service.

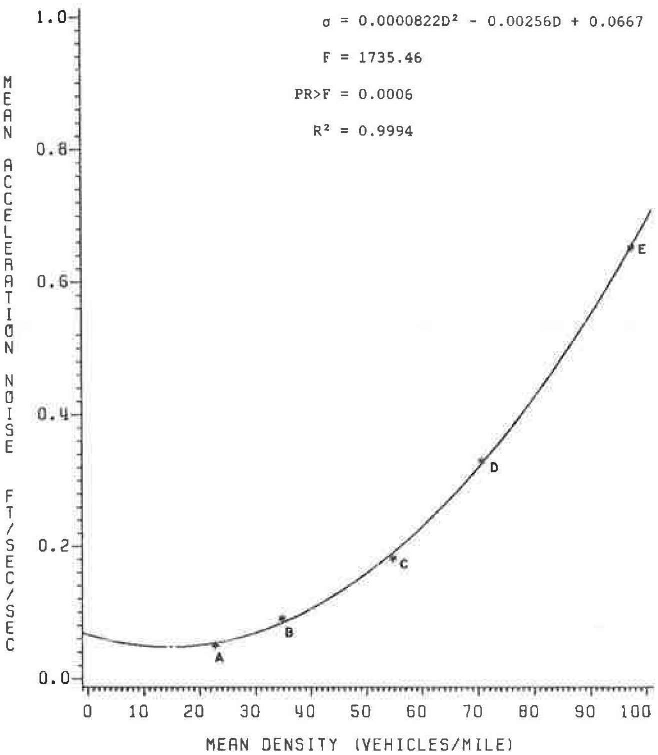

FIGURE 10 Average acceleration noise versus average density at each level of service.

exists between the two variables, show the values of F and PR > F to be 475.78 and 0.0001, respectively. These values indicate that the relationship between acceleration noise and speed is significant.

The value of R^2 is 0.5804. This value indicates that some linear dependence is present between the variables, but not enough to warrant complete linear dependence of acceleration noise on speed. This value of R^2 indicates that the data have a great deal of variance or scatter as can be observed in the scatter diagrams.

Figure 6 shows the relationship between acceleration noise and 15-min volume. The results show that F = 128.98, PR > F = 0.0001, and R^2 = 0.2727. These results are similar to the results of the analysis of acceleration noise versus speed. The relationship between the variables is significant, but the value of R^2 indicates that there is only a small degree of linear dependence between the variables. Visual inspection of the figure shows that the data are widely scattered as in the case of acceleration noise versus speed.

Figure 7 shows the relationship between acceleration noise and density. The results show that F = 304.86, PR > F = 0.0001, and R^2 = 0.4698. Again, as in the previous two relationships, the results indicate a significant relationship between the variables with little or no linear dependence.

Figure 8 shows the relationship between mean acceleration noise and mean speed at each level of service. The results show that F = 826.2, PR > F = 0.0001, and R^2 = 0.9964 for a linear model. These results indicate that a significant relationship exists between the mean values of the variables and that the relationship is linear in nature, with a high degree of correlation.

Figure 9 shows the relationship between mean acceleration noise and mean 15-min volume at each level of service. Visual inspection of the figure indicates that the relationship is nonlinear in nature, so various nonlinear models were analyzed in an attempt to define the relationship between the variables. The results show that F = 67.06, PR > F = 0.0038, and R^2 = 0.9572 for an exponential model. These results indicate that the relationship between the variables is significant and that the relationship is exponential.

Figure 10 shows the relationship between mean acceleration noise and mean density at each level of service. Again, as in the case of mean acceleration noise versus 15-min volume, the relationship is nonlinear; therefore, various nonlinear models were analyzed in an attempt to characterize the relationship between the variables. The results of this analysis show that F = 1,735.46, PR > F = 0.0006, and R^2 = 0.9994 for a quadratic model. The results again indicate statistical significance between the variables and a high degree of correlation with a quadratic model.

The scatter diagrams in Figures 5-7 indicate that acceleration noise is related to level of service. However, wide scatter in the data masks the true relationship between the variables. Figures 8-10 show strong relationships between the variables when the scatter is removed.

