Accident Analysis of an Urban Expressway System

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Statistical studies based on turnpike accident data showing the interaction between influencing factors have been available for some time (1, 2). The analytical techniques developed for these studies have clearly helped to define the problem and to give direction to an effective accident prevention program.

The same approach has now been successfully applied to a typical urban expressway system. Approximately 1,100 accidents during 1956 have been studied on the Detroit John C. Lodge and Edsel B. Ford Expressways. This particular year was chosen because the geometry of the system was unchanged during this period of time. Since then, additional sections have been opened for use.

Particular care was given to an accurate estimate of vehicle-miles traveled under various conditions such as weather and light conditions. Thus the analysis is based on the most commonly used index of exposure.

● IT WAS FOUND that 57.5 % of all accidents were rear-end collisions, sideswipe accidents accounted for 29.2 %, and 9.5 % were fixed-object accidents.

Weather and light conditions had equal effect on both expressways. However, head-on and rear-end collisions on the Ford and sideswipe on the Lodge were greater than statistically expected. Rain had a particularly important effect on all types of accident causation, and chain reaction accidents were much more likely during rain. Snow was a strong influencing factor in sideswipe collisions. Fog did not appear to influence accident causation.

Rear-end collisions were greater than statistically expected during daytime and, similarly, fixed-object and sideswipe accidents were greater at night. Commercial vehicle drivers had fewer accidents than would be expected. Although all age groups were affected by inclement weather—particularly the 14-24 and 35-44 groups—the 25-34 group showed up best.

A Poisson distribution technique was developed to pinpoint statistically significant accident-prone expressway segments.

A companion paper (3) discusses the results of a driver behavior study.

DESCRIPTION OF SYSTEM

The Detroit expressway system at the time of this study (1956) is shown in Figure 1. The small rectangular area on the John Lodge refers to the driver behavior study reported previously. The John C. Lodge Expressway had its southern terminus in the downtown area and extended approximately 5.7 mi northwesterly to Glendale (beginning of the dotted line). The Edsel B. Ford Expressway runs approximately east and west, crossing the Lodge at its midpoint. Only accidents within the limits of the City of Detroit (dot-dash lines) were used in this study.

The cross-section of both expressways includes three 12-ft lanes in each direction with a 10-ft medial strip and two 10-ft shoulders.

The Lodge carried slightly more than 135 million vehicle-miles annually. The average weekday count at a typical location (Warren) was about 99,000 vehicles, north- and southbound combined.

The Ford carried almost 192 million vehicle-miles annually and at the time of the study was 6.10 mi long. The average weekday count at a typical location (Livernois) was about 109,000 vehicles, east- and westbound combined.

ACCIDENT DATA

An urban expressway is somewhat similar to a turnpike in the sense that very accurate accident data are available. It is highly probable that all accidents, serious or minor, are officially recorded because even a slight rupture in smooth traffic flow is immediately reflected in serious congestion. Continuous police surveillance both on the expressway and on the adjoining service drives assures immediate and complete reporting.

All accidents on the Detroit expressway system are recorded on the standard accident form. The information on the accident report forms is tabulated daily on IBM cards. These IBM cards, supplied from the files of the Detroit Police Department, were the source of data for the analysis reported in this paper.

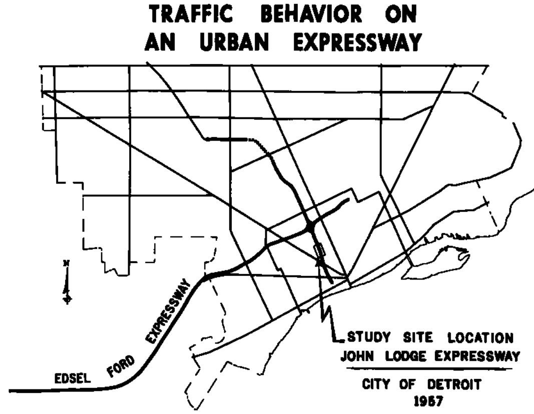

Figure 1.

