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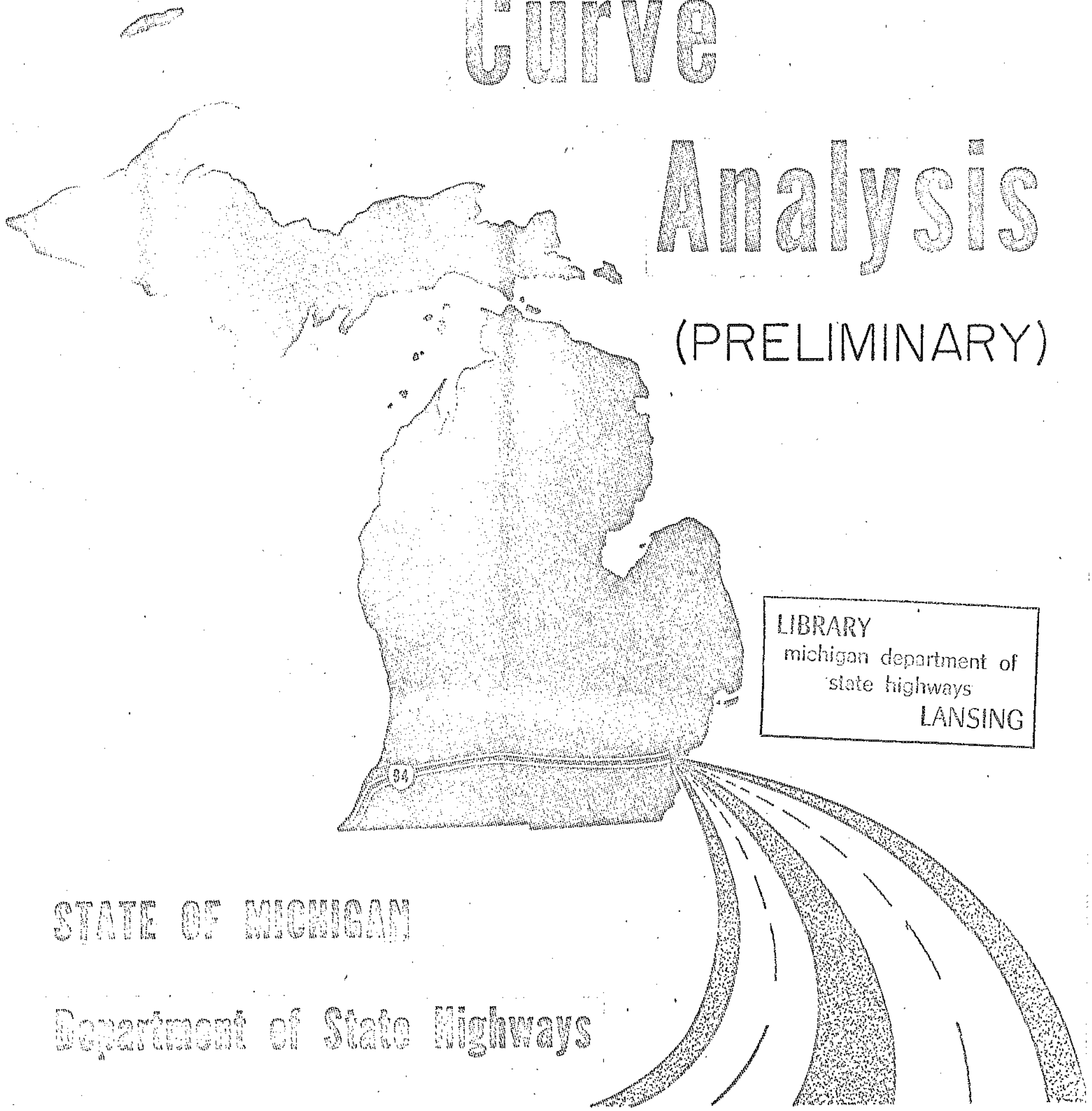
Freeway Curve Analysis

(PRELIMINARY)



STATE OF MICHIGAN

Department of State Highways

Traffic and Safety Division

November 1968

Freeway Curve Analysis

an appraisal of existing horizontal curves based on operations

PREPARED BY
Standards Unit
Geometrics Section
Traffic and Safety Division
Bureau of Operations
Michigan Department of State Highways
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Abstract

An analysis of the accident records for a portion of I-94 revealed that horizontal curves sharper than 2°00' experienced significantly higher accident rates 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. Curves in interchange areas received particularly low ratings.