CONCLUSIONS

The results of this study support the premise that acceleration noise reflects the internal energy component of the traffic stream and is a quantitative measure of the quality of traffic flow. This conclusion is based on the analysis of the scatter diagrams shown in Figures 5-7 and the graphs shown in Figures 8-10.

The scatter in the data shown in Figures 5-7 increases as level of service deteriorates from A to E. This increasing scatter can be explained by the shape of the speed-flow curves for freeway operations (Figure 4) and the criteria for determining level of service given in Table 1. These curves show that the average running speed remains nearly constant at approximately 50 to 55 mph for a significantly wide range of traffic volumes. At a volume of approximately 1,500 passenger cars per hour per lane, speed drops rapidly as volumes increase only slightly. The maximum capacity for a freeway lane is approximately 2,000 vehicles per hour at a speed of approximately 35 mph.

This rapid decrease in speed for such a small increase in volume has a critical impact on the relationship between acceleration noise and level of service. At low volumes (levels of service A and B), the speed of the traffic stream will be relatively constant and acceleration noise, which is dependent on the number of speed changes, will be at or near the natural acceleration noise value. At higher volumes (level of service C to E), the speed of the traffic stream can be as high as 50 mph (Table 1). The critical parameter for each level of service is density. At higher volumes, a wide range of speed changes, which affect the parameter acceleration noise, can occur. It is entirely possible that under some conditions only a few speed changes may occur at these high volumes resulting in some low values of acceleration noise. On the other hand, there may be conditions under which several speed changes occur resulting in high values of acceleration noise. This implies that acceleration noise may not be as sensitive to volume changes as might be expected.

Scatter diagrams tend to show the relative trend in the relationship between two variables. Such diagrams can be useful in determining the significance of the relationship between two variables through an F-test. However, the true relationship between two

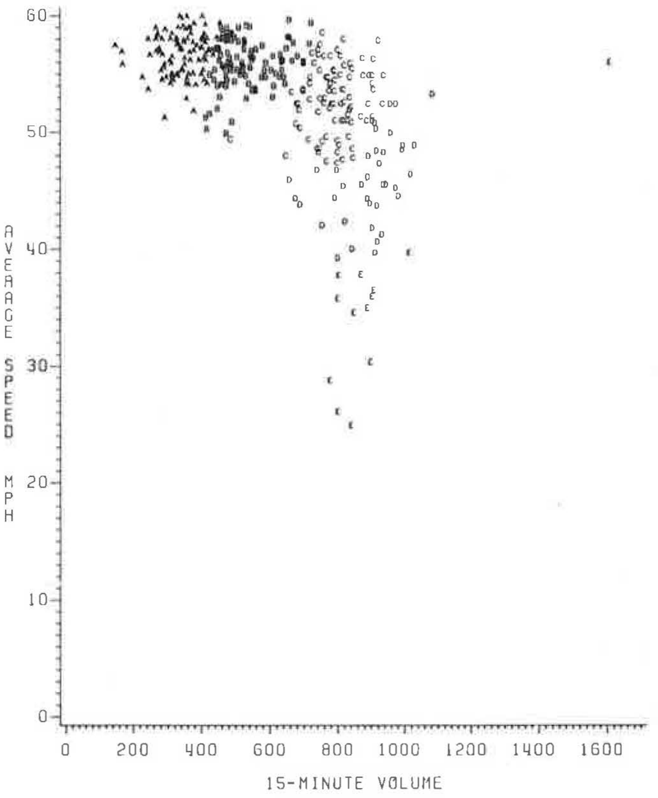

FIGURE 11 Scatter diagram of speed versus 15-min volume.