WEIGHTING OF DATA

The most commonly used index of exposure is the number of vehicle-miles traveled; recently, other (4) indices of exposure have been suggested. Two types of weighting are used in this analysis: vehicle-miles determined from special counts at all ramp locations, and vehicles per hour determined from continuing periodic counts made at one location on each expressway. The latter is only an approximation to instantaneous volume since it is based on a total count for a complete hour.

More specifically, the single location count is made at the same location in both directions—once a month and limited to measurements on any one of the first four working days of the week, randomly selected. The resulting data are in the form of hourly totals for the entire 24-hr period, taken twelve times a year. These data were averaged to obtain the hourly counts used in the analysis.

Three basic weighting factors were used in this study: by each expressway, by weather, and by light conditions. The first follows directly from a summation of flow distribution counts and is in terms of vehicle-miles per expressway.

Vehicle-mile distribution by weather conditions is somewhat more complex. The specific steps in the procedure are shown in Appendix A. It is measured, basically, from hourly vehicle counts. The assumption is made that the percentage of vehicles per hour at a location is representative of the percentage distribution on the entire expressway and that the percentage of vehicles per hour is approximately equal to the percentage of vehicle-miles per hour. The latter assumption is justified if the average trip length remains essentially constant at all times. Although this was not checked experimentally because of the cost involved, it is felt to be a safe assumption. Very briefly, hourly weather conditions for each day in the year were obtained from official climatological charts. From this information and the percentage of vehicle-miles per hour, the percentage of vehicle-miles per year were computed for rain, snow, and fog. The remaining percentage vehicle-miles were assumed to have been traveled under clear or cloudy conditions.

Somewhat similarly, the distribution of vehicle-miles between daylight and night conditions was also determined from the vehicle per hour counts. The time for daylight was assumed to range from one-half hour before sunrise to one-half hour after sunset. The remaining time was considered a night condition. The times of sunrise and sunset were chosen as shown in the "Traffic Engineering Handbook" (5).

TABLE 1

VEHICLE-MILES AS FUNCTION OF WEATHER

Conditions	% Vehicle-Miles Per Year
Clear/Cloudy	91.0
Rain	4.3
Snow	2.9
Fog	1.8
Total	100.0

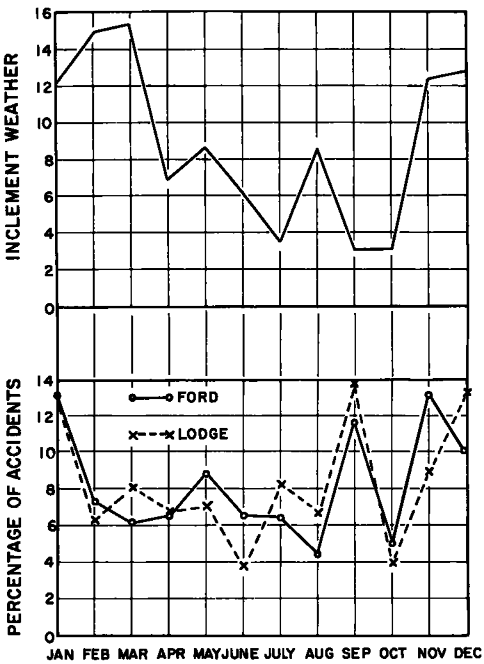

Figure 2.

STATISTICAL RESULTS

The percentage of accidents on the expressway system (exclusive of service drive accidents) as a function of the month is shown in Figure 2. The estimated percentage of vehicle-miles of inclement weather for each month is also plotted on the same chart. The method of estimating vehicle-miles traveled under various weather conditions is described in Appendix A. Attention is called to the high incidence of accidents in September when weather conditions are nearly ideal. Certainly, differences in volume and/or density cannot account for the September rate being 2 to 3. 5 times that of either August or October. Careful analysis of expressway operation did not yield a reason for the sharp rise in the September rate.

