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AN EVALUATION OF GREENSHIELDS QUALITY INDEX AND THE ACCELERATION NOISE PARAMETER FOR USE IN SUFFICIENCY RATING PROCEDURES

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ABSTRACT

The Greenshields Quality Index and the Acceleration Noise Parameter were determined for three sections of highway in New Jersey for similar volume groupings. The two methods were analyzed for possible use in a Sufficiency Rating procedure.

Neither method was determined to be satisfactory for use in the Sufficiency Rating procedure. The Quality Index does not readily lend itself to standard statistical analysis and both measures require too large a sample size to be practical for use in a Sufficiency Rating procedure.

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An Evaluation of Greenshields Quality Index and the Acceleration Noise Parameter for Use in Sufficiency Rating Procedures

For many years, engineers have been seeking measures to describe the various interrelated effects of road, driver and traffic conditions. No one measure has been derived that completely explains all of these aspects; however, two measures of fairly recent vintage have been shown to be capable of giving at least partial explanations.

The traffic parameter "Acceleration Noise" which was first discussed by Herman, et al[1] and the "Quality of Traffic Flow"[2] as derived by Greenshields, appear to be tools which may allow the engineer to evaluate or compare roadway sections, taking into account some of these interrelated effects.

Purpose

The New Jersey Department of Transportation is in the process of developing a "Sufficiency Rating" procedure for the New Jersey State Highway System. As part of this study it was decided to utilize the above two measures on three different sections of highway to compare the ratings rendered by the individual measures. The two measures cannot be compared statistically since one measure takes the form of a unitless index number and the other is the root-mean square of the acceleration of a car. (These two methods will be discussed in a following portion of the report.)

To compare the two measures, each route was rated by each measure for the same hourly volume groupings. This allowed for a determination as to whether each rating gives the same or different relative ratings to the individual roadways under similar volume conditions.

Also, a statistical analysis of the acceleration noise parameter was made to determine if there is any significant difference between the rating of each roadway under equal volume groups. For instance, the acceleration noise rating for one roadway under each volume group will be compared statistically with each acceleration noise rating for the other roadways under the same volume grouping to determine if there is a significant difference in the ratings. The average acceleration noise parameters will also be statistically analyzed to determine if there is a difference between these values for different volume groups on the same route.

Study Sites

Three sections of roadway in New Jersey were selected for study. These sections are as follows:

1. Interstate 295

   A 6.8 mile section between Routes 73 and 30 in Camden County was studied. This section is built to interstate standards with 2 - 12' lanes/direction, 10' shoulders and divided by a 40' wide grass median. There are 4 interchanges within the section. This section has full controlled access. The 1967 AADT was 33,000 vehicles, with a 50 percent directional distribution and 12 percent trucks.

2. U.S. 1

   An 11.9 mile section between Route 546 in Mercer County, and New Road in Middlesex County was studied. There are 2 - 12' lanes/direction with 10' shoulders. There are 15 jughandle signalized intersections. The signals are interconnected and progressively timed for a speed of 54 mph. The speed limit is 55 mph. There is a 24" high New Jersey concrete median divider separating the opposing directions of travel. In addition, there are 5 non-signalized intersections. In the northbound direction there are 4.7 private driveways/mile and 3 commercial driveways/mile. In the southbound direction there are 2.7 private driveways/mile and 4.7 commercial driveways/mile. This is considered to be a partially controlled access roadway since turning movements are restricted to intersections due to the median barrier and are handled by means of the jughandles, thus minimizing conflicting movements. The 1967 AADT was approximately 22,000 vehicles, with a 50 percent directional distribution and 18 percent trucks.

3. U.S. 130

A 5.0 mile section between Route 73 and the Camden Airport Circle in Camden County was studied. There are 3 - 11.5' lanes/direction with no shoulders. There are 4 jughandle signalized intersections and 7 four-leg signalized intersections. There is a 24" high New Jersey concrete median barrier separating opposing directions of travel. In the southbound direction there are 15 commercial driveways/mile and 17.9 commercial driveways/mile in the northbound direction. Although turning movements are restricted to jughandle intersections, there is a great deal of marginal friction due to the commercial land use. This section is considered to have a minimum degree of access control. The AADT is approximately 35,000 vehicles, with 50 percent directional distribution. The speed limit is 50 mph and traffic is composed of 17 percent trucks.

Acceleration Noise

The acceleration noise, a traffic parameter, is basically defined as the root-mean-square of the acceleration of a car and measures the turbulence of the vehicle in the traffic stream. This parameter was first discussed by Herman[1] and further developed by Montroll.[3] For the sake of brevity, the development of this parameter will not be discussed here, but a very complete summary may be found in a report entitled, "Developing Traffic Indices for the Detection of High Accident Potential Highways in North Carolina" by C. L. Heimbach, et al.[4]

For this study, the acceleration noise is defined as follows:

If v(t) and a(t) are the speed and acceleration of a car at time t, then the average acceleration of the car for a journey taking time T is

$$a_{av} = \frac{1}{T}\int_0^T a(t)\,dt = \frac{1}{T}[v(T) - v(0)]$$

The acceleration noise σ is defined to be the root-mean square of the acceleration, so that

$$\sigma^2 = \frac{1}{T}\int_0^T a(t)^2\,dt - (a_{av})^2$$

If the car's final speed is the same as its initial speed, then

$$a_{av} = 0 \quad \text{and} \quad \sigma^2 = \frac{1}{T}\int_0^T a(t)^2\,dt$$

In most other cases, the extra term $(a_{av})^2$ is comparatively small and can be neglected.

This can be approximated to

$$\sigma = \sqrt{\frac{(\Delta V)^2}{T} \cdot \sum \frac{1}{\Delta t}}$$

where Δt is time taken for a change, ΔV is speed, ΔV being taken constant throughout the measurement. ΔV for this study was taken as 5 mph. T is the running time which is equal to overall time minus stopped time.

Quality of Traffic Flow

Again, for the sake of brevity, the development of the "quality index" will not be discussed here, but a complete discussion may be found in "Quality of Traffic Transmission" by Greenshields[5] or "Quality and Theory of Traffic Flow" by Greenshields, et al.[2]

The "quality index" is defined by the following equation:

$$Q = \frac{K.S}{\Delta_s \sqrt{f}}$$

where

Q = quality index

S = average speed (mph)

Δ_s = absolute sum of speed changes/mile

f = number of speed changes/mile

K = constant (1000) to avoid small numbers.

In order for a speed change to be considered, its magnitude had to be 5 mph.

Data Collection

The data collection was accomplished by using the average car method. The car was equipped with a traffic data compiler (a graphic recorder) manufactured by the Marbelite Company. A two-man team composed of driver and observer were used for each run. Five different drivers were utilized to minimize the effect of an individual driver. The data compiler gave a continuous graphical recording of speed, speed changes and frequency of speed changes over time as well as total, running and stopped time. Continuous volume counts were taken on each section while the runs were being made.

Fifty runs were made on Route 1 and Route 130 for each direction of travel. Thirty runs for each direction were made on I-295. The analysis of the data combines the directions of travel on each route.

Data Analysis

The directional hourly volumes on each route were grouped into 400 vph groups beginning at 600 vph and extending to 3800 vph. The volume groups are 600 - 999, 1000 - 1399, etc.

The first comparison is to rank each measure (σ or Q) for each route by similar volume groups. For instance, the σ value and the Q value will rank each route for the same volume group. This will allow for a relative comparison of each route under same volume conditions.

The second comparison is to compare statistically the acceleration noise parameter for the same volume grouping, but on different routes. For instance, the average σ value for the 1000 - 1399 volume group on I-295 is compared with the σ parameter for the same volume group on Routes 130 and 1. The method of comparison is to test for a statistically significant difference in averages by use of the Student t Test. This test is discussed in a following section.

The third method of comparison is to compare by the use of the Student t test the difference in average σ values on the individual routes for differing volume groups. For instance, on Route I-295, the σ value for each volume group will be compared statistically with every other volume group on that route to determine if there is a significant difference in the values.

Statistical Test

The Student t test was used to determine if the average values of σ on one route are equal to their corresponding values on the other routes under similar volume groupings.

The Student t test is a standard statistical test used to test the hypothesis that the means of two normal distributions are equal. A discussion of the test may be found in "Engineering Statistics" by Bowker, et al.[6] The equation utilized in the test is:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}}$$

where

$\bar{X}_1$ and $\bar{X}_2$ = the mean values of σ for each route.

n_1 and n_2 = the number of test runs to determine $\bar{X}_1$ and $\bar{X}_2$

S_1 and S_2 = the standard duration of $\bar{X}_1$ and $\bar{X}_2$

Since the data are obtained from different populations and the standard deviations are not necessarily equal, the associated degrees of freedom were determined from the following formula:

$$v = \frac{(S_1^2/n_1 + S_2^2/n_2)^2}{\frac{(S_1^2/n_1)^2}{(n_1 + 1)} + \frac{(S_2^2/n_2)^2}{(n_2 + 1)}} - 2$$

where

v = associated degrees of freedom and the other terms are the same as in the previous equation.

The .05 level of significance was used in all tests.

Results

Table 1 which shows the relative ratings by volume groups for σ and Q values indicates that the two rating methods agree for all similar volume groups. In all cases, the σ value is lower (better) for Route I-295 than either Route 1 or Route 130. When all three routes have equal volumes, Route 1 is always second, and Route 130 is third.

From the same Table, it can be seen that the same is true for the Q value. In all cases, for equal volumes, the Q value is higher (better) for Route I-295 than either Route 1 or Route 130. Route 1 is second and Route 130 third when all three routes have equal volumes.

Having driven the three routes and knowing the characteristics of geometrics, marginal friction, etc., this is certainly a logical relative rating.

Table 2 shows the ratings for individual routes for each volume group for each rating method. Route 1 shows the only consistent pattern of ratings. Here, both the σ and Q values give a worse rating with increase in volume groups. There appears to be no definite pattern for either the individual ratings for the same route or for comparison of different (σ or Q) ratings for the same route as far as Routes I-295 and 130 are concerned.

Up to this point in the study, only relative ratings have been considered. Although the ratings may appear to give logical results, it will become apparent that significant problems exist.

Table 3 shows a breakdown of average Q values and their sample size for each route in each volume group.

First, an analysis of the distributions of the Q values on all three routes indicates that the distributions are not normal, and the "t" test to analyze significant differences in mean values is not applicable. The Q distributions are skewed to the right in all cases. This is due to the nature of the equation for Q values and the distribution, if adequate samples are taken, will always be skewed to the right.

It also appears that the average Q ratings may be misleading from a relative standpoint. For instance, on a route such as I-295, where changes in speed are very infrequent and where the magnitude of change is usually small, one change in frequency and a small change in magnitude give a large relative difference in the Q value. As an example, if we assume that the S value is 60 mph and that for a one-mile section the frequency of changes (f) is 1, the magnitude (Δs) is 5 mph, then the Q value is

$$Q = \frac{1000 \times 60}{5 \times \sqrt{1}} = \frac{60000}{5} = 12000$$

whereas, if the S value remains at 60 mph and the frequency changes to 2 and the magnitude to 10 mph, then the Q value becomes

$$Q = \frac{1000 \times 60}{10 \times \sqrt{2}} = \frac{60000}{14} = 4290$$

this value is less than half of the previous value, yet only one additional speed change of 5 mph was made.

Now, if we look at the Q value on a section of road where many changes of speed are made, we find a different case.

If many speed changes are made, then S will probably decrease since it is determined from distance divided by travel time.

Therefore, if we assume S is 30 mph and f is 25 and Δs is 180 mph, Q becomes

$$Q = \frac{1000 \times 30}{180 \times \sqrt{25}} = \frac{30000}{900} = 33$$

and if we double the f to 50 and double the Δs to 360 mph and let S be 25 mph, Q becomes

$$Q = \frac{1000 \times 25}{360 \times \sqrt{50}} = 9$$

It first appears that there would certainly be an appreciable difference between the 12,000 and 4,290 values and perhaps not between the 33 and 9 values.

Yet, from a realistic standpoint, it is possible that a driver would not notice the additional 5 mph change on the

60 mph roadway, whereas he may be quite concerned with the doubling of frequency and magnitude of changes on the 25-30 mph road.

It appears that the Greenshields Quality Index is not satisfactory for routes of the nature studied since relative rating may be misleading and since it does not lend itself to standard statistical tests to determine significant differences in mean values.

Table 4 shows a breakdown of average σ values, their standard deviation and sample size for each route in each volume group.

The distributions of the σ values appeared normal and therefore lends itself to standard statistical testing.

The acceleration noise method does appear to be capable of realistically rating the separate routes for equal volume groups and also for rating different volume groups on the same route.

From a driver's standpoint, there appears to be little noticeable difference in traveling Route I-295 in any of the volume groups. The test for difference in σ values indicates that statistically there is no difference. Also, there would appear to be a difference from the driver's standpoint in travelling Route I-295 and Routes 1 or 130. Statistically, there is a significant difference.

Of the two methods, it would appear that the acceleration noise method would give results that are more satisfactory for rating methods since they are subject to standard statistical tests.

However, when the purpose of the rating is considered, that being its use as a portion of a Sufficiency Rating procedure, it becomes apparent that it is not practical. A relatively large number of runs would be necessary on each section rated when the entire state highway system is considered.

Conclusions

Both methods, the acceleration noise and Greenshields Quality Index, appear to measure parameters that are representative of the "comfort or convenience" of a route. However, the Q value appears to be misleading when the differences in average Q values are analyzed on different routes. A large difference in Q values on one route between different volume groups may be meaningless from the practical standpoint, whereas a relatively small difference in Q values on another route between different volume groups may be meaningful. It also does not lend itself to standard statistical tests.

The σ value does lend itself to standard statistical tests and appears to be a satisfactory rating method. However, the sample sizes necessary to evaluate the entire system of roadways analyzed in a sufficiency rating study become too large to be practical.

Many other problems enter into the use of these measures as a rating procedure within a sufficiency rating. However, they are beyond the scope of this study and will not be discussed here.

A P P E N D I X

TABLE 1

Relative Ranking of σ and Q Values for
Each Route with Equal Volume Groups

Directional Hourly Volume Group	Rt. I-295		Rt. 1		Rt. 130	
	σ	Q	σ	Q	σ	Q
600- 999	1	1	2	2	-	-
1000-1399	1	1	2	2	3	3
1400-1799	1	1	2	2	3	3
1800-2199	1	1	-	-	2	2
2200-2599	1	1	-	-	2	2
2600-2999	1	1	-	-	-	-
3000-3399	1	1	-	-	-	-
3400-3799	1	1	-	-	-	-

TABLE 2

Relative Ranking of σ and Q Values for Each Individual Route Regardless of Volume Groups

Directional Hourly Volume Group	Rt. I-295		Rt. 1		Rt. 130	
	σ	Q	σ	Q	σ	Q
600- 999	7	5				
1000-1399	1	1	1	1	-	-
1400-1799	2	2	2	2	2	2
1800-2199	3	4	3	3	4	3
2200-2599	4	3	-	-	1	1
2600-2999	6	8	-	-	3	4
3000-3399	5	6	-	-	-	-
3400-3799	5	7	-	-	-	-

TABLE 3

Q Values

Directional Hourly Volume Group	Route 1		Route 130		Route 295	
	Avg. Q	# Runs	Avg. Q	# Runs	Avg. Q	# Runs
600- 999	1637	77	-	-	10155	7
1000-1399	895	10	417	32	27895	9
1400-1799	707	14	298	40	16576	18
1800-2199	-	-	443	15	11908	9
2200-2599	-	-	288	16	16294	8
2600-2999	-	-	-	-	8867	4
3000-3399	-	-	-	-	9731	3
3400-3799	-	-	-	-	9573	6

TABLE 4

σ Values

Directional Hourly Volume Group	Route 1			Route 130			Route 295		
	Avg. σ	Std. Dev.	# Runs	Avg. σ	Std. Dev.	# Runs	Avg. σ	Std. Dev.	# Runs
600- 999	1.28	.465	77	-	-	-	.41	.209	7
1000-1399	1.54	.292	10	1.60	.435	32	.23	.160	9
1400-1799	1.58	.338	14	1.86	.469	40	.24	.124	19
1800-2199	-	-	-	1.50	.377	15	.31	.201	12
2200-2599	-	-	-	1.81	.286	16	.34	.168	8
2600-2999	-	-	-	-	-	-	.38	.109	4
3000-3399	-	-	-	-	-	-	.37	.093	3
3400-3799	-	-	-	-	-	-	.37	.181	6

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