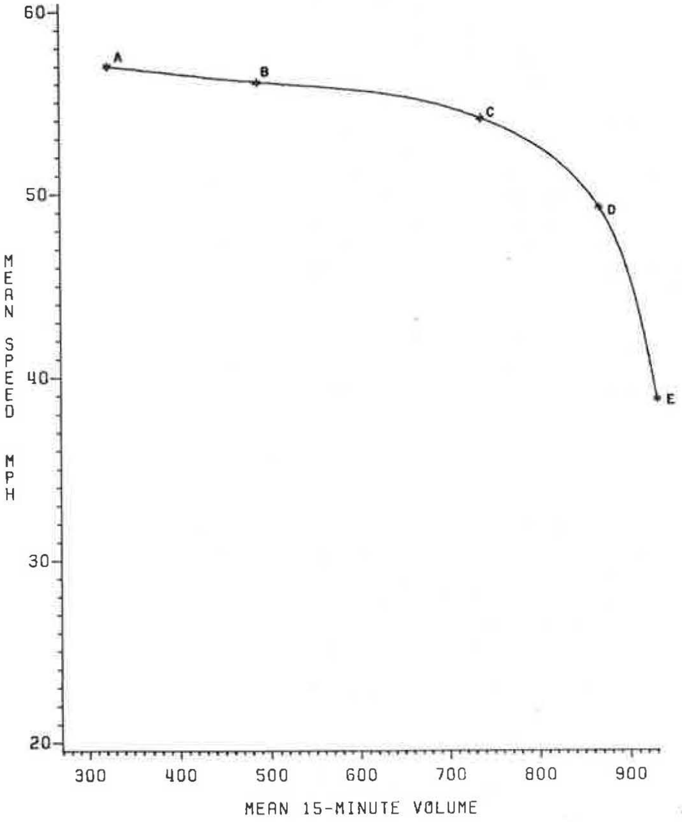

FIGURE 12 Speed-volume relationship with scatter removed.

variables can be masked by the scatter and is often difficult to determine. Figure 4 shows the relationship between speed and volume on freeway sections. The shape of these curves is accepted by traffic engineers as a typical speed-volume relationship with the maximum volume being approximately 2,000 vehicles per hour per lane at a speed of 35 mph. Real speed-volume data from traffic flow studies have the same general shape when graphed as does the ideal speed-volume curve; however, there is a significant amount of scatter associated with the real data. This is evident in Figure 11, which is a scatter diagram showing the speed and volume data collected in this study. Figure 12 shows the same speed-volume relationship after the scatter is removed by calculating the mean values of each variable at each level of service. The curve shown in Figure 12 represents the true relationship between speed and volume for the test sections associated with this study. The shape of this curve is close to the shape of the theoretical curve. Therefore, Figures 8-10, which are based on the mean values of the variables, show the true relationships between the variables. Figures 8-10 show that a strong relationship between acceleration noise and level of service exists, and, furthermore, each relationship can be modeled by the regression equation presented.

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Highlights of the Canadian Capacity Guide for Signalized Intersections

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ABSTRACT

A unified approach to the treatment of capacity-related issues in urban networks has been emerging in Canada during the last 10 years. In 1982 the Executive of District 7 (Canada) of the Institute of Transportation Engineers appointed a committee to develop a series of documents that, eventually, will form a Canadian Urban Transportation Capacity Guide. The committee decided to proceed with the section on signalized intersections as the first task. The main reason for this decision was that the capacity of traffic signals is usually the key factor in all urban capacity considerations, and, as a result, a chapter on signalized intersections was most urgently needed. Moreover, a number of analytical and design procedures related to traffic signals have been tested in the Canadian context in the past decade. Although capacity research and development have been only marginally coordinated in Canada, a common philosophy has been forming, as may be seen in documents prepared in Ontario and Alberta. The first edition of the Canadian Capacity Guide for Signalized Intersections was preceded by three draft versions that were discussed both within and outside the committee. One of the guide's principal objectives is to test the approach and procedures and to elicit comments from users and researchers on a country-wide basis. The objective of this paper is to inform the North American transportation research community about the document and to highlight its philosophy and associated techniques. In essence, capacity analysis is based on a lane-by-lane saturation flow procedure that allows for calibration to local community conditions.

The need for a specifically Canadian document on capacity arises mainly from differences in climate; driver behavior; structure of cities; traditional traffic engineering practices; and political, judicial, and legal systems compared with those of other countries. In addition, it has been recognized that, in a country as vast as Canada, there is a great need for a common philosophy that can accommodate a wide variety of regional issues. Such a philosophy has been forming (1-3).

The objectives of the guide (4) can be detailed as follows:

- To consolidate current Canadian practice and research and to emphasize common features of the techniques used in different regions,
- To make it possible to incorporate parameters specific to a community or region,
- To identify the "missing links" and to focus future development of Canadian practice on a common philosophy,
- To set up the background for such a philosophy, and
- To provide a direction for the future education of users without restricting the development of regional and individual expertise

Although the document should provide basic guid-