The percentage of accidents as a function of day is shown in Figure 3. Although the estimated percent vehicle-miles per hour of day peaks at the same time as the percent accidents, there is not nearly the difference between vehicle-mile peaks that exists between the corresponding accident peaks. The answer may lie in greater mental and physical fatigue after a day's work.

All service drive accidents (Table 2) were eliminated from further analysis.

The large incidence (17. 8 %) of accidents on the Lodge exit ramps, shown in Table 3, was due to the Glendale exit at the temporary expressway terminus.

The inbound and outbound directions (Table 4) correspond in a general way to traffic flow toward and away from the downtown area, respectively. The large percentage on the outbound (north) Lodge is also due to the large accident rate at the Glendale exit.

In Table 5, the statistically expected number of accidents is shown in parentheses. The method of obtaining these values is as follows: It has been estimated from a 24-hr count that the percentage of Ford inbound vehicle-miles is 47. 9, and the percentage of Lodge inbound vehicle-miles is 49. 6. For example, the expected value of accidents on the Ford outbound would be

$$(1.000 - 0.479)(636) = 331.25$$

The chi-square test was used to determine significance in Table 5 as in all succeeding contingency tables. The chi-square value of 24. 05 indicates that the probability is less than 1 in 1, 000 that the

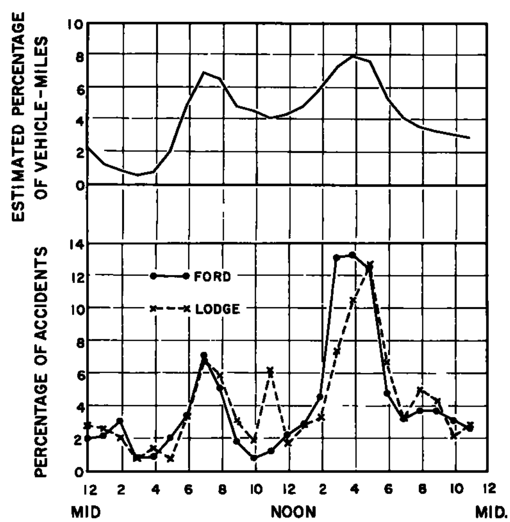

Figure 3.

TABLE 2
ANALYSIS BY LOCATION

General Location	% of Accidents
Main roadway	73. 3
Ramps	13. 5
Interchange area	8 4
Service drives	4. 8
Total	100. 0

differences between observed and expected values result from chance. In other words, the conclusions to be drawn from these differences are highly significant. Thus, the outbound Lodge had many more accidents than chance would dictate. Similarly, the Ford has somewhat more accidents than should be expected. At least part of the reason lies in the fact that the outbound traffic on both expressways is heaviest between 4 P.M. and 6 P.M. The statistical analysis, therefore, appears to be in agreement with the hypothesis concerning late-afternoon mental and physical fatigue discussed in association with Figure 3.

In Table 7, it was determined from a continuous 24-hr count that the Ford carried 58.7 % of the vehicle-miles and the Lodge carried 41.3 %. The expected values in parentheses were obtained with this weighting factor. Thus, the expected rear-end collisions on the Ford are

$$0.587 \times 616 = 361.69$$

The resulting chi-square value is 12.36. For a three-degrees-of-freedom contingency table the level of significance is about 0.007. This means that only seven times in 1,000 the differences between observed and expected values can be attributed to chance. In other words, the differences are highly significant. Therefore, it can be said that the number of rear-end and head-on collisions on the Ford and sideswipe collisions on the Lodge are higher than would be expected.

