Effect of Expressway Design on Driver Tension Responses

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This study was an attempt to use the galvanic skin response technique to differentiate among the characteristics of four different expressway designs under different volume conditions. Six test subjects drove an 8- to 10-mi section of each highway four to eight times and events causing a speed or placement change were recorded. Only GSR aroused by the observed events was analyzed. The data were broken down by routes, volume, type of conflicts, and subjects. Using the analysis of variance it was found that there were significant differences among the designs on both design and traffic characteristics. Correcting for volume it was found that the Interstate design highway generated the lowest GSR rate relative to traffic interferences with the parkway and divided highway with only partial control of access generating the highest. On interferences related to design features, however, the Interstate design yielded the highest GSR rate. One reason for this reversal appears to be the higher speeds on the Interstate System.

This relation between GSR rate and volume was statistically reliable, showing a linear change up to volumes of 1,400 vehicles per lane per hour. For volumes greater than that, the GSR rate rose exponentially up to the maximum volume of 1,800 vehicles per lane per hour.

The results indicate that the GSR rate is directly related to the frequency of interferences and their relative predictability up to the point where the information load becomes excessive. At this point tension increases very rapidly. Also, the data indicate that modern highway design eliminates a large part of the major traffic conflicts. However, this reduction apparently leads to an increase in speed, which causes increased tension arousal from interaction with the physical characteristics themselves. Thus, GSR rate on highway interferences is higher on the highway of the most modern design.

• IN A PREVIOUS study (1) the galvanic skin response (GSR) was used to differentiate between two urban arterial streets. This study indicated that driver responses could be used as a means of discriminating between different types of city streets. The present study was an attempt to apply this technique to different types of expressway design to see if it were possible to discriminate among them and also to relate this to other types of highways.

Here the interest lay in two classes of tension-inducing events that may arise on expressways. The first are traffic interferences very similar to those encountered on urban streets. The second are those events associated with the interferences caused by geometric design features of the highways. There is considerable evidence for the superiority of expressway design over older or less highly controlled types of highway design. However, it is still a rather moot point whether there are differences among the various philosophies of design that are being proposed for controlled access highways. It was the basic aim of this study to differentiate among different designs using driver tension as a measure.

In the Washington metropolitan area, it was possible to find expressways of considerably different designs. These, in part, are distinguishable on the basis of age as well as their design features and speed. For this study, four different expressway

TABLE 1

DRIVING INTERFERENCES

Event No.	Name	Description
1	Instream vehicles	Conflicts caused by vehicles traveling in same direction.
2	Merging or crossing vehicles	Position or speed change caused by vehicles converging on test car.
3	Exiting vehicles	Position or speed change caused by vehicles diverging from traffic stream.
4	Gradient	Change in speed or position due to grade.
5	Curvature	Change in speed or position due to curvature.
6	Pavement changes	Position or speed change caused by variations in highway surface.
7	Shoulder objects	Position of speed change caused by shoulder objects such as cars or abutments.
8	Pedestrians	Changes caused by conflicts with pedestrians or animals.

designs were selected. One was built specifically to Interstate standards and is an Interstate route with a design speed of 70 mph. Another is a 15-year-old parkway with a design speed of 50 mph designed to standards that are considerably less rigorous in terms of both curvature and grade than are presently acceptable in flat or rolling terrain for Interstate highways. The third is an intermediate highway in terms of both age and design criteria. It is a 10-year-old urban freeway with relatively modern curvature and grade characteristics and a design speed of 70 mph. Its weakness lies in the substandard design of the acceleration and deceleration lanes. The fourth route was an expressway with geometric design quite comparable to that of the Interstate except that the magnitude of grade and curvature is somewhat higher than used for the Interstate route. The main difference is that it has only partial control of access, at least in the section under study. There are crossovers in the median as well as several at-grade intersections. Furthermore, there is a frontage road over a good portion of the route with commercial establishments being given access to the frontage road at a variety of points and the frontage road connections to the expressway are substandard. Thus, these four routes represent considerably different freeway designs although none of them may be considered extreme in any sense.