The study recommends that the maximum allowable curvature be reduced, with greater use being made of long, flat curves with long clear vision distance, and that interchanges be of consistent design.

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 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 Highway Department 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 considered in rural freeway design. These improved standards resulted from observing the effects that alignment, grade and geometrics have on traffic movement.

About one-fourth of 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 accident history of 200 miles of I-94, stretching across southern Michigan from the Indiana border to Detroit. In addition, all the curves on Michigan's 1964 rural freeway system were driven and rated as being good, fair, or poor, depending on the reactions of the driver and the front-seat passenger.

The accident records for the section over the three-year period from 1964 through 1966 were investigated to determine which of the 4602 accidents occurred on 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", abbreviated as "Acc/100 MVM."

The accident rates for seven ranges of degree of curvature are compared to each other and to the rate for the tangents. The observers' ratings are similarly grouped by degree of curvature. The tangent sections, however, were not rated, so the observers' opinion of the curves compared to tangents cannot be determined.

Conclusion

SUMMARY

The three-year accident history of a 200-mile section of Interstate 94 showed a significantly high accident rate for curves sharper than 2°00' and a significantly low rate for curves flatter than 0°31'. The rate for the curves between 1°31' and 2°00' was also high, but not significantly high at the confidence level used. In the absence of any other factor that might be responsible for these variations, they are assumed to result from the relative drivability of the various degrees of curvature.

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. Many drivers, however, cannot cope with rapid changes of direction at freeway speeds.

The Department of State Highways 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.

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. There is insufficient evidence based on accidents, however, to justify a blanket disapproval of curves within an interchange.

When rating the curves according to the impressions that they made on the drivers, the most common complaint was that they 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 driver apprehension. As the car approached the structure and the road curved away from the obstacle, the driver 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.

Curves within interchange areas earned worse ratings than did non-interchange curves — even worse than might have been expected from the accident rates. Even at 60 mph it was not immediately obvious to the drivers where they were supposed to go. They have become accustomed to leaving the freeway by turning right to enter an exit ramp; left-hand exits confused them. Ramps that follow the freeway tangent while the freeway curves will often mislead the unwary driver in the wrong direction. The observers also objected to exit ramps that were not readily visible to the approaching motorist, but which were hidden by bridge structures, signs, or other obstructions.

RECOMMENDATIONS

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

1. The design criteria for horizontal curves on rural freeways 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. Long 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.
4. Irremovable objects which are not actually traffic hazards should be blended into the surrounding terrain. This could be done by using soft-colored paint or by planting shrubs in advance of the object.
5. Exit ramps should not be constructed so that they leave the freeway along the tangent as the freeway curves away, nor should they leave the freeway from the left.

6. Interchanges should be of consistent design, including uniform signing and painting, so the driver can quickly differentiate between the through lanes and exits. A system of using blue signs, delineators and edge markings to define the exits is currently under study. That study will determine the feasibility of that system, but this study concludes that the present use of yellow delineators only is inadequate and a more elaborate system is needed.

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 (Exit 4) to Milepost 204 at the Monroe Street structure near Detroit, (Figure 1, page 8). 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 1940s, is now the eastern portion of the section; the western portion was completed in 1963.