TABLE 3

PERCENTAGE OF ACCIDENTS BY GEOMETRY

Geometry	Ford	Lodge
Main roadway	82.2	69.0
Ramps	10.1	20.4
Exit	6.1	17.8
Access	4.0	2.6
Interchange Area	7.7	10.6
Ramps	5.1	5.5
Thru	2.6	5.1

TABLE 4

PERCENTAGE OF ACCIDENTS BY DIRECTION OF TRAVEL

Expressway	Inbound	Outbound
Ford	46.4 (East)	53.6 (West)
Lodge	37.3 (South)	62.7 (North)

TABLE 5

INFLUENCE OF DIRECTION ON ACCIDENTS

Expressway	Inbound	Outbound	Total
Ford	295	341	636
	(304.75)	(331.25)	
Lodge	144	242	386
	(191.57)	(194.43)	
Total	439	583	1,022

TABLE 6

ANALYSIS BY TYPE OF ACCIDENT

Type of Accident	Ford (%)	Lodge (%)	Total (%)
Rear-end	60 5	52.9	57.5
Sideswipe	26.2	33.6	29.2
Fixed-object	9.4	9.8	9.5
Head-on	2.0	0.7	1.6
Other	1.9	3.0	2.2
Total	100.0	100.0	100.0

TABLE 7

INFLUENCE OF EXPRESSWAY ON TYPE OF ACCIDENT

Type of Accident	Ford	Lodge	Total
Rear-end	394	222	616
	(361.69)	(254.31)	
Sideswipe	171	141	312
	(183.19)	(128 81)	
Fixed-object	61	41	102
	(59 89)	(42 11)	
Head-on	13	3	16
	(9 39)	(6 61)	
Total	639	407	1,046

TABLE 8

PERCENTAGE OF ACCIDENT TYPE BY WEATHER CONDITIONS

Type of Accident	Clear/Cloudy	Rain	Snow	Fog
Rear-end	82 7	13.0	2 9	1 4
Sideswipe	83.1	9.9	6 4	0 6
Fixed-object	81.1	11.7	4.5	2.7
Head-on	71.3	14.3	7.2	7.2
Other	78.3	13.0	0.0	8.7

TABLE 9

INFLUENCE OF WEATHER ON TYPE OF ACCIDENT

Type of Accident	Clear/Cloudy	Rain	Snow	Total
Rear-end	513	81	18	612
	(569.16)	(24.48)	(18.36)	
Sideswipe	259	31	20	310
	(288.30)	(12.40)	(9.30)	
Fixed-object	90	13	5	108
	(100.44)	(4.32)	(3.24)	
Total	862	125	43	1,030

TABLE 10

PERCENTAGE OF ACCIDENT TYPE BY ROAD SURFACE CONDITION

Type of Accident	Dry	Wet	Snow	Ice
Rear-end	74.0	22.9	1.9	1.2
Sideswipe	76.2	17.4	4.7	1.7
Fixed-object	72.2	22.2	1.9	3.7

TABLE 11

PERCENTAGE OF ACCIDENT TYPE BY LIGHT CONDITIONS

Type of Accident	Daylight	Night
Rear-end	72.7	27.3
Sideswipe	65.7	34.3
Fixed-object	40.3	59.7
Head-on	45.5	54.5

The frequency of head-on and "other" accidents (Table 8) is too small to provide statistically reliable percentages.

In order to perform a reliable statistical analysis only three types of accidents and three weather conditions are used in the contingency table. Table 9 covers 96.5 % of all accidents during 98.2 % of the time. The value of chi-square for a four-degrees-of-freedom table is 198.70. The probability of the differences between expected and observed values being attributable to chance is less than 1 in 1,000. Therefore, the differences are highly significant. It can be concluded that rain has an exceptionally serious effect on all accidents. Snow affects sideswipe accidents primarily. This seems to indicate that drivers do not compensate fully for the poorer visibility and longer stopping distances during rain. Although they appear aware of increased driving hazards during snow, they suffer from reduced visibility through the side windows, possibly caused by fogging or snow accumulation.

It is to be noted (Table 10) that a snow surface has an important effect on sideswipe accidents and an ice surface has an important effect on fixed-object accidents. Since there was no way to estimate the weighting factors for road surface conditions, no further statistical analysis was made.