In general, then, the present study was an attempt to (a) differentiate among the four different types of expressway designs; (b) examine the tension responses generated on these expressways as a function of design characteristics, traffic interferences, and more generally in terms of traffic volume; and (c) relate these results to other types of highways.

PROCEDURE

Sections of the four test routes were chosen, all of which were approximately 8½ mi long. Generally, these were sections that were closest to the Washington area. Two of the routes had a relatively low volume; that is, less than 500 vehicles per hr in two lanes during daylight hours, and they had no appreciable peak hour. Consequently, only off-peak hours, running from 10 a.m. to 3 p.m. were studied. The other two routes, however, did have very definite peak periods and were, in fact, important routes for work trips into Washington. For these two routes, runs were made not only during the same off-peak hours as the other two but also during both the morning and evening peak hours. The times run on the latter two routes were adjusted to cover the maximum traffic load period. Volume counts were made on these two routes during the off-peak and peak hours before beginning the study so that the GSR data could be related to volume.

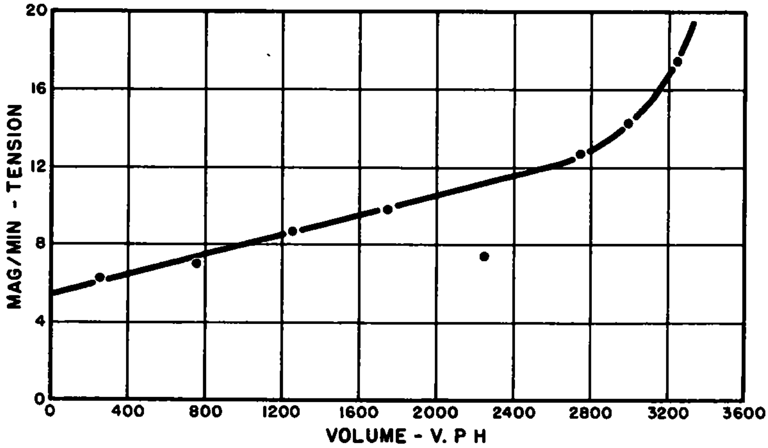

Figure 1. Effect of volume on tension responses.

Six test subjects were used. All were male ranging in age from 17 to 22 years. Two of the six had had previous experience in using the GSR and were fairly familiar with the plan of the study and the operation of the instrument. The six were broken into two teams of three drivers each.

The procedure followed in the present study was essentially the same as that used in the study of urban arterials (1). A standard passenger car with automatic transmission was used. Three people were in the test car during all the runs. Each member of this three-man team served as driver, observer, and data recorder. The observer sat in the front seat with the driver. Whenever there was a change in placement or speed of the test vehicle, caused by interferences from traffic or from the characteristics of the highway, the cause of the change was defined by the observer and was recorded on the GSR record by the data recorder. The interferences causing changes in venicle speed or position were coded into eight categories, four of which were traffic related and four of which were design related. The list of interferences are given in Table 1, Nos. 4 through 7 being related to highway features and the rest to traffic.

For the runs, electrodes were fixed to the first and third fingers of the driver's left hand. The sensitivity level of the GSR was adjusted to a point where a shock stimulus presented by the observer would give a full-scale deflection of the recorder pen. Once adjusted, the sensitivity was not changed while the particular driver was making his runs. The test driver drove the test route in one direction and then took a short break before returning in the opposite direction. Approximately 8½-mi sections were used, and the travel times ranged from 8 to 12 min. All six subjects drove each of the four routes 12 times for both off-peak and peak hours except for the two routes that had no peaks.

RESULTS

All the data were recorded on chart paper on which was not only the GSR information but also all the pertinent data about the route and the drivers. The only GSR data that were analyzed were those associated with the interferences shown in Table 1. Thus, this study concerned itself with only the galvanic skin response aroused by the specific, observable interferences. The basic measure of tension was defined as the magnitude of GSR per unit of time. This measure equalizes the routes for differences in either length or more generally running time. Furthermore, the use of this rate measure tends to make the distribution of the GSR more symetrical than when GSR magnitude is employed.