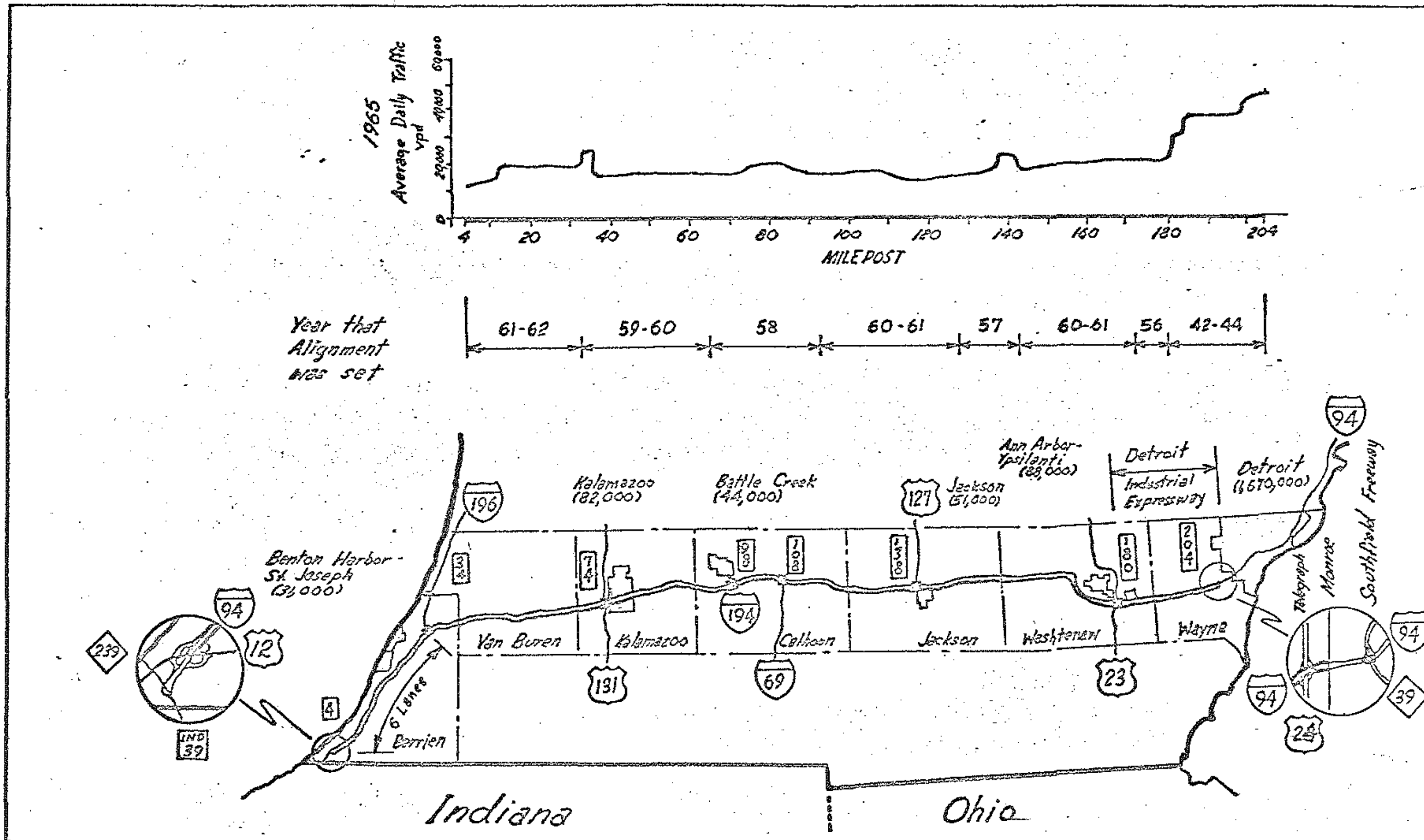

Figure I.
Map of the Analyzed Section of I-94.

LEGEND

Interchange with Another Freeway

Milepost at Interchange

(00,000) Population

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 Expressway, beyond that, I-94 becomes an urban expressway into Detroit.

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-foot lanes, a 14-foot median, a 31-foot 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 a 22-mile stretch was termed a "disaster zone" at a State Senate Highway Committee Hearing in May 1966.

The entire 200-mile section of I-94 conforms to national uniformity in the design and use of traffic control devices such as the white 3-inch diameter shoulder delineators spaced at 200 feet on the outside edge of the right-hand shoulder along the mainline, double yellow reflectors spaced at 50 feet 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 crossroads.

ACCURACY OF THE DATA

The data was subjected to statistical analysis, using a 99 percent confidence level, to determine the effect of chance variation on the results.

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. Nor is it possible for the data to be fully objective. Statistics, however, provides a means for making inferences, cautiously-made generalizations that go beyond the face value of the information at hand.