It was estimated that 70.6 % vehicle-miles were traveled in daylight and 29.4 % at night. These weighting factors were then used to determine the expected values in parentheses (Table 12). The chi-square value was calculated to be 56.35. For a three-degrees-of-freedom contingency table the significance level is less than 0.001. Therefore, it can be said that the probability of the differences between observed and expected values being attributable to chance is less than 1 in 1,000.

TABLE 12

INFLUENCE OF LIGHT CONDITIONS ON ACCIDENT TYPE

Type of Accident	Daylight	Night	Total
Rear-end	448 (434.90)	168 (181.10)	616
Sideswipe	203 (218.15)	106 (90.85)	309
Fixed-object	44 (76.95)	65 (32.05)	109
Head-on	5 (7.77)	6 (3.23)	11
Total	700	345	1,045

TABLE 13

ACCIDENTS (%) BY NUMBER OF VEHICLES INVOLVED

Number of Vehicles	%
Single car	10.7
Two cars	71.7
Three or more cars	18.2
Total	100.0

TABLE 14

INFLUENCE OF WEATHER ON VEHICLES PER ACCIDENT

No. of Vehicles	Clear/Cloudy	Rain	Snow	Total
1	88 (98.58)	14 (4.24)	4 (3.18)	106
2	640 (694.33)	87 (30.52)	36 (22.89)	263
3 or more	161 (176.54)	30 (7.76)	3 (5.82)	194
Total	889	131	43	1,063

TABLE 15

PERCENTAGE OF ACCIDENTS BY VEHICLE TYPE

Vehicle Type	#1 Vehicle	#2Vehicle	Both Vehicles
Ford			
Passenger cars	90.2	92.0	91.0
Trucks and buses	9.8	8.0	9.0
Lodge			
Passenger cars	91.2	92.5	91.8
Trucks and buses	8.8	7.5	8.2

TABLE 16

INFLUENCE OF EXPRESSWAY ON TYPE OF VEHICLE INVOLVED IN ACCIDENTS

Vehicle Type	Ford	Lodge	Total
Passenger cars	1,124 (1,030.04)	728 (753.53)	1,852
Tricks and buses	111 (160.76)	65 (83.73)	176
Total	1,235	893	2,028

TABLE 17

PERCENTAGE OF ACCIDENTS BY SURFACE CONDITIONS

Surface Condition	Ford	Lodge	Total
Dry	75 2	71.9	73 8
Wet	21 2	23 1	21 9
Snow	2.5	3.1	2 7
Ice	1 1	1.9	1.6
Total	100.0	100 0	100 0

TABLE 18

PERCENTAGE OF ACCIDENTS BY WEATHER CONDITIONS

Weather	Ford	Lodge	Total
Clear/Cloudy	82.5	81.9	82.3
Rain	12.0	12.6	12.2
Snow	3.8	4.3	4.0
Fog	1.7	1.2	1.5
Total	100.0	100.0	100.0

It may be concluded that rear-end collisions in daylight are higher than expected. Fixed-object accidents are much too high at night, and to a lesser extent, sideswipe accidents are too high at night. It would appear, then, that "bumper riding," especially at the peak hours, contributes markedly to the cause of rear-end collisions. At night, volumes are much smaller and "bumper riding" becomes negligible. Lack of driver compensation for poorer visibility at night seems to be reflected in higher fixed-object and sideswipe accidents.

TABLE 19

INFLUENCE OF WEATHER ON EXPRESSWAY

Expressway	Clear/Cloudy	Rain	Snow	Fog	Total
Ford	539 (573.85)	78 (27.12)	25 (18.29)	11 (11.35)	653
Lodge	345 (403.49)	53 (19.07)	18 (12.86)	5 (7.98)	421
Total	884	131	43	16	1,074

TABLE 20

PERCENTAGE OF ACCIDENTS BY LIGHT CONDITIONS

Light Condition	Ford	Lodge	Total
Daylight	67.9	65.3	66.8
Night	32.1	34.7	33.2
Total	100.0	100.0	100.0

The expected values in parentheses in Table 14 are obtained from the estimated relative vehicle-miles traveled during each weather condition. Chi-square value is 206.52. For a four-degrees-of-freedom contingency table the probability that the differences between observed and expected values result from chance is less than 1 in 1,000. Therefore, the differences are highly significant. It may be concluded from this analysis that "chain-reaction" accidents are much more likely to occur in rain than in snow or in good weather. This again substantiates the conclusion that the combination of "bumper riding" and lack of driver compensation for rain have a serious influence on accident causation.