Of fundamental interest was the relationship between tension responses and the traffic volume. Over all four routes volumes ranged from approximately 300 to 3,500

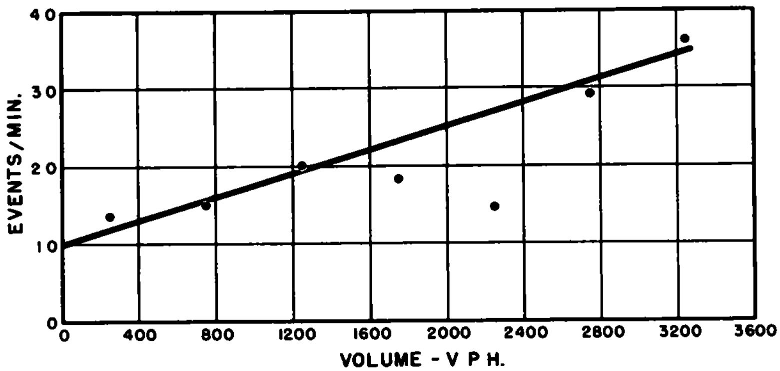

Figure 2. Effect of volume on the rate of occurrence of interferences.

vehicles per hour in two lanes. Data for all routes were combined according to volume. The curve of tension responses vs volume is shown in Figure 1. This curve includes tension responses only to traffic-caused interferences and not those caused by design characteristics. Thus, this relationship shows the effect of only traffic interferences on tension. It may be seen that there is a direct relationship between tension and volume. The relationship seems to be quite linear up to about 2,400 vehicles per hour in two lanes, and then the rise in tension appears to increase exponentially. These data were also analyzed by the subjects individually and the same general form of the curve was found for all.

A two-way analysis of variance was done on these data. In addition, an analysis of the trend of tension with volume was carried out. The summary is given in Table 2. The interaction term was found to be insignificant and was pooled with the residual. The results indicate a significant difference both among drivers and among volumes at better than the 0.01 level. In addition, the quadratic as well as the linear component of trend is significant at 0.01 level. Thus, the form of the curve shown in Figure 1 appears reliable.

One basic question in the use of the GSR concerns whether it is measuring something more than simply the frequency of occurrence of the interferences. Thus, if the same function defines the relation between interferences per unit time and volume as that which holds for tension and volume then the same results will be available simply by counting the number of changes in vehicle speed or placement. To examine this, the number of traffic interferences per unit time as a function of volume was calculated. The data are shown in Figure 2. An analysis of variance was carried out on the events per minute data the same as that for the tension responses. The summary is given in Table 3. Here, as in the previous analysis, differences among the two major variables are significant. The linear trend among the volumes is also significant at the 0.01 level but the quadratic component does not reach significance at this level. Thus, the straight line relation shown in the figure is the best fit to the data. From these two analyses it seems reasonable to conclude that the traffic interferences induce a greater behavioral response than is indicated simply by their frequency of occurrences. Thus, the GSR may be a behavioral measure of the operational efficiency of a highway, and also may be a measure of practical capacity of a highway.

Discrimination Among the Highways

The average magnitude of response per minute was determined for each subject, for each route, for the four traffic events during the off-peak hours. These data were subjected to an analysis of variance, given in Table 4. It may be seen that there are no significant differences between the directions (inbound vs outbound). There are significant differences, however, among subjects and also among the four routes.

Ordering the tension data according to highway, the highway built to Interstate standards generates less tension for each of the six drivers than do the other three highways.

TABLE 2

SUMMARY OF ANALYSIS OF VARIANCE ON TENSION CAUSED BY TRAFFIC VOLUME

Source of Variance	Sum of Squares	D F	Mean Square	F
Between subjects	2,034 38	5	406 88	25 70[a]
Between volume	2,865 04	5	573 01	36 20[a]
Error	1,535 76	97	15 83	—
Total	6,435 18	107	—	—
Linear trend	1,705 45	1	—	107 73[a]
Quadratic trend	117 72	1	—	7 44[a]

[a]Significant at the 0 01 level

TABLE 3

SUMMARY OF ANALYSIS OF VARIANCE ON FREQUENCY OF EVENTS CAUSED BY VOLUME

Source of Variance	Sum of Squares	D F	Mean Square	F
Between subjects	15 99	5	3 20	4 77[a]
Between volume	79 87	5	15 97	19 72[a]
Error	78 16	97	0 81	—
Total	174 02	107	—	—
Linear trend	70 15	1	70 15	86 60[a]
Quadratic trend	4 47	1	4 47	5 52

[a]Significant at the 0 01 level

However, this ranking includes differences in tension due to traffic volume. The urban freeway always carried, even during off-peak hours, three to four times as much traffic as did the other routes. To eliminate the effect of volume, a correction was applied using the data shown in Figure 1. All of the tension responses were corrected by multiplying them by a weight that was the ratio of tension at a volume of 500 vehicles per hour to that at 1,250 vehicles per hour. With the data so corrected, an analysis of variance was performed and, as before, a significant difference among the routes was found. Now, the ranking of the four routes was still reliable but the lowest level of tension was found on the urban freeway, followed by the Interstate route, parkway, and the freeway with only partial control of access.

The data were also analyzed to determine the effects of highway design interferences for the off-peak hours. Analysis of variance was done for the highway interferences just as for the traffic interferences. The results, given in Table 5, show significant effects among the drivers and routes.

Significant rank order among the highways was also found, which from the lowest to highest tension induction was urban freeway, parkway, freeway with partial control of access, and Interstate route.

Average Magnitude of Response for Each Event

Analysis was made of the average magnitude of GSR among the eight driving interferences. Rather than analyzing the average magnitude of GSR themselves, a rank test was employed. Such a test is weak but it avoids the necessity for meeting the distributional assumptions that would be required for stronger normal tests. The ranks were compared for each route with the test drivers considered as replicates. A summary of the four routes is given in Table 6 with the significance of the rank order. The Interstate route has a ranking among the events that is significant at the 0.01 level, and the parkway one that is significant at the 0.07 level. A further comparison was made on the rankings of the events on the four routes, combined. This was found to be significant at better than the 0.01 level.

The ordering among the eight different driving interferences indicates quite clearly that the traffic interferences consistently generate the highest magnitude of GSR. The highest average magnitude occurs for merging vehicles, and then secondarily, for both instream conflicts and exiting vehicles. Among the highway characteristics, the most tension inducing interference occurs with changes in the pavement characteristics followed quite closely by tension aroused during negotiation of curves.

Frequency of Occurrence of Events

The importance of the rankings of the average magnitude of the GSR previously described is meaningful in part according to the frequency with which these interferences actually occurred. Further analysis of the distribution of the occurrence of the interferences was carried out. The distributions for the four highways are given in Table 7. Here, the data for all subjects were combined. As the table shows, two interferences account for approximately 70 percent of all the driving interferences on all the routes: instream traffic interferences and negotiation of curves.

The differences given in the table indicate that on the urban freeway, instream interferences are considerably greater than the changes in curvature. This is to be expected from the relatively high volume of traffic that occurs even during the off-peak hours on this route. On the parkway, however, this pattern is reversed. This indicates the greater frequency and higher degree of curvature that occurs in this type of highway design. Further, this occurs even though the volume is greater on the parkway than on the remaining routes. This also indicates that the differences are due to design characteristics.

The eight interferences were broken into two groups: one involving traffic and the other highway features. The frequency of occurrence for the two groups is given in Table 8. Inspection shows that there is considerable similarity among the four routes. The major difference occurs in the parkway which demonstrates the sharp increase in the interferences due to highway curvature over and opposed to the other three routes.

The data on the distribution of traffic interferences given in Table 8 indicate that instream conflicts are the dominant type of interference that occur for drivers on freeways. All the routes are consistent during the off-peak hours running between 90 and 95 percent of all interferences. Also, Table 8 gives the proportion of all the observed events that are due to traffic interferences. The high-volume urban freeway has more than one-half due to traffic interferences while the Interstate highway has approximately one-quarter of its interferences caused by traffic.

TABLE 4

SUMMARY OF ANALYSIS OF VARIANCE OF TENSION RESPONSES CAUSED BY TRAFFIC EVENTS

Source	Sum of Squares	D F	Mean Square	F
Subjects	1,122 6	5	224 52	11 79[a]
Routes	468 0	3	156 0	8 19[a]
Direction	32 5	1	32 50	1 71
Routes and subjects	300 6	15	20 04	1 05
Direction and routes	118 5	3	39 50	2 07
Direction and subjects	64 7	5	12 94	—
Error	4,858 8	255	19 05	—
Total	6,965 7	287	—	—

[a]Significant at the 0 01 level

TABLE 5

SUMMARY OF ANALYSIS OF VARIANCE OF HIGHWAY FEATURES (4-7)

Source	Sum of Squares	D F	Mean Square	F
Subjects	2,416 4	5	483 3	26 6[a]
Routes	1,592 5	3	530 8	29 2[a]
Direction	95 4	1	95 4	5 2
Routes and subjects	1,564 6	15	104 3	5 7
Direction and routes	19 1	3	6 4	—
Direction and subject	243 1	5	48 6	2 7
Error	4,633 2	287	18 2	—
Total	10,564 3	255	—	—

[a]Significant at the 0 01 level

TABLE 6

RANK ORDER OF AVERAGE MAGNITUDE OF GSR GENERATED BY THE INTERFERING EVENTS FOR EACH ROUTE[1]

Rank[2]	Interstate	Urban Freeway	Parkway	Partial Control	All
1	2	2	2	3	2 (merging vehicles)
2	1	3	3	1	1 (instream vehicles)
3	7	1	1	2	3 (exiting vehicles)
4	6	5	6	8	6 (pavement)
5	5	6	7	6	7 (shoulder objects)
6	3	8	5	5	5 (curvature)
7	4	4	4	4	4 (grade)
8	8	7	8	7	8 (pedestrians)
Reliability	P<0 01	P<0 15	P<0 07	P<0 11	P<0 01

[1]For definition of events, see Table 1
[2]Ordering is from highest average GSR to lowest

Tension Induction on Freeways as Compared to Urban Arterials

Data were also available for two of the six subjects for the same urban arterial as studied previously (1). The data are, however, restricted to traffic interferences and do not reflect highway features. Table 9 gives a comparison of the high-type expressway, a parallel four-lane highway without control of access or grade separation, and the urban arterial. Tension increased greatly from expressway to the arterial; the ratios are shown in the last column of the table. These results indicate the superiority of controlled-access design in reducing these types of interferences.

DISCUSSION

The results of the study indicate that the GSR discriminates among different types of expressway design. Even though the actual differences among the designs of the four expressways used in this study were relatively small and all four expressways were in

TABLE 7

PERCENTAGE DISTRIBUTION OF INTERFERING EVENTS FOR THE TEST ROUTES—OFF-PEAK DATA

Event	Distribution (%)							
	Interstate		Urban Freeway		Parkway		Partial Control	
	In	Out	In	Out	In	Out	In	Out
1	21.0	24.0	48.4	51.9	29.4	28.3	30.7	31.3
2	0.8	0.7	2.4	1.2	1.7	1.1	2.6	2.2
3	0.5	0.3	0.4	0.9	0.8	1.4	0.9	1.0
4	23.9	26.8	11.2	12.9	8.0	11.3	17.2	18.0
5	37.4	39.1	26.3	22.3	43.7	41.9	37.2	38.8
6	11.9	3.9	5.5	5.2	6.2	6.2	9.0	5.5
7	2.3	1.8	0.2	0.8	0.5	0.7	1.0	0.8
8	0.2	0.2	0.1	0.4	0.8	0.5	0.6	0.2

TABLE 8

PERCENTAGE DISTRIBUTION OF INTERFERING EVENTS FOR HIGHWAY AND TRAFFIC SEPARATELY-OFF PEAK HOURS

Route		Highway Events (%)				Traffic Events (%)				Percent of Total That Are Traffic Events
		4	5	6	7	1	2	3	8	
Interstate	In	31.7	49.5	15.8	3.0	93.0	3.8	2.3	0.9	23.0
	Out	37.4	54.5	5.5	2.6	95.5	2.7	1.1	0.7	26.0
Urban Freeway	In	25.9	60.9	12.7	0.5	94.3	4.7	0.9	0.1	54.4
	Out	31.2	54.2	12.6	1.9	95.4	2.2	1.7	0.7	56.9
Parkway	In	13.8	74.9	10.5	0.8	89.8	5.2	2.4	2.6	35.9
	Out	18.8	69.7	10.3	1.1	90.5	3.6	4.5	1.4	34.2
Partial Control	In	26.7	57.7	14.0	1.6	88.4	7.4	2.5	1.7	35.1
	Out	28.5	61.5	8.7	1.2	90.2	6.3	2.9	0.7	35.5

good operating condition, there were significant differences among them in terms of tension responses. The differences relative to the two classes of driving interferences demonstrate the effects of the designs.

For traffic interferences, the urban freeway and the Interstate route were significantly less tension inducing than the other two highways. Actually, for the through driver both of these roads are quite comparable, for the urban freeway had geometric design characteristics that met Interstate standards over almost all of the study section. Its deficiencies as a highway had to do with marginal characteristics such as shoulders and ramps. Thus, when equated for volumes, the two routes are quite similar. The results indicate that as far as the frequency and magnitude of traffic conflicts, highways designed with complete control of access are clearly superior to those in which less

TABLE 9

TENSION GENERATED ON THREE DIFFERENT TYPES OF HIGHWAYS

Type of Highway	Tension (max/min)			Ratio of Tension on 3 Routes to Tension on Expressway		
	Driver A	Driver B	Avg.	Driver A	Driver B	Avg.
Controlled access	5.7	5.5	5.6	1.00	1.00	1.00
Uncontrolled primary	10.8	8.8	9.8	1.89	1.60	1.75
Urban arterial	13.9	23.5	18.7	2.44	4.27	3.34

rigorous designs are employed. There is little question that control of access eliminates much of the marginal conflict for the through driver. In this respect, it is interesting to contrast the Interstate route with one of similar design but with only partial control of access. The latter is consistently the most tension-inducing route. The major difference between this and the low-tension-inducing routes is an increase in the frequency of occurrence of conflicts with merging and exiting vehicles; that is, marginal interferences. This point is further shown in comparisons with the primary and urban arterial. These routes generate around 30 percent of their conflicts from marginal interferences whereas the high-type expressway generates less than 10 percent.

There is, moreover, a similar but more subtle interaction on the parkway. Here the tolerance of high curvature and gradient interact with the traffic interferences to increase the level of tension for drivers. As far as handling the conflicts in traffic, the driver has increased difficulties when he must also cope with rather large changes in the geometrics of the highway itself.

These relationships among the highways lend support to the hypothesis proposed previously (1) that one of the basic determinants of driver tension is the degree of predictability that exists in the driving environment. It is apparent from the present study that under high-volume conditions the driver is interacting with vehicles around him and must condition his performance to his expectations of what other vehicles are doing, and will do. In general, he does not have enough information to develop stable or reliable predictions about the activities of these other vehicles. In the case of a highway with only partial control of access, his problem is confounded by the increase in marginal activity, especially with both entering and exiting interferences involving large angular closing rates. Thus, increasing volume, increasing marginal activity, and finally, increasing variations in the highway itself all act to increase the complexity of driving. These, in turn, make it more difficult for the driver to develop stable predictions about his driving environment.

The results of the rankings of the routes for the highway features are rather anomolous. The Interstate route which operates well relative to traffic interferences generates the highest tension of all the routes on the highway interferences. The resolution of this paradox may well be due to differences in travel speed among these highways. Examination of the travel time for the test subjects indicated that the travel speed on the Interstate route averaged between 60 to 65 mph, whereas on the urban freeway it was near 50 mph, and on the parkway it was near 40 mph. Thus, there is a systematic difference among these roads in terms of the speed that drivers adopt.

The fact that speeds did increase would indicate that where traffic interferences are infrequent either because of low volume or by improved design, drivers compensate by traveling faster. In other words, drivers tend to make their speeds contingent on the perceived complexity of the driving situation. In effect, the design of the Interstate route permits the driver to increase his speed and he does so to the point where the characteristics of the highway (that is, curvature, grade, and pavement condition) begin to affect his operation of the vehicle. This would suggest that drivers adopt some kind of critical level of tension in driving.

In these terms, tension induced in driving may well represent one mechanism by which the driver can stabilize the system. That is, by driving at or near the speed at which tension responses increase sharply, the driver is able to determine qualitatively an upper limit to his control over the driving situation. This kind of criterion will be applicable to interferences due either to traffic or highway conditions, or both. When traffic conditions are such that the driver is subject to considerable stress, he will reduce his speed, thereby decreasing the frequency of tension inducing stimuli. When traffic is not a factor then he utilizes the highway characteristics, driving sufficiently fast to get information back from the road itself to give him a measure of performance.

The results of this study also bear on the problem of comfort and convenience. For many years it has been known that drivers' choices among alternative routes could not be accounted for on the basis of economy of operation or of time alone. It has been necessary, therefore, to postulate the additional factor of comfort and convenience. The basic problem with such a construct is to develop an operational definition that will make it measurable. Difference in tension responses on different highways may represent one avenue for resolving this problem.

The sample of data in this study indicates that there is twice as much tension generated on a highway that is an alternate route for an expressway than on the expressway itself. Furthermore, for traffic interferences, nearly 30 percent arose from marginal conflicts on the uncontrolled route whereas less than 10 percent arose on the expressway. For instream conflicts, however, there was little difference in tension generated; however, there were fewer of them on the expressway. Thus, there appears to be two major factors that account for the differences in tension between the expressway and the parallel, uncontrolled route: (a) proportion of marginal interferences; and (b) frequency of instream conflict. Such a breakdown suggests a logical distinction between comfort and convenience. Thus, what is called the "comfort" of a route may be defined as the tension caused by unpredictable conflicts. Route comfort may be considered in terms of the predictability of the interferences, and this appears to be measurable using the GSR.

Convenience may be defined as the degree of freedom that a driver has in setting the level of performance of his own system. Elements in the route that restrict the driver or force conformity to external controls would make that route inconvenient. Thus, for example, a wide variety of traffic control devices are generally predictable, but they force the driver to make control changes that may conflict with both the operation of his system and his driving objectives. Similarly, interaction with other vehicles in the traffic stream are frequently predictable (at least at moderate volumes) yet they restrict the driver's freedom of action. The relation between tension and traffic volume, shown in Figure 1, breaks sharply around 2,800 vehicles per hour or an average of 1,400 vehicles per lane per hour. This may represent the point at which the traffic situation becomes highly unpredictable. In terms of this discussion this would be the point where driving changes from being inconvenient to being uncomfortable.

Because the data show only small differences in average GSR among the instream events, it is quite possible that the frequency of occurrence of the events alone may be an adequate measure of convenience. Claffey (2) used such a measure in his studies of comfort and convenience, but made no distinction between the two factors.

It is difficult to determine the weighting of the two factors to fit some route choice equation. However, using the GSR as an over-all measure of both factors, the data in Table 9 show that the noncontrolled primary route was 1.75 times more tension inducing than the expressway and the arterial about 3.34 times. The subjective responses to the three routes reported by the subjects indicate that they subjectively evaluated the route in a direct but nonlinear relation with tension; that is, their dislike of a route increased more rapidly than tension increased. Considerable research is required to verify this relation and one determining choice among alternative routes.

The comparison of expressway designs with other types of roadways is quite clear in showing the superiority of modern highway design. These modern designs show that almost all traffic interferences are eliminated except those within the traffic stream itself. Thus, even under the highest volume conditions modern freeway design helps to restrict the kind of conflicts with which the drivers must deal to those that are easiest for him to resolve efficiently. However, this study also indicates that modifications in highway design alone may not necessarily increase over-all system stability.

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