No traffic accident can be charged to only one specific cause, if a "cause" is considered to be any condition whose correction would have prevented the accident. 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 system failed or other mechanical trouble occurred, causing the car to travel only in a relative 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 fast enough 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.

Even all effort to be accurate on the accident reports does not prevent mistakes. In 1965, five accidents were recorded as occurring 0.2 miles 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, 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 are concentrated on either the curves or the tangents, they will bias 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.

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.

These ten accidents slightly bias the data; they account for 0.28 percent of the tangent rate.

The American Association of State Highway Officials' policy on "Design Standards for the Interstate System" specifies that "Bridges and overpasses . . . should be located to fit the overall alignment and profile of the highway". It is assumed, therefore, 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 report. It is theorized that the speed change lanes, the related vehicle weaving and driver decisions related to the directional signing are collectively conducive to higher accident rates.

ACCIDENTS AT CURVES

The curves were grouped into seven ranges of degree of curvature — each range representing 0.5 degree (Table 1).

As shown in Figure 2, the accident rates increase sharply as the degree of curvature increases. The graph closely follows (correlation coefficient = 0.97) the equation:

$$y = 50 + 53.6 (x^{1.54})$$

where $\underline{y}$ is the accident rate per 100 million vehicle-miles and $\underline{x}$ 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' and 2°00' had a combined rate 39 percent higher than the overall rate. But the sample of these curves was so small (2.27 miles) that the confidence interval was reduced to 95.3 percent — chance variation is five times more prominent than desired. The curves more gradual than 0°31' had a significantly lower accident rate; about half the overall rate.

Degree of Curvature		Number of Curves	Length in Miles	Number of Accidents	Acc/Mi/Yr	Acc/100 MVM
0°01' to 0°30'		85	33.5	190	1.9	56
0°31' to 1°00'		74	37.0	270	3.3	98
1°01' to 1°30'		41	19.0	221	3.9	114
1°31' to 2°00'		7	2.3	36	5.3	147
2°01' to 2°30'		11	2.9	96	11.2	253
2°31' to 3°00'		8	2.6	113	14.4	252
3°01' to 3°30'		3	1.1	71	21.5	495
TOTALS	All Curves	229	98.4	1097	3.7	106
	Tangents		301.0	3505	3.9	108
	Entire Section		399.4	4602	3.8	107

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

The influence of the Detroit Industrial Expressway portion (east of US-23) is also shown in Figure 2 and is tabulated in Table 2.

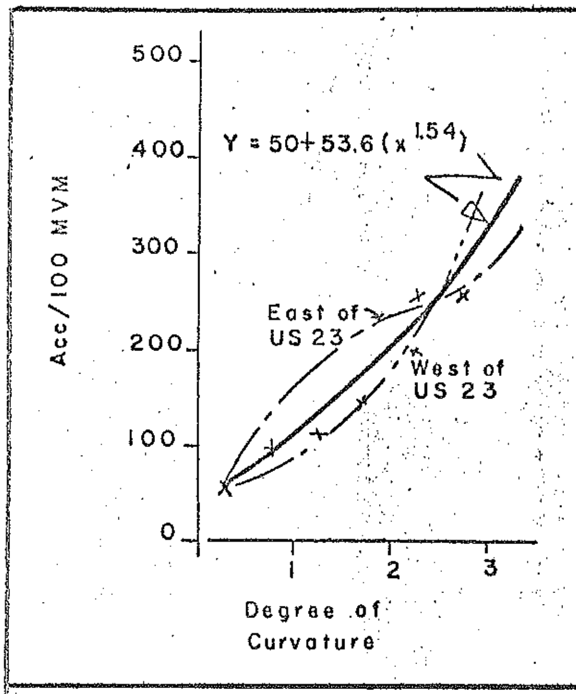

Figure 2.
Relationship between Accident Rate and Degree of Curvature, 1964-66.

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 sample size of most ranges is too small, however, for the numerical values of those ranges to be conclusive.

The added hazards of the older portion plus the higher concentration of sharp curves did not combine to bias the rate curve.

Degree of Curvature		West of US-23		East of US-23	
		Number of Curves	Acc/100 MVM	Number 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°31'		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.