Tables 15 and 16 are limited to the first two vehicles in an accident. Vehicle #1 is the presumed violator.

Table 16 is unique in that the expected values were obtained by using weighting factors on both rows and columns. The distribution of vehicle-miles by expressway is 58.7 % on the Ford and 41.3 % on the Lodge. From a 7 A. M. to 7 P. M. count in July 1955 it was determined that the Ford carried 13.5 % trucks and buses while the Lodge carried 10.0 %. Thus in order to obtain the expected number of passenger cars, for example, involved in accidents on the Ford, the following computation is made:

$$(1.000 - 0.135)(0.587)(2,028) = 1,030.04$$

The calculated chi-square value of this table is 29.02. For a one-degree-of-freedom table the probability is then less than 1 in 1,000 that the differences between observed and expected values are caused by chance. The differences, therefore, are highly significant. The conclusions reached from this analysis are that there are more than the

TABLE 21

INFLUENCE OF LIGHT BY EXPRESSWAY

Expressway	Daylight	Night	Total
Ford	442 (444.38)	209 (185.05)	651
Lodge	275 (312.45)	146 (130.11)	421
Total	717	355	1,072

TABLE 22

INFLUENCE OF LIGHT AND WEATHER

Light	Clear/Cloudy	Rain	Snow	Fog	Total
Daylight	607 (693.21)	73 (32.76)	22 (22.09)	10 (13.71)	712
Night	284 (288.68)	58 (13.64)	20 (9.20)	5 (5.71)	367
Total	891	131	42	15	1,079

TABLE 23

ALL INVOLVED DRIVERS BY PHYSICAL CONDITION (%)

Condition	%
Normal	94.2
Drinking or drunk	5.5
Asleep	0.3
Physical handicap	0.0
Total	100.0

expected number of car accidents on the Ford, and that truck and bus drivers have fewer accidents than expected on both expressways.

The expected values in parentheses in Table 19 were obtained by double weighting. Thus, the number expected on the Ford during clear or cloudy weather is obtained by the following computation:

$$0.587 \times 0.91 \times 1,074 = 573.85$$

The chi-square value is 172.06. For a three-degrees-of-freedom table the probability that the differences between observed and expected values are due to chance is less than 1 in 1,000. Therefore, the differences are highly significant. It may be concluded that:

1. Weather had equal effect on both expressways;
2. Rain is exceptionally important in accident causation;
3. Snow causes more than the expected number of accidents, but not to the same extent as rain; and
4. Fog has less effect than would be expected.

The expected values in Table 21 are obtained by double weighting as demonstrated in the sample calculation below for daylight accidents on the Ford:

$$0.587 \times 0.706 \times 1,072 = 444.38$$

The chi-square value is 9.54. For a single-degree-of-freedom table the probability that the differences between observed and expected values are due to chance is less than 5 in 1,000. Therefore, the differences are highly significant. It may be concluded that more than the expected number of accidents occur at night on both expressways.

The expected values in Table 22 are obtained by double weighting, and a sample calculation is shown below for daylight accidents in clear or cloudy weather:

$$0.706 \times 0.91 \times 1,079 = 693.21$$

The chi-square value is 218.27. For a three-degrees-of-freedom table the probability is less than 1 in 1,000 that the differences between observed and expected values are due to chance. The differences are highly significant. It is concluded that there is no justification for added visibility devices in fog. However, there is a definite need for improved visibility from within the car on this type of expressway at night during rain or snow. The rain-daylight combination seems to influence accident causation much more than the snow-daylight combination.

