FREEWAY CURVE ANALYSIS

TSD-G-102-69

TRAFFIC and SAFETY DIVISION

DEPARTMENT OF STATE HIGHWAYS
STATE OF MICHIGAN

FREEWAY CURVE ANALYSIS

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Abstract

KEY WORDS: Accident Rates, Alignment, Curvature, Evaluation, Freeway Driver, Geometric Design, Highway Curves, Psychological Effects.

ABSTRACT: An analysis of the accident records for a portion of I-94 revealed that horizontal curves sharper than 2°00' experienced significantly high accident rates, compared to tangent sections, while those flatter than 0°31' had significantly low rates. There was a sharp increase in the rates of both the curves and the tangents at interchanges. The study also revealed that there are certain characteristics of curves that cause adverse reactions on drivers. The prime complaints were; curve too sharp, lack of sight distance, and obstacles appearing to be in the roadway. The study recommends that the maximum allowable curvature be reduced, with greater use being made of long, flat curves with long clear vision distance.

REFERENCE: Mercer, Donald J., Freeway Curve Analysis, Michigan Department of State Highways Report TSD-G-102-69, Lansing, Michigan, August 1969.

Introduction

PURPOSE OF THE STUDY

The driving public has complained that some of the horizontal curves on Michigan's freeways are uncomfortable and seem unsafe at freeway speeds.

This study investigates the accident history of one of those freeways, I-94, to determine if the curves are more hazardous than the tangents and evaluates the curves on all of the freeways to determine if they do, in fact, cause driver apprehension, all with the intention of improving design criteria. Only the freeway lanes are considered; the interchange ramp curves and ramp accidents are not included, since ramp alignment is not typical of freeway lanes.

Design criteria is constantly being improved. For example, during World War II the Michigan Department of State Highways designed the Detroit Industrial Expressway at what was then considered to be 100 mph standards; now this road is to be virtually rebuilt to meet modern standards for 70 mph. Early design features, such as narrow medians, at-grade railroad crossings, at-grade intersections, barrier curb at underpasses, and wing walls at the edge of the shoulder, are no longer accepted in rural freeway design. These improved standards resulted from observing the effects that alignment, grade, and geometrics have on traffic flow and safety.

About one-fourth of Michigan's freeway mileage involves a change in horizontal alignment, using curves of some definite degrees and lengths. By observing how successful the motorists are at negotiating these curves, this study will suggest improvements in current design practices.

APPROACH USED

The data for this study was obtained from the three-year (1964-66) accident records of 200 miles of I-94, stretching across southern Michigan from the Indiana border to Detroit. These records were investigated to determine which of the 4602 reported accidents occurred on the 229 curves and which occurred on tangents. They were compared to the traffic volumes over that same period to give the results in "accidents per 100 million vehicle miles" (Acc/100 MVM).

The curves were grouped into seven Class Intervals of curvature, each interval representing 1/2 degree. The accident rate of each interval was computed and compared to the rate for the tangent sections, using the null hypotheses: "There is no difference between the accident rate for this class interval and the tangent rate". Or, in other words, "the accidents are randomly distributed, independant of the alignment".

This hypothesis was tested using the probability equation:*

CONFIDENCE INTERVAL = $(TR) \pm (Z\sqrt{\frac{TR}{V}} - \frac{1}{2V})$

where TR = Tangent Rate

V = Traffic Volume in the Class Interval

Z = Factor (2.576 for this study) corresponding to the degree of confidence desired

* Marin, Donald A., "Application of Statistical Concepts to Accident Data," Public Roads, Vol. 34, No. 7 (April 1967) pp.135-138.

The degree of confidence desired in this study is 99 percent -- if the null hypothesis is true, the actual rate will fall within the confidence interval in 99 percent of all samples, above the interval in 0.5 percent of all samples, and below the interval in 0.5 percent of all samples. Thus, if the actual rate falls outside of the confidence interval, there is only 1 chance in 100 that the null hypothesis is true; in such a case the null hypothesis is rejected and this study then concludes that there _is_ a significant difference between the two rates.

In this equation, the confidence interval increases as the traffic volume decreases.

In addition, all the curves on Michigan's 1964 rural freeway system were driven and ranked good, fair, or poor, depending on the reactions of the driver and the front-seat passenger. These rankings are similarly grouped by degree of curvature. The tangent sections, however, were not ranked, so the observers' opinion of the curves compared to tangents cannot be determined.

Conclusion

SUMMARY

The three-year accident experience of a 200-mile section of I-94 produced actual accident rates greater than can statistically be expected for all class intervals of curvature greater than 2°00' (Figure 1). The actual accident rate for the class interval for curves up to 0°30' was significantly lower (at the 99 percent confidence level) than the tangent rate. Thus, for these class intervals, the null hypotheses is rejected; some factor other than random error is responsible for these variations. In the absence of major factors other than those directly related to curvature, these variations in accident rates are assumed to result from the drivers' ability to negotiate these curves.

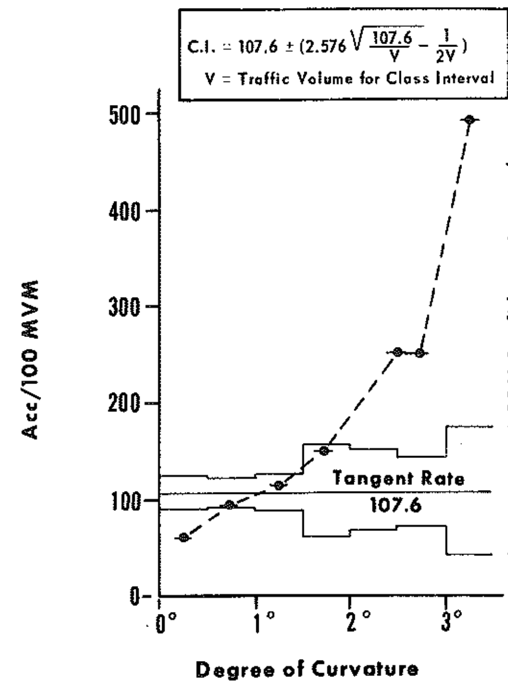

FIGURE 1
Actual Accident Rates for Each Class Interval Compared to 99 percent Confidence Interval

Horizontal curves help keep the driver alert by providing him with an ever-changing view of the scenery. They also provide the driver with a side view of the traffic ahead, allowing him to observe the number, types, and the spacing between the vehicles ahead of him. But some drivers apparently cannot cope with rapid changes of direction at freeway speeds.

The Department presently tends to use flat curves in design. In the older portion of the route used in this study, 58 percent of the 33 curves are flatter than 1°31', while in the new portion, 92 percent of the 196 curves are flatter than 1°31'.

Nearly every curve on the studied route is superelevated at the rate now specified for its degree of curvature or at a steeper rate. The crown was carried through the curve, however, so the lane on the outside of the curve was superelevated at a lower rate.