A curve can be made easier to negotiate by: (1) using a spiral transition curve to introduce the curve, (2) increasing the superelevation rate for the curve, (3) constructing a flatter curve at the location, or (4) some combination of these three.

None of the curves on I-94 have spirals, 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. Since this study has no basis to recommend a change in the present superelevation policy and since spirals are not used, 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 rest of the curves (Figure 3). Considering the tangent sections only, however, the rate increased 52 percent in the

Degree of Curvature	Superelevation Rate								Total
	.00	.01	.02	.03	.04	.05	.06	Not Given	
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)

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.

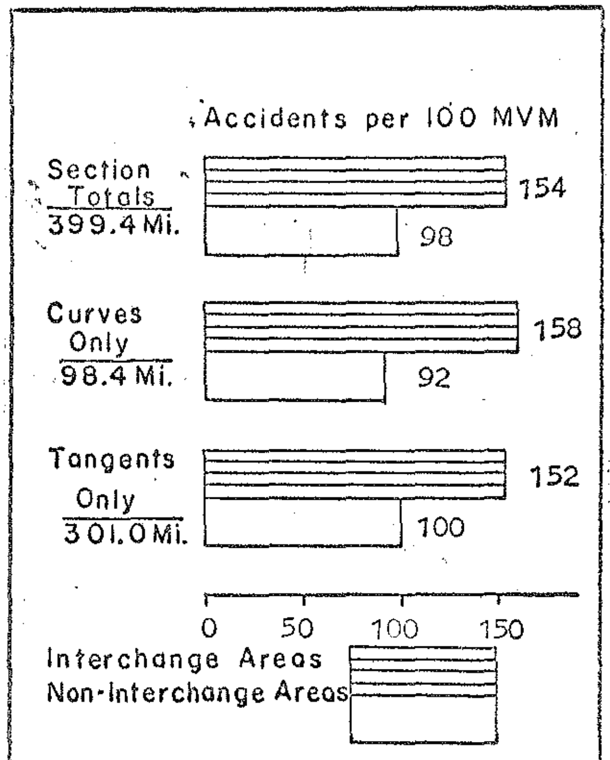

Figure 3.
Comparison Between Interchange and Non-interchange Accident Rates.

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

Ratings 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 rated 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 rated poor. Most of the curves fell between the two extremes and had to be weighed and rated under the criteria that most nearly applied. If any apprehension was felt, the curve was not given a good rating and the factor that the observers thought was causing the apprehension was noted. The "fair" or "poor" rating was determined on the premise that if the test group of young men (average age in the mid-twenties) experienced apprehension, then older drivers with slower reflexes would experience more anxiety and difficulty.

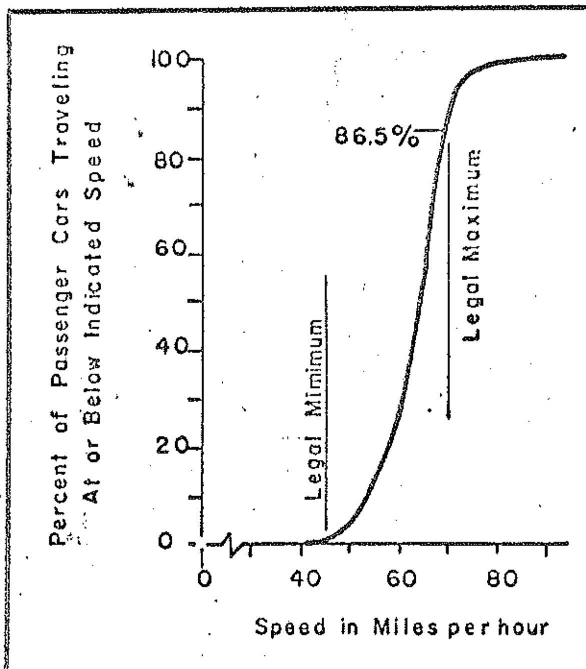

Figure 4.
Daytime Passenger Car Speeds,
Michigan Rural Freeways, July 1967.

The curves were driven at the different specified 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 4), the 80 mph ratings were included because 13 percent of the passenger cars were timed going between 70 and 80 mph.