A chi-square test comparing violators and non-violators (Table 25) involved in accidents shows that the probability is very high ($p = 0.6$) that both groups are samples of the same population. Therefore, there is no difference between violators and non-violators so far as age group is concerned.

In Table 26, the chi-square value is 150.02. For a five-degrees-of-freedom table

TABLE 24

PERCENTAGE OF ACCIDENTS BY VIOLATIONS

Violation	%
Too fast for conditions	45.5
Cutting in	26.2
Following too closely	20.6
Wrong way	1.9
Improper turn	1.7
None	1.0
Miscellaneous	3.1
Total	100.0

TABLE 25

PERCENTAGE OF ACCIDENTS BY AGE GROUP

Age Group	Violators	Non-Violators
Under 14	0.6	0.6
14-24	14.4	14.6
25-34	36.8	35.5
35-44	24.2	23.7
45-54	15.3	17.0
55-64	7.4	7.2
65 and over	1.3	1.4
Total	100.0	100.0

the probability is less than 1 in 1,000 that the differences between observed and expected values are caused by chance. Therefore, the differences are highly significant. The conclusion to be drawn from this analysis is that while all age groups are adversely affected by poor weather, the 14-24 and 35-44 age groups are particularly unsuccessful in compensating for poor weather in their driving.

TABLE 26

INFLUENCE OF WEATHER ON AGE GROUP

Age Group	Good Weather	Inclement	Total
14-24	248 (281 19)	61 (27.81)	309
25-34	642 (704.34)	82 (69.66)	774
35-44	410 (465.92)	102 (46.08)	512
45-54	289 (312.13)	54 (30.87)	343
55-64	136 (141.92)	20 (14.04)	156
65 and over	24 (26.39)	5 (2.61)	29
Total	1,749	374	2,123

ACCIDENT ANALYSIS BY EXPRESSWAY SEGMENTS

A new technique is proposed for the relative evaluation of various expressway segments for accident causation. It is based on the Poisson Distribution which is particularly applicable to rare event phenomena, such as accidents.

Each expressway was first divided into a number of equal segments. In this case the segments were approximately one-half-mile long. Thus there were 12 segments on the Ford and 10 segments on the Lodge. Selection of a segment length is more or less arbitrary. However, the choice is restrained in the sense that too large a segment would be insensitive to localization of trouble spots and too small a segment would reduce the frequency of observed accidents to the degree that statistical handling of the data would be impossible. There is no reason to believe that a segment smaller than half a mile—a quarter-mile, for example—would not provide better localization.

The technique is based on two assumptions:

1. That the normal system is linear. In other words, there is a constant ratio of vehicle-miles between any two segments at all times. For example: If segment A carries a volume of 4,000 vehicles/hr while segment B carries a volume of 2,000 vehicles/hr, then if A changes to 2,000 vehicles/hr, B will be 1,000 vehicles/hr. There is no reason to believe this assumption inaccurate so long as the ratios are determined from a large enough sample. A 24-hr count along the expressways made in December 1955 was used in establishing the ratios in this analysis.
2. That the number of accidents is linearly related to the exposure in vehicle-miles. Although it is known to be not exactly true, it is felt that the degree of error resulting from this approximation will not seriously affect the results.

The method of analysis is described in Appendix B. By this method the number of expected accidents due to chance is determined for each segment at the 5 percent level. This means that the odds are 1 in 20 that it is pure chance if the observed number of accidents in that segment is greater than the expected number. It is then safe to assume that when the ratio of observed to expected is greater than unity, some additional accident prevention effort—engineering, enforcement, or education—should be concentrated in that particular segment. Another advantage of this technique is that it permits direct comparison between segments on different systems.