Interchanges affect accident rates: the accident rate for curved roadways in interchange areas increased faster than did the accident rate for tangent roadways in interchange areas. This study, however, did not obtain sufficient evidence based on accidents to justify a disapproval of curves within an interchange.

The results of the observer-ranking portion of the study were not conclusive. The probability of a curve being ranked fair or poor did increase as the degree of curvature increased, similar to the results of the accident portion. Upon review, however, it is felt that the testing method used did not give truly objective results. So the data from this portion can be used only to make general observations.

The most common complaint given by the observers (to explain the fair and poor rankings) was that the curves were too sharp -- a complaint found only on curves 1°45' or sharper. The observers also objected to obstructions that blocked their view of the roadway ahead, though they did not indicate how many feet ahead they wanted to see.

The starkness of a bridge pier or similar structure appearing to be in the path of the car also caused observer apprehension. As the car approached the structure and the road curved away from the obstacle, the observer realized that his apprehension was unwarranted. But for a short time his attention was needlessly drawn away from other aspects of driving, such as the unexpected moves of other motorists.

RECOMMENDATIONS

On the basis of what was learned, this study makes five recommendations:

1. The design criteria for horizontal curves on <u>rural</u> <u>freeways</u> should be changed to:

   1°30' Desirable Maximum Curvature,

   2°00' Absolute Maximum Curvature.

2. Long, flat curves, 0°30' or flatter, should be used in place of short curves and long tangents.

3. Enough sight distance should be provided to permit drivers to see beyond the curve.

This could be done by removing trees, billboards, and road signs that obstruct vision. Caution is required to avoid a kink appearance on those curves where the driver can see both tangents without refocusing his eyes.*

4. Future structures should be so designed that the driver can instantly see the opening through which the road travels. On existing structures the visual impact of piers 30 ft or more from the pavement should be softened (with shrubbery or pastel paints), so that the driver is inclined to direct his attention to the roadway and not to the piers.
5. The Traffic and Safety Division should conduct a study of the causes of accidents at curves. The purpose of the study would be to determine if there are any accident patterns developing at the curves that can be correlated to any of the design elements of the curves. The method of study would be to choose a small number of curves in each class interval (the curves being as identical as possible to reduce variables) and to closely examine each accident at these curves to determine not only what happened, but also why it happened (why the

*Smith, Bob L., and Yotter, E.E., "Computer Graphics and Visual Highway Design", Highway Research Record Number 270, Highway Research Board, Washington, D.C., p. 60.

driver took whatever actions he did that resulted in the accident). The various design elements of the different curves would be compared to frequency, type, and causes of accidents. Such a study would continue for several years and would investigate the accidents when they occur. The written reports of accidents do not have the detail required for an in-depth analysis.

Accidents at the Curves

SAMPLE OF THE WHOLE

The three-year accident history of a 200-mile section of I-94 was analyzed -- from the US-12 interchange at New Buffalo (Milepost 4) to the Monroe Street structure (Milepost 204) near Detroit, (Figure 2). Since the eastbound and westbound lanes do not always follow the same alignment and since hazards for one direction of travel might not affect traffic across the median, each roadway was studied separately, yielding 399.4 miles of one-way roadway, with 98.4 of those miles (24.6 percent) contained in 229 horizontal curves.

This section constitutes 17 percent of Michigan's 1967 freeway mileage and is considered to be a representative sample of the whole because:

1. Its traffic volumes reflect the wide range found throughout the state. The 1965 average daily traffic varied from 11,800 vehicles in Calhoun County to 56,000 vehicles in Wayne County.
2. It reflects the changes in design practices over a 20-year span. Michigan's oldest freeway, constructed in the early 1940's, is now the eastern portion of the section; the western portion was completed in 1963.

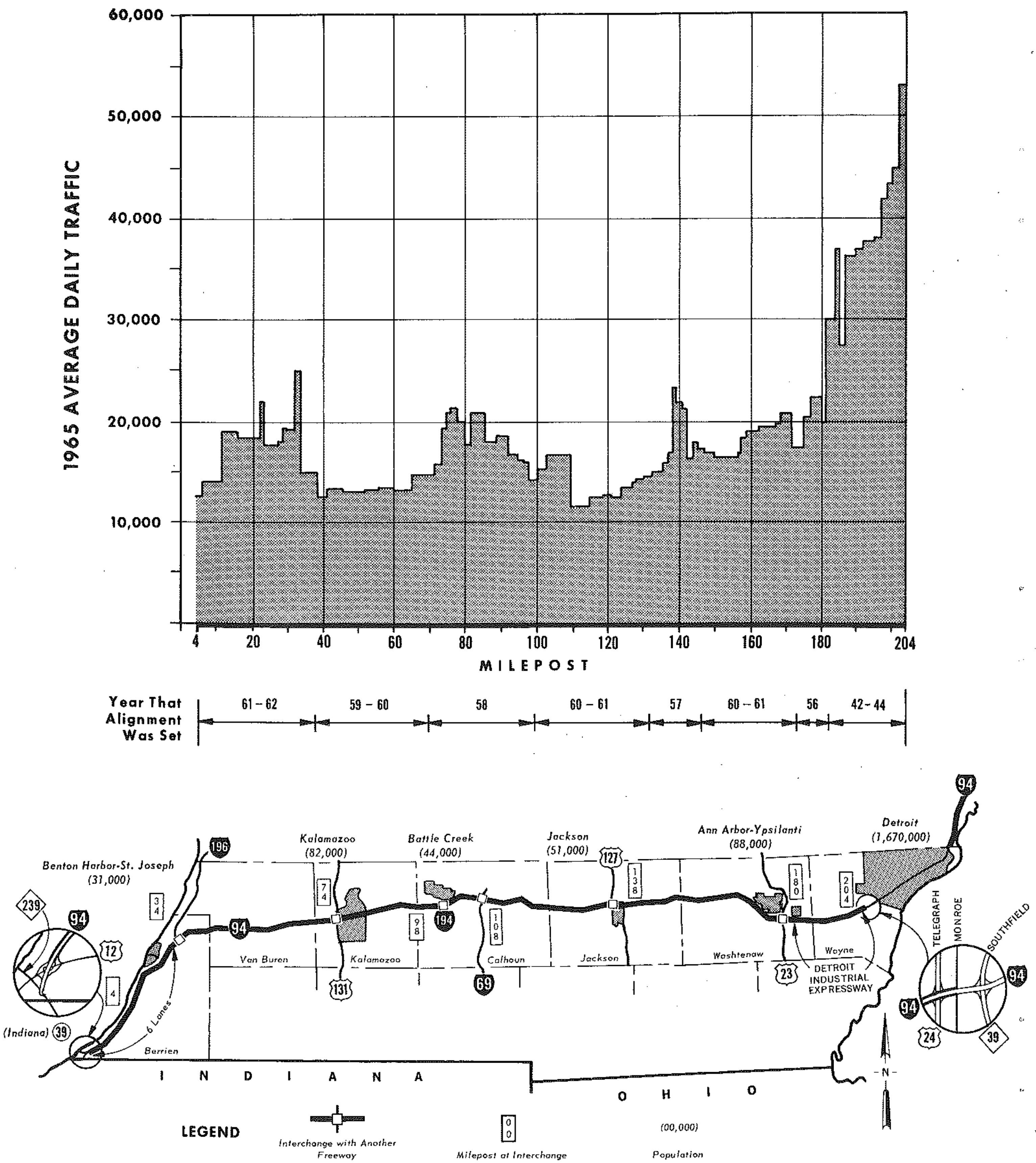

FIGURE 2

MAP OF THE ANALYZED SECTION OF I-94

DESCRIPTION OF THE SAMPLE

The limits of the analyzed section of I-94 were so chosen because the roadway sections beyond those limits are not typical rural freeways. The western limit is two miles east of the temporary end of I-94. All traffic is either entering or leaving a freeway at that point; the two-mile buffer zone keeps the accompanying erratic movements from influencing the study. The eastern limit is 1 1/2 miles west of the Southfield Freeway (M-39), beyond that, I-94 becomes an urban freeway into Detroit.

The section has white 3-in. diameter shoulder delineators spaced at 200 ft on the outside edge of the right-hand shoulder along the mainline, double yellow delineators spaced at 50 ft on the outside edge of both shoulders on interchange ramps, and white edge line along the ramp pavement. There is no edge marking on the freeway lanes. In 1968 obstruction panels were installed on the piers of structures for overpassing cross-roads along I-94.

According to the Michigan Department of State Highways' 1967 Sufficiency Rating (a completely adequate section of roadway rates 100), the analyzed section has a rating of 75 to 100 with two exceptions; one is the Detroit Industrial Expressway (constructed in the 1940's to serve a bomber assembly plant, now Willow Run Airport) which is rated between 35 and 77; the other is the Jackson North Belt portion which is rated between 58 and 78.

The design features of the Detroit Industrial Expressway included 11-ft lanes, a 14-ft median, a 31-ft clearance between the freeway and service roads, close spacing of relatively sharp curves, and at-grade intersections. Numerous improvements have since been made on the roadway, such as widening and capping the original unreinforced concrete pavement, installing median guardrail, and constructing grade separations and interchanges. Yet the Department still plans to do extensive work on the route to bring it up to current standards.

INTERPRETATION OF THE DATA

If complete data on every accident were known, the conclusions would become obvious. As in most studies, only a sample of the data is available for this study and this data is not always fully objective.

No traffic accident can be charged to only one specific cause, if a "cause" is considered to be <u>any</u> condition whose correction would have prevented the accident. While there may be an obvious major cause, such as a blown tire; there are also other contributory causes, such as speed, soft shoulder, steep sideslope, other vehicle nearby, or roadside obstacle which had to be present in order for an accident to occur.

In investigating accidents, a major cause might never be discovered. A car, for example, is found smashed into a center bridge pier at a curve late one night. An investigation reveals the accident might be blamed on "speeding", or on "driver falling asleep" if no skid marks are found. With no witnesses or survivors and with the front end of the vehicle demolished, the fact that the steering and brake systems failed and caused the car to travel only in a straight line might never be considered.

A driver, in another example, is not likely to indict himself on an accident report, even if he's told it cannot be used against him. He might rightly point out that the other vehicle pulled out of the entrance ramp at 30 mph right in front of him and he couldn't slow down in time to avoid it. Yet he withholds the fact that he had been looking for a service station to match his credit card at the interchange and didn't see the other car until he was too close to stop.

Normal effort to be accurate on the accident reports does not prevent mistakes. In 1965 five accidents were recorded as occurring 0.2 mile west of the Cooper Street overpass in Jackson. Yet three of the accidents were also recorded as occurring on a straight road, the other two on a curved road. These accidents did not all happen in the same spot, although the reports say that they did.

Any attempt, therefore, to isolate certain accidents as being due solely to the fact that the road curves would be inaccurate and meaningless. But a comparison of the overall rates of the curves compared to the tangent rate can be used.

The accident history of I-94 showed a significantly high accident rate for curves sharper than 2°00' and a significantly low rate for curves flatter than 0°31'. If no factor other than that the road turns at a specified rate can be found to account for these differences in rates, then the responsibility can be placed on the curves themselves.

Are there, then, any factors peculiar to the curves or tangents to account for these differences?

There are two types of factors found on the highway; those which are continuous over a portion of the highway and those which are found in isolated conditions. Continuous factors include such items as lighting, weather, pavement condition and width, shoulder condition, median width, and shoulder delineation. These factors exist on both the curves and the tangents simultaneously and affect both the curves and the tangents simultaneously, although not necessarily to the same degree. Consider, for example, natural lighting. The higher curve accident rate cannot be blamed on the fact that it is nighttime on the curves much of the time, since it is also nighttime on the tangents. The combined effect of darkness and a flat curve is different from the combined effect of darkness and a sharp curve. But it is the alignment, not the lighting, that is responsible for the difference.

Other factors are found in spots along the roadway, such as median crossings, parked cars, railroad grade crossings, structures and interchanges. All of these alter the accident rates; if they were concentrated on either the curves or the tangents, they would have biased the data.

Median crossover locations are determined by definite specifications that make no reference to the alignment, so it is assumed that the crossovers are randomly located relative to the alignment. A similar assumption is made for parked cars. Parking is illegal on the freeways, although there are some violations, most vehicles parked along the freeway are there due to mechanical failure. The occurrence of such failures is independent of the alignment.

There are two railroad grade crossings on I-94, both on tangents. Although there were no car-train collisions during the three-year span, ten accidents* occurred at these crossings. These accidents slightly bias the data; but they account for only 0.28 percent of the tangent accidents.

It is assumed that the horizontal alignment of the section was not forced, in order to meet the structures on tangent, and that the structures are randomly located relative to the alignment.

Although interchanges might also be randomly located, the effect that they have on the accident rates is given special attention in this study.

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* 1. One driver hit a railroad tie lying on the pavement 40 feet from the track.
2. Four drivers hit the crossing signal. Two fell asleep, one was forced off the road and the other was drunk.
3. Four drivers were hit when they slowed or stopped because the tracks were there. A salt truck was hit when it stopped to raise its blade before crossing the tracks (the only fatal accident involving the tracks); another vehicle was hit when it stopped because the warning lights were flashing (they were being tested); another was hit when it slowed because traffic was channeled to one lane due to work on the tracks; and the other was hit in the traffic buildup caused by a bus making its required full stop before crossing the tracks.
4. One driver claimed that he lost control while crossing the tracks.

ACCIDENTS AT CURVES

The curves were grouped into seven class intervals -- each interval representing 0.5 degree (Table 1).

As shown in Figure 3, the accident rates increase sharply as the degree of curvature increases. The graph closely follows (correlation coefficient = 0.97) the equation:

$$A = 50 + 53.6\ (D^{1.54})$$

where A is the accident rate per 100 million vehicle miles and D is the degree of curvature.

For each range of curvature above 2°00', it can be said with 99 percent certainty that the corresponding high accident rate is not due merely to chance. The curves between 1°31'

	Degree of Curvature	Number of Curves	Length in Miles	Number of Accidents	Acc/mile per year	Acc/100MV per curve	Acc/100 MVM
	0°01' to 0°30'	85	33.5	190	1.9	23	56
	0°31' to 1°00'	74	37.0	370	3.3	49	98
	1°01' to 1°30'	41	19.0	221	3.9	53	114
	1°31' to 2°00'	7	2.3	36	5.3	48	147
	2°01' to 2°30'	11	2.9	96	11.2	66	253
	2°31' to 3°00'	8	2.6	113	14.4	82	252
	3°01' to 3°30'	3	1.1	71	21.5	182	495
TOTALS	All Curves	229	98.4	1097	3.7	46	106
	Tangents		301.0	3505	3.9		108
	Entire Section		399.4	4602	3.8		107

Table 1.
Accident Rates for Each Range of Degree of Curvature, 1964-66.

and 2°00' had a combined rate 39 percent higher than the tangent rate. But since the sample size of these curves is small (2.27 miles), the confidence interval is large and the sample did not fall outside the confidence limits (Figure 1). The curves more gradual than 0°31' had a significantly lower accident rate; about half the tangent rate.

Two other methods of computing the accident rates are also given in Table 1. All three methods show the accident rate increasing as the degree of curvature increases. However, it is felt that the two other methods do not present an accurate picture. The "accidents per mile per year" method ignores the volume. Since the sharper curves are concentrated on the high-volume portions of I-94, this method tends to increase the relative value of the rates of the sharper curves. The "Accidents per 100 million vehicles per curve" method ignores the length. Since flat curves are generally longer than sharp curves, this method tends to increase the relative value of the rates of the flat curves. The "Accidents per 100 million vehicle miles" method, which considers both length and volume, is therefore considered to be the most representative method.

The influence of the Detroit Industrial Expressway portion (east of US-23) is also shown in Figure 3 and is tabulated in Table 2. In Figure 3, the lines have been fitted between the actual accident rates.

For both the Detroit Industrial Expressway portion and the newer portion (west of US-23), the trend of the accident rates is to increase as the degree of curvature increases, although at different rates. The overall rate (both curves and tangents) of the portion east of US-23 is 151 Acc/100 MVM, compared to 92 Acc/100 MVM for the west portion. Thus, although the added

Degree of Curvature		West of US-23		East of US-23	
		No. of Curves	Acc/100 MVM	No. of Curves	Acc/100 MVM
0°01' to 0°30'		81	55	4	59
0°31' to 1°00'		65	88	9	141
1°01' to 1°30'		35	102	6	173
1°31' to 2°00'		5	112	2	245
2°01' to 2°30'		6	249	5	257
2°31' to 3°00'		2	382	6	231
3°01' to 3°30'		2	299	1	864
TOTALS	Curves	196	88	33	171
	Tangents		93		146

Table 2.
Comparison of the Accident Rates between the Newer Portion of I-94 and the Detroit Industrial Expressway Portion, 1964-66.

hazards of the older portion plus the higher concentration of sharp curves and higher volumes did result in higher overall accident rates, they did not combine to bias the general trend of the rate curve.

A curve can be made easier to negotiate by: using a spiral transition curve to introduce the curve, increasing the superelevation rate for the curve, constructing a flatter curve at the location, or some combination of these three.

None of the curves on I-94 are spiraled, so the effects of spirals cannot be weighed. As shown in Table 3, nearly all the curves are superelevated at or above the present design criteria. This study has no basis to recommend a change in the present superelevation policy. So, unless the Department changes its policy toward spirals, the only means available to improve the curves would be to construct flatter curves.

ACCIDENTS AT INTERCHANGES

The curves within interchange areas had a combined accident rate 73 percent higher than the combined rate for the

Degree of Curvature	Superelevation Rate .00	.01	.02	.03	.04	.05	.06	.07	Not Given	Total
0°01' to 0°30'	19	66								85
0°31' to 1°00'	1	11	61						1	74
1°01' to 1°30'			6	6	25				4	41
1°31' to 2°00'					2	5				7
2°01' to 2°30'					1	7	3			11
2°31' to 3°00'					1	2	5			8
3°01' to 3°30'							3			3

Table 3.
Superelevation on the Curves in the Entire Section of I-94.
(underlined rates indicate current design practices)

rest of the curves (Figure 4). Considering the tangent sections only, however, the rate increased 52 percent in the interchange areas. Combining the two, the interchanges had a significant 57 percent increase in accident rates over the non-interchange areas. Although the curve rate showed a greater percentage increase than did the tangents, the difference is not enough to warrant a blanket disapproval of curves within interchange areas.

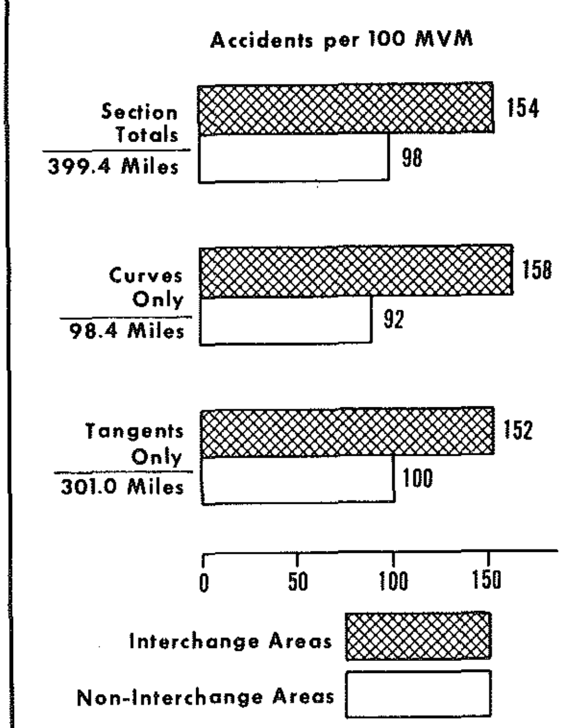

FIGURE 4
Comparison Between Interchange and Non-interchange Accident Rates.

When the interchange curve data is broken down into the seven class intervals of curvature, the sample sizes become too small to show anything significant.

ACCIDENTS AT EIGHT CURVES

As a pilot for a possible future study, four curves in the 1°01'-to-1°30' class interval with "low" accident frequencies (0,0,0, and 1 accident in the three-year span) were compared to four others in that class interval with "high" accident frequencies (7,9,10, and 11 accidents), on the basis of:

1. length of the curve
2. length of the tangent before the curve
3. superelevation on the curve
4. crown retained in superelevated section
5. direction of turn
6. degree of curvature on the curve immediately preceding the subject curve
7. distance from previous interchange to the PC of the curve
8. distance to next interchange from the PT of the curve
9. traffic volume at the curve
10. vertical alignment of the curve

The three most common types of accidents at these curves were loss of control due to slippery pavement, loss of control due to tire failure, and sideswipe due to lane change.

In this small sample, no physical differences were seen between the curves in the "low" group and those in the "high" group, except that the "high" curves were generally closer to the next interchange than were the "low" curves.

A more elaborate study conducted along these lines, involving a larger number of curves and a closer investigation of accidents at those curves might reveal some correlations between certain types of accidents and certain geometric characteristics of the curves.

Rankings of the Curves

METHOD OF EVALUATION

Before the accident records were studied, the entire 1964 Michigan rural freeway system (containing 1197 curves) was driven to determine drivers' reaction to the appearances of the curves.

Each curve was driven at 60, 70, and 80 mph and ranked as being either "good", "fair", or "poor" at each speed according to the impression it made on the driver and the front-seat passenger. An exact dividing line between good, fair, and poor could not be established since the criteria was intangible. However, if the curve could be negotiated with little or no effort it was obviously good; if the driver was compelled to slow the vehicle as he entered or proceeded along the curve, the curve was ranked poor. Most of the curves fell between the two extremes and had to be weighed and ranked under the criteria that most nearly applied. If any apprehension was felt, the curve was not given a good ranking and the factor that the observers thought was causing the apprehension was noted. The fair or poor ranking was determined on the premise that if the test group of young men (age in the mid-twenties) experienced apprehension, then older drivers with slower reflexes would experience more anxiety and difficulty.

The curves were driven at the three different speeds to determine at what speed they first appeared to be unsafe. Although the design speed and the posted speed limit are both 70 mph and the 85th percentile speed is 69.7 mph, (Figure 5), the 80 mph ratings were included because 13 percent of the passenger cars were timed going between 70 and 80 mph.

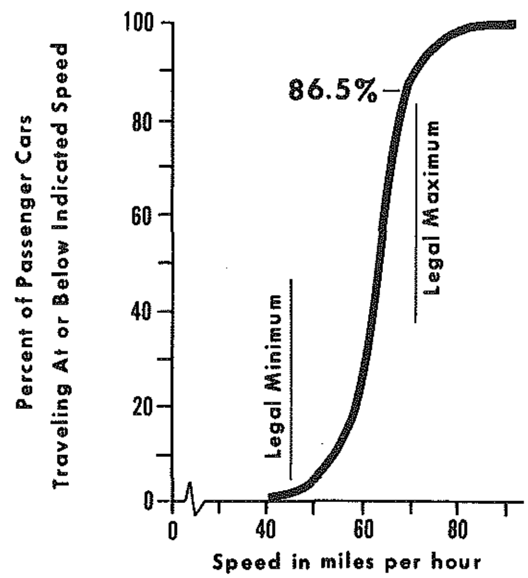

FIGURE 5
Daytime Passenger Car Speeds, Michigan Rural Freeways, July 1967.

Employees of the Michigan Department of State Highways drove late-model standard domestic passenger cars in the test. The drivers were assigned to sections of the freeways that they had previously driven only a few times, if at all.

The freeways in Detroit were not included in this study since the high traffic volumes and resultant lower speeds coupled with the frequency of interchanges not typical of a rural freeway system would produce biased results.

A 465-curve sample of the 1197 curves was further evaluated by relating the good, fair, and poor rankings to the degree of curvature and rate of superelevation. To determine the influence of interchanges, the rankings of curves in interchange areas were compared to the rankings of curves along the entire route.

Numerous trial runs of portions of the freeways were driven prior to running the entire system to determine an effective study method. The observers' comments were recorded and the curves were located in relation to some prominent characteristic, such as a crossroad, structure, or county line. This made it possible to locate curves on plans and to determine which accidents occurred on each specific curve.

To obtain more uniform rankings, the curves on the section of I-94 discussed in the accident portion of the study were driven a total of six times, with different observers for each run.

LIMITATIONS OF THE EVALUATION

Obtaining a fully objective analysis of the curves would have required a far more extensive test than was undertaken. This analysis is limited in that (1) the observers were all highway-oriented men who understood why they were running the test and were therefore more alert to the curves than a typical driver would be, (2) the freeways were driven only during the daytime, and (3) the test was conducted only in good weather when the pavement was dry. The observers were alternated as frequently as possible to avoid their becoming conditioned to the curves, and their reactions becoming neither spontaneous or natural.

Since the test was subjective, the drivers ranked the curves relative to the previous curves and to the same curve at different speeds. A moderately sharp curve that would earn a fair ranked by itself would likely be ranked good if it were tested immediately after a series of poor curves. Also, a curve negotiated at 80 mph with a little difficulty would appear much better at 70 and receive a much more favorable ranking. On the other hand, if a driver experienced some difficulty at 70 mph, he was likely to remember it and downgrade the curve at 80 even before he drove it. Whether the traffic was heavier or lighter than normal also affected the ranking. The same curve, although driven at the same speed on the same day, will likely receive different rankings if driven in the afternoon when the sun is high, two hours later, when the sun is in the driver's eyes, and again, sometime later, when it is dark.

The rankings were biased to some unknown degree by the personal prejudices of the observers. For example, they consistently ranked left-hand exits poor, not necessarily because they had difficulty maneuvering thru the interchange but possibly because they had the preconceived idea that left-hand exits were poor design.

In short, then, a fully objective study of the curves would involve a complete analysis of all characteristics of the entire freeway system. Such an analysis would require a large number of drivers, both male and female, of all ages and driving experience and occupations, driving various sizes of cars and trucks. These drivers would have to drive the entire system, or at least a truly representative sample, in all weather conditions a number of times, and each time start at a different randomly-chosen point to avoid influence from a previous run.

This test, then, is not all-inclusive. It does, however, indicate a <u>trend</u> of the impressions that the various curves created in male Department of State Highways' employees driving low-mileage, standard weight passenger cars in good weather in daylight at three different speeds. Under these conditions, the rankings were consistent; most curves received a good ranking from each observer, while other curves were always ranked poor. On a few curves, the rankings fluctuated between good and fair or between fair and poor.

Bearing in mind the limitations of the test, the rankings are projected as being an indication of the impressions that the curves make on the driving public.

DRIVERS' OBSERVATIONS

Table 4 shows the breakdown of the rankings of the curves according to the routes and to the speed of the ranking vehicle.

Freeway	Number of Curves	Speed of Ranking Vehicles								
		60			70			80		
		GOOD	FAIR	POOR	GOOD	FAIR	POOR	GOOD	FAIR	POOR
I- 75	458	445	12	1	417	30	11	380	60	18
I- 94	229	227	1	1	215	12	2	196	22	11
I- 96	227	225	1	1	217	8	2	180	37	10
I-196	44	44	0	0	43	1	0	43	1	0
US- 23	157	155	1	1	142	13	2	125	25	7
US-127	26	26	0	0	26	0	0	26	0	0
US-131	56	56	0	0	56	0	0	55	1	0
TOTAL	1197	1178	15	4	1116	64	17	1005	146	46
PERCENT OF TOTAL		98.4	1.3	0.3	93.3	5.3	1.4	84.0	12.2	3.8

Table 4.
Curve Rankings for Each Freeway, Entire System.

At the design speed of 70 mph, 93 percent of the curves were ranked good; at 80 mph, the observers found one out of six curves defective.

The observers complained that 49 curves were too sharp for 80 mph; either the driver was inclined to slow down or a definite side thrust was felt. Sight distance was inadequate on another 49 curves, caused by a side obstruction such as a bridge pier or abutment, a crest vertical curve, or in some cases, other vehicles that prevented the driver from adequately seeing the downstream roadway. The observers wanted assurance that there was a wide open highway ahead.

Another 34 curves caused uneasy feelings because they appeared too sharp at first glimpse. Once the car was into the curve, however, the feeling disappeared and no side-thrust was felt.

The drivers were apprehensive about 15 of the curves at 80 mph when the guardrail or bridge railing appeared too confining and they felt an urge to decelerate. At three locations, a steep downslope behind the guardrail on the right side made the front-seat passenger uneasy. On another 39 curves the observers had an apprehensive feeling that they could not define.

ANALYSIS OF A SAMPLE OF THESE CURVES

Next, the degree of curvature and rate of superelevation were taken from road plans for 465 (39 percent) of the curves. In this sample, which included portions of all the freeways in the study, 384 (82.6 percent) of the curves were ranked good at 80 mph. Statistically, a sample of this size can be expected to have a mean value between 79.6 and 88.4 percent since 84.0 percent of the 1197 curves were ranked good at 80 mph (Table 4). It is therefore concluded that the sample is a representative sample of the whole, from which conclusions can be drawn. Table 5 shows the breakdown of the rankings at 80 mph in relation to the degree of curvature.

Although three-degree curves are tolerated on Michigan's freeways, 19 of the 23 three-degree curves in the sample were considered "too sharp". In addition, more than one-third of the curves over 2°00' were considered too sharp, that being the most common complaint in the sample, although only one curve flatter than 2°00' had that fault.

Degree of Curvature	Observers' Complaint									Totals		
	Inadequate Sight Distance	Too Sharp	Appears to be Too Sharp	Exit Ramp	Exit Straight; Freeway Curves	Pier	Guardrail	Slope Behind Guardrail	Undefinable	POOR and FAIR	GOOD	All Curves
0°01' to 0°30'	2			1	1					4	98	102
0°31' to 1°00'	6		2	3	1				1	13	153	166
1°01' to 1°30'	8		4	3	1	1	1	2	4	24	92	116
1°31' to 2°00'	5	4	1	1		1	1			13	31	44
2°01' to 2°30'		2	2							4	6	10
2°31' to 3°00'	1	21								22	4	26
3°01' to 3°30'										0	0	0
3°31' to 4°00'										0	0	0
4°01' to 4°30'		1								1	0	1
TOTAL	22	28	9	8	3	2	2	2	5	81	384	465

Table 5.
Objections to the Fair and Poor Curves in the 465-Curve Sample.

Degree of Curvature	Superelevation Rate .00	.01	.02	.03	.04	.05	.06	.07	Not Given	Total
0°01' to 0°30'	6	69	2						25	102
0°31' to 1°00'	8	12	122						24	166
1°01' to 1°30'	4		1	7	64				40	116
1°31' to 2°00'					—	36			8	44
2°01' to 2°30'	1					6	2		1	10
2°31' to 3°00'						—	16		10	26
3°01' to 3°30'							—			
3°31' to 4°00'							—			
4°01' to 4°30'							—	1		1

Table 6.
Superelevation on the Curves in the 465-Curve Sample.
(underlined rates indicate current design practices)

The rate of superelevation of all the 3°00' curves for which the rate was available was 0.06 ft/ft (Table 6). This is the maximum rate presently permitted on rural freeways.

Since spiral transition curves are not used on Michigan's highways, the effect that spirals would have had on the observers could not be measured.

RANKINGS OF I-94

Table 7 shows the breakdown of the curve rankings on I-94 by degree of curvature. At the design speed of 70 mph, 45 percent of the curves sharper than 1°30' were ranked fair or poor, compared to 0.5 percent of the curves 1°30' or flatter. At 80 mph those values become 90 percent for the curves sharper than 1°30' and 3.5 percent of those flatter. All the curves sharper than 3°00' were considered poor at 80; only one of them earned as high as a fair ranking at 70 mph.

The results of the six test runs on I-94 were combined to arrive at these rankings.

Degree of Curvature	Speed of Rating Vehicle								
	60			70			80		
	GOOD	FAIR	POOR	GOOD	FAIR	POOR	GOOD	FAIR	POOR
0°01' to 0°30'	85	0	0	85	0	0	85	0	0
0°31' to 1°00'	74	0	0	73	1	0	71	3	0
1°01' to 1°30'	41	0	0	41	0	0	37	4	0
1°31' to 2°00'	7	0	0	7	0	0	2	5	0
2°01' to 2°30'	11	0	0	6	5	0	1	8	2
2°31' to 3°00'	8	0	0	3	5	0	0	2	6
3°00' to 3°30'	1	1	1	0	1	2	0	0	3
TOTAL 229 curves	227	1	1	215	12	2	196	22	11
PERCENT OF TOTAL	99.2	0.4	0.4	93.9	5.2	0.9	85.6	9.6	4.8

Table 7.
I-94 Curve Rating by Degree of Curvature.

RANKINGS AT INTERCHANGES

A motorist traveling through an interchange area has a number of special factors to contend with. Rather than the relatively uniform velocities usually found elsewhere on a freeway, there is a wide variety of speeds; some vehicles traveling over the speed limit, some vehicles decelerating to enter an exit ramp, and others accelerating from an entrance ramp. There is also considerable weaving as vehicles vie for space on the through lanes. Interchanges also contain structures, guardrail, and signs, which demand additional alertness from the driver. Table 8 indicates the effect of these factors on the rankings of the interchange curves.

Nevertheless, better than two out of three interchange curves were satisfactory at 80 mph, indicating that the observers had no serious objections, in general, to curves at interchanges although such curves appeared more dangerous

Freeway	Number of Interch Curves	Speed of Ranking Vehicle								
		60			70			80		
		GOOD	FAIR	POOR	GOOD	FAIR	POOR	GOOD	FAIR	POOR
I- 75	106	99	6	1	83	20	3	73	24	9
I- 94	86	84	1	1	81	3	2	68	12	6
I- 96	51	50	0	1	44	6	1	28	16	7
I-196	2	2	0	0	2	0	0	2	0	0
US- 23	26	24	1	1	18	7	1	15	7	4
US-127	0	0	0	0	0	0	0	0	0	0
US-131	18	18	0	0	18	0	0	18	0	0
TOTAL	289	277	8	4	246	36	7	204	59	26
Non-interchange Curves	(908)	901	7	0	870	28	10	801	87	20

Table 8.
Curve Rankings for Each Freeway, Curves within Interchange Areas; and Comparison with Non-interchange curves.

than did curves elsewhere along the route. The observers did not compare interchange curves to interchange tangents.

CURVES RANKED POOR AT 60 MILES PER HOUR

Four of the 1197 curves deserve special consideration since they were ranked poor at 60 mph. They were all located at or near an interchange. These curves are sketched in Figure 6.

One of these curves is on US-23 at the M-14 interchange north of Ann Arbor. It is a 4°30' curve (a two-lane freeway-to-freeway ramp) that observers thought was "sharp" with "poor sight distance". Since there is no advisory speed posted, it is driven at 70 mph. At the temporary ending of I-75, the freeway traffic curves right onto a two-lane ramp to join US-27, while the tangent lanes become a left-hand exit to a two-way trunkline. Near Ann Arbor, I-94 turns through 90° in 2735 ft; the eastbound lanes were rated poor

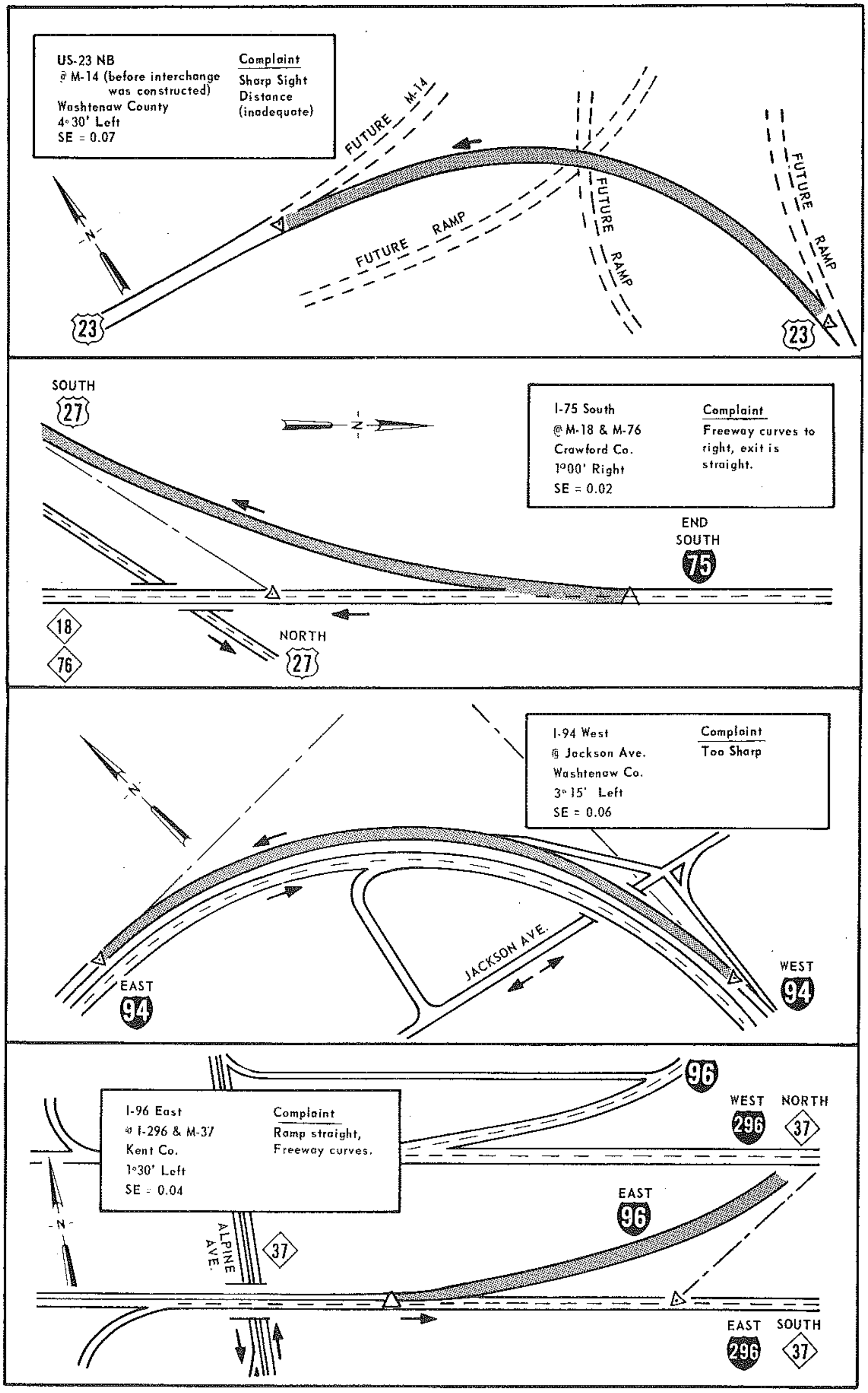

FIGURE 6

DIAGRAMS OF THE CURVES RANKED POOR AT 60 M.P.H.

at 80 and 70 mph and fair at 60 mph. North of Grand Rapids, I-296 follows the tangent from I-96 just 700 ft downstream from the addition of a third lane at an entrance ramp.

It should be remembered that although curves and interchanges may appear simple to negotiate in a small-scale overhead view, 90° to the pavement, the driver sees the pavement unrolling before him life-size at an angle of less than one-half degree, giving him a completely different perspective of the situation.

Accidents Compared to the Rankings

AGREEMENT BETWEEN ACCIDENT RATES AND RANKINGS

The accident experience on freeway I-94 bore out the drivers' apprehensions — those curves that appeared hazardous did actually have higher accident rates (Table 9). A graphical representation of this data (Figure 7) shows that the freeway miles containing fair or poor curves had three times their share of accidents.

The 14 curves on I-94 that were ranked fair or poor at 70 mph had the highest combined accident rate, while the 196 that were ranked good at 80 mph had the lowest rate (these speeds refer to the speeds of the observers' vehicles, not to the speeds of the vehicles involved in the accidents).

Ranking Speed	Rating	Number	Mileage	Accidents	Acc/mile per year	Acc/100 MVM
60	Good	227	97.55	1069	3.6	104
	Fair	1	0.42	11	8.4	235
	Poor	1	0.42	17	13.5	363
	Fair+Poor	2	0.84	28	11.1	299
70	Good	215	93.22	860	3.0	89
	Fair	12	4.33	209	17.0	332
	Poor	2	0.84	28	11.1	299
	Fair+Poor	14	5.17	237	16.0	328
80	Good	196	86.65	740	2.9	85
	Fair	22	7.77	176	7.6	191
	Poor	11	3.97	181	16.2	322
	Fair+Poor	33	11.74	357	9.8	228

Table 9.
Comparison of I-94 Ratings to Accident Records, 1964-66.

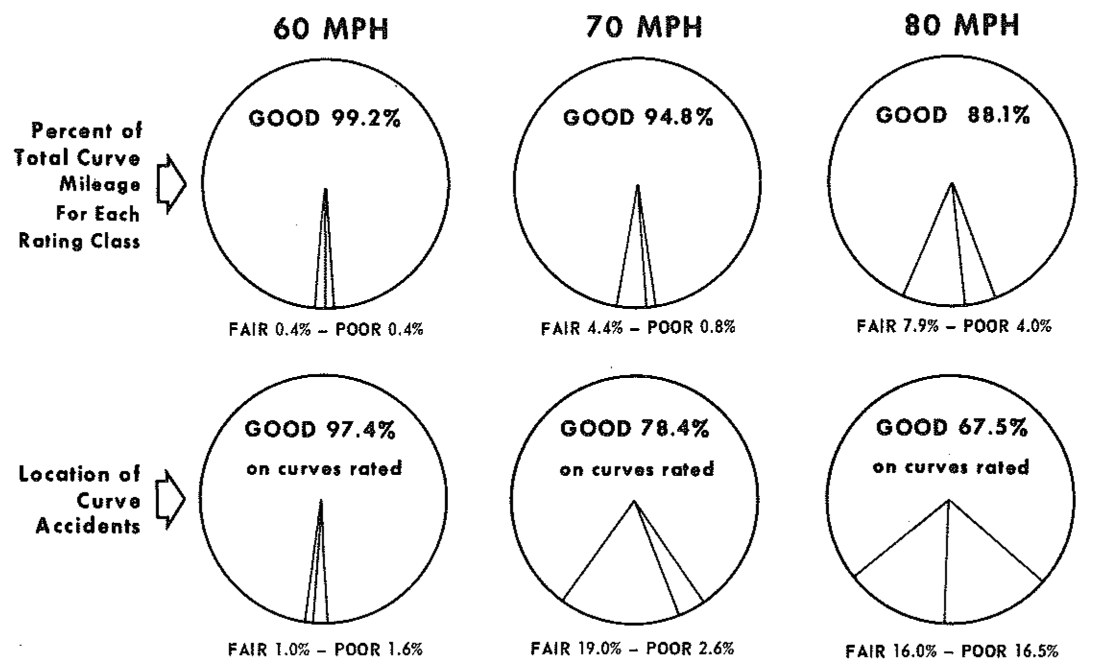

FIGURE 7

Comparison of Ratings with Accident History of I-94, 1964-66.

HIGH-ACCIDENT CURVES

Twenty-four of the curves had an accident rate greater than 200 Acc/100 MVM. When the rates of these curves were compared to the overall curve rate by statistical analysis, the high rates of 21 of them could be attributed to some factor other than statistical variation. On one of these curves, the factor was the construction of a third lane; 9 of the 13 accidents on that curve resulted directly from the hazards created by the construction work. There then remained twenty curves (Table 10) accounting for 35 percent of the curve accidents on only 7.6 percent of the curve mileage. The combined accident rate for the 20 curves was 3.6 times as great as the combined rate for all curves on I-94.

Number	County	Direction	Location	Length in miles	Degree of Curvature	3-Year Totals: Accidents	3-Year Totals: Million Vehicle Miles	Accidents per 100 MVM	Rating: At 60 mph	Rating: At 70 mph	Rating: At 80 mph	Reason for Fair or Poor Rating
1	Wayne	E	1st E. Huron River Dr.	.26	3°30'	43	5.00	860	G	F	P	Reverse Curve
2	Wayne	E	2nd E. Huron River Dr.	.30	1°00'	30	3.84	782	G	F	F	Compound Curve
3	Jackson	E	At Cooper St. (M-106)	.27	1°30'	20	3.48	575	G	G	G	
4	Jackson	W	At Cooper St. (M-106)	.27	1°30'	18	3.48	517	G	G	F	High Abutment
5	Washtenaw	E	1st E. Kalmbach	.44	2°32'	18	4.08	441	G	F	P	Compound Curve
6	Washtenaw	E	At Kalmbach	.55	2°30'	22	5.04	436	G	F	P	Compound Curve
7	Washtenaw	E	At Michigan Ave.	.39	2°30'	26	6.91	376	G	F	F	Too Sharp
8	Wayne	E	1st W. Huron River Dr.	.23	2°34'	17	4.58	372	G	F	P	Roadway Not Visible
9	Washtenaw	W	At Jackson Ave.	.42	3°10'	17	4.68	363	P	P	P	Too Sharp
10	Washtenaw	E	At US-23	.28	2°00'	11	3.28	336	G	G	F	Looks Dangerous
11	Jackson	E	At Sargent Rd.	.23	2°30'	7	2.28	308	G	G	F	Exit Ramp on Tangent
12	Wayne	W	At Beech-Daly Rd.	.34	1°00'	25	8.31	301	G	G	G	
13	Washtenaw	W	1st W Rawsonville	.43	3°00'	24	8.46	284	G	G	P	Roadway Not Visible
14	Wayne	W	3rd E Rawsonville	.25	2°33'	14	5.06	277	G	G	P	Roadway Not Visible
15	Berrien	W	1st W Puets Rd.	.38	2°30'	10	4.15	248	G	F	P	Looks Dangerous
16	Wayne	E	3rd E Rawsonville	.25	2°33'	12	5.06	237	G	G	P	Roadway Not Visible
17	Calhoun	W	At 11-Mile Rd.	.53	1°15'	11	4.67	236	G	G	G	
18	Washtenaw	E	At Jackson Ave.	.42	3°10'	11	4.68	235	F	P	P	Too Sharp
19	Wayne	E	At Beech-Daly Rd.	.59	1°30'	34	14.53	234	G	G	G	
20	Calhoun	W	1st W 28-Mile Rd.	.64	1°30'	10	4.45	225	G	G	G	
			TOTALS	7.47		380	106.02	358				

Table 10
The Curves Having an Accident Rate Greater Than 200 Acc/100 MVM, 1964-66.

Ten of the eleven curves ranked poor at 80 mph are included in these 20, including both curves ranked poor at 70. Five of these 20 were ranked good at all speeds.

Among the ten curves having the highest rates, five were ranked poor and four were ranked fair at 80 mph. The curve ranked poor at 60 and two of the three curves sharper than 3°00' are included in these ten curves.

An eastbound motorist passing near Romulus, in Wayne County, encounters a two-lane left-hand exit that follows the tangent as the freeway curves 2°34' right. This is followed by a 410-ft tangent, a 3°31' curve left, a 340-ft tangent, and a 1°00' curve left. An at-grade intersection at this location was closed in January 1965. This combination contains the curves with the highest, the second highest, and the eighth highest accident rates. Relief from this hazardous location will be provided by the reconstruction of I-94 to interchange with the I-275 freeway, now in the preliminary design stage.