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 expressways 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" ratings to the degree of curvature and rate of superelevation. To determine the influence of interchanges, the ratings of curves in interchange areas were compared to the ratings 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.

The section of I-94 used to compare the accident rates with the observers' ratings was driven a total of six times to acquire a more uniform and significant opinion of the curves.

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 raters 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 rated the curves relative to previous curves and to the same curve at different speeds. A moderately sharp curve that would earn a fair rating by itself would likely be rated 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 rating. 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 rating. The same curve, although driven at the same speed on the same day, would likely receive different ratings if driven in the afternoon when the sun was high, two hours later, when the sun was in the driver's eyes, and again, sometime later, when it was dark.

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 point, randomly chosen, to avoid influence from a previous run.

This test, then, is not all-inclusive. It does, however, indicate a trend 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 ratings were consistent; most curves received a good rating from each observer, while other curves were always rated poor. On a few curves, the ratings fluctuated between good and fair or between fair and poor.

Bearing in mind the limitations of the test, the ratings 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 ratings of the curves according to the routes and to the speed of the rating vehicle.

Freeway	Number of Curves	Speed of Rating Vehicle								
		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 Ratings for Each Freeway, Entire System.

At the design speed of 70 mph, 93 percent of the curves were rated 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. Another 39 curves left the observers with an apprehensive feeling that they could not describe.

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 rated 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 rated 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 ratings 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, over one-third of the curves over 2°00' were considered too sharp, that being the

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
0°01' to 0°30'	6	69	2						25
0°31' to 1°00'	8	12	122						24
1°01' to 1°30'	4		1	7	64				40
1°31' to 2°00'					—	36			8
2°01' to 2°30'	1					6	2		1
2°31' to 3°00'						—	16		10
3°01' to 3°30'							—		
3°31' to 4°00'							—		
4°01' to 4°30'							—	1	

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

most common complaint in the sample, although only one curve flatter than 2°00' had that fault.

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.

RATINGS AT INTERCHANGES

A motorist travelling 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 travelling 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

Freeway	Number of Curves	Speed of Rating 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
PERCENT OF TOTAL		95.8	2.8	1.4	85.1	12.5	2.4	70.6	20.4	9.0
Non-interchange Curves (908)		901	7	0	870	28	10	801	87	20
Percent of Total		99.2	0.8	0.0	95.8	3.1	1.1	88.2	9.6	2.2

Table 7.
Curve Ratings for Each Freeway, Curves within Interchange Areas; and Comparison with Non-interchange curves.

vie for space on the through lanes. Interchanges also contain structures, guardrail, and signs, which demand additional alertness from the driver. Table 7 indicates the effect of these factors on the ratings of the interchange curves.

The observers were far more critical of interchange curves than of non-interchange curves. Only 0.8 percent of non-interchange curves were considered deficient at 60 mph, while 4.2 percent of the interchange curves were rated fair or poor at 60; a 425 percent increase. At 70 mph, the increase was 250 percent, while at 80 mph, the increase was 150 percent.

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

The geometrics of the interchange often added to the confusion. Twenty-five locations were noted for confusion and apprehension caused by exit or entrance ramps. Left-hand exits were nearly always rated as fair or poor.

Many right-hand exits located part-way around a curve seemed to draw the driver towards them until he realized it was an exit, especially when the exit was hidden at the beginning of the curve. The greatest confusion was caused by exit ramps that followed the tangent alignment while the main roadway curved away. This was the problem on two of the four curves rated poor at 60 mph.

Twelve other curves were considered undesirable due to general confusion in the interchange area. Contributing confusion factors included the adding or dropping of a lane, signing, and pavement markings.

CURVES RATED POOR AT 60 MILES PER HOUR

Four of the 1197 curves deserve special consideration since they were rated poor at 60 mph. They were located at or near an interchange.

One of these curves is on US-23 north at the M-14 interchange. It is a 4°30' curve that observers thought was "sharp" with "poor sight distance". This curve is a two-lane freeway-to-freeway ramp separating US-23 from M-14 westbound, north of Ann Arbor. Since there is no reduced-speed sign, it is driven at 70 mph.

The three other curves are sketched in Figure 5. 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 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.

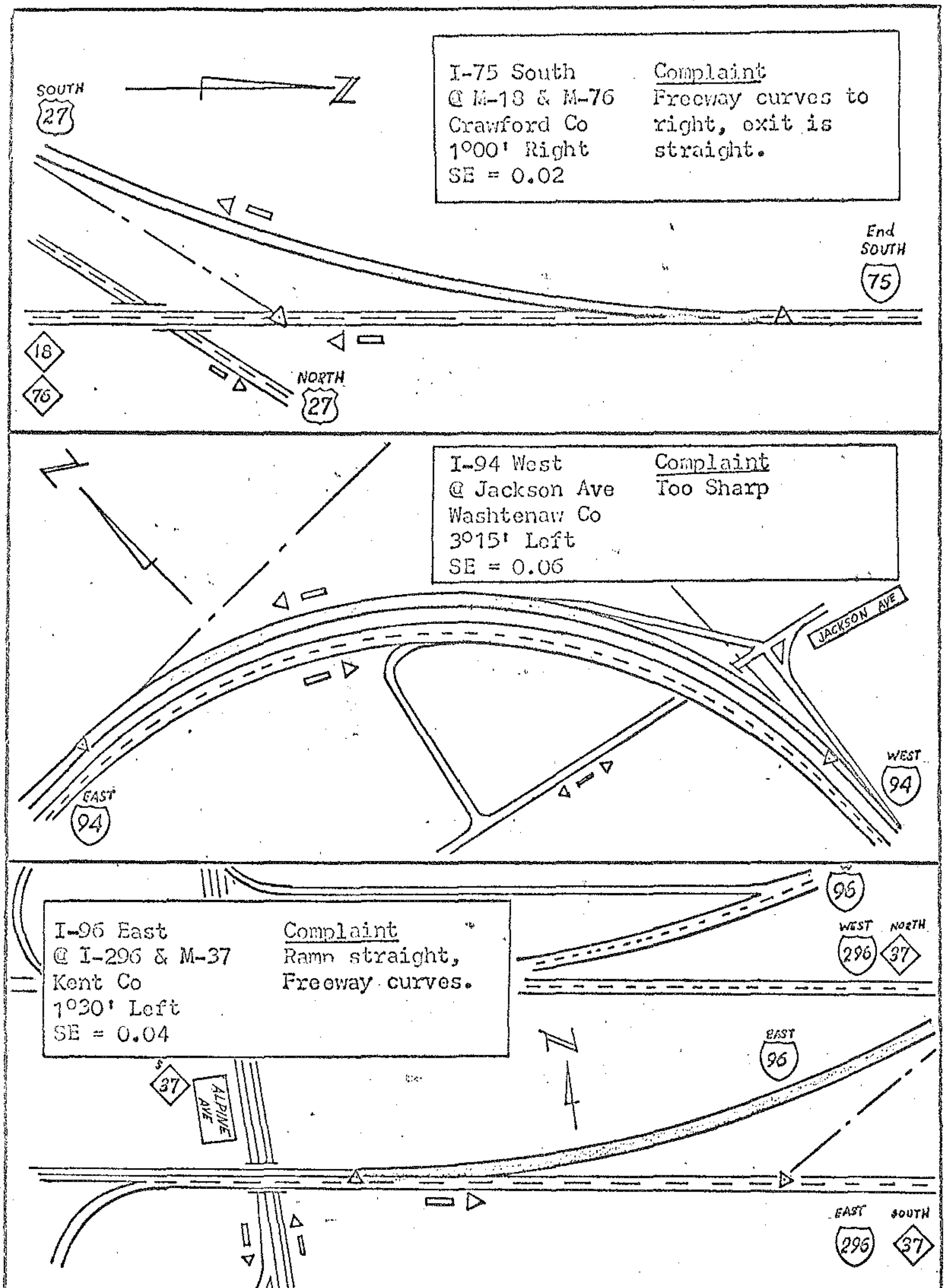

Figure 5.
Diagrams of Three Curves
Rated POOR at 60 mph.

Scale: 1":500'

0 500 1000

Accidents Compared to the Ratings

AGREEMENT BETWEEN ACCIDENT RATES AND RATINGS

The accident experience on freeway I-94 bore out the drivers' apprehensions — those curves that appeared hazardous did actually have higher accident rates (Table 8). A graphical representation of this data (Figure 6) 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 rated fair or poor at 70 mph had the highest combined accident rate, while the 196 that were good at 80 mph had the lowest rate (these speeds refer to the speed of the rating vehicle, not to the speeds of the vehicles involved in the accidents).

Rating Speed	Rating	Number	Mileage	Accidents	Acc/Mi/Yr	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 8.
Comparison of I-94 Ratings to Accident Records, 1964-66.

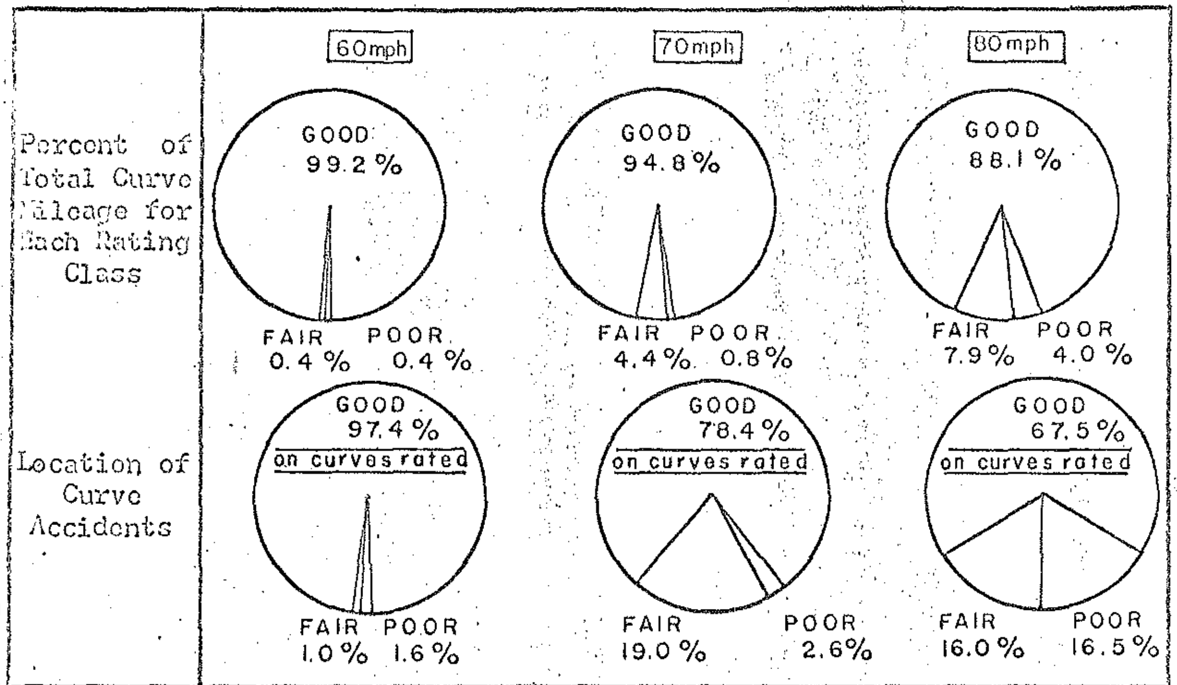

Figure 6.
Comparison of Ratings with Accident History of I-94, 1964-66.

RATINGS OF I-94

Table 9 shows the breakdown of the curve ratings on I-94 by degree of curvature. At the design speed of 70 mph, 45 percent of the curves sharper than 1°30' were rated 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 rating at 70 mph.

TWENTY 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

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 9.
I-94 Curve Rating by Degree of Curvature.

factor other than statistical variation. For one of them, the factor was the constructing 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.

Ten of the eleven curves rated poor at 80 mph are included in these 20, as are both curves rated poor at 70 and the curve rated poor at 60 mph. Five of these 20 were rated good at all speeds.

Among the ten curves having the highest rates, five were rated poor and four were rated fair at 80 mph. The curve rated 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 left-hand exit that follows the tangent as the freeway curves right, then a sharp reverse curve, from 2°34' right to 3°30' left in 410 feet. 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.

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 Puetz 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	17.0 Acc / Mile			

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