TABLE 27

FORD EXPRESSWAY

Segment	Observed	Expected	Index
(11) Second to Brush	39	32	1.22
(8) Lawton to Wabash	72	67	1.08
(4) Daniels to Wesson	77	72	1.07
(10) Brooklyn to Second	46	45	1.02
(9) Wabash to Brooklyn	67	71	0.94
(7) McKinley to Lawton	62	68	0.91
(6) 28th to McKinley	55	65	0.85
(1) Wyoming to Ogden	33	61	0.54
(5) Wesson to 38th	34	68	0.50
(12) Brush to Rivard	13	29	0.45
(3) Florida to Daniels	25	73	0.35
(2) Ogden to Florida	24	70	0.34

TABLE 28

LODGE EXPRESSWAY

Segment	Observed	Expected	Index
(1) Glendale to Lawrence	30	22	1.36
(7) Reed Pl. to Canfield	65	52	1.25
(5) Bethune to Holden	46	45	1.02
(4) Pingree to Bethune	33	48	0.69
(3) Longfellow to Pingree	24	36	0.67
(9) Noble to Henry	26	44	0.59
(8) Canfield to Noble	25	50	0.50
(6) Holden to Reed Pl.	21	44	0 48
(10) Henry to Howard	15	32	0.47
(2) Lawrence to Longfellow	10	32	0.31

The numbers prefixing the segments in Tables 27 and 28 refer to consecutive numbering of segments west to east on the Ford and north to south on the Lodge. The conclusions to be drawn from the data shown in these tables are that the Second to Brush segment on the Ford, and Glendale to Lawrence and Reed Pl. to Canfield on the Lodge, definitely require additional preventive effort; and it is highly probable that Lawton to Wabash, Daniels to Wesson, Brooklyn to Second on the Ford, and Bethune to Holden on the Lodge require similar action. It is also interesting to note that the Lodge Interchange (Holden to Reed Pl.) segment is much safer than the Ford Interchange (Brooklyn to Second) segment. Two design features may be responsible for the greater safety in the Holden to Reed Pl. segment. First, there are added lanes on the Lodge segment of the Interchange which provide more capacity and allow more space for maneuvering. Second, the ramps entering this segment overpass the other lanes and therefore provide a greater visibility. The ramps entering the Ford segment pass under a series of bridge structures which have some effect on visibility and probably result in greater accident hazard.

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Appendix A

1. The state of the system is assumed to be linear.
2. Hourly count of vehicles at a single location in both directions on each expressway is made one day per month.
3. Compute the percentage of vehicles per hour as an approximation to the percentage of vehicle-miles per hour.
4. From climatological charts use the following values:
   a. Rain condition if 0.01 in. or more was recorded.
   b. Snow condition if 0.01 in. equivalent precipitation or more, as approximately 0.1 in. snow or more, was recorded.
   c. Fog condition as approximately from sunset to sunrise for days when fog was indicated.
5. For each month, count the number of times rain, snow, or fog existed at a particular hour of the day.
6. For a particular hour of the day, multiply the estimated percentage of vehicle-miles per hour by hours of rain, snow, or fog in the month.
7. Sum for the 24 hours of the day and divide by the number of days in the month. More symbolically:

$$\text{\% Vehicle-miles per month of rain} = \frac{\sum_{h=1}^{24} (\text{\% Veh.-mi/hr})_h \times (\text{No. of days it rained that hr})_h}{\text{No. of days in month}}$$

$$\% \text{ Vehicle-miles per month of snow} = \frac{\displaystyle\sum_{h=1}^{24} (\% \text{ Veh.-mi/hr})_h \times (\text{No. of days it snowed that hr})_h}{\text{No. of days in month}}$$

$$\% \text{ Vehicle-miles per month of fog} = \frac{\displaystyle\sum_{h_1 = \text{sunset}}^{h_2 = \text{sunrise}} (\% \text{ Veh.-mi/hr})_{h_1 < h < h_2} \times \left(\begin{array}{l}\text{No. of days fog was} \\ \text{indicated that hr}\end{array}\right)_{h_1 < h < h^2}}{\text{No. of days in month}}$$

$$\% \text{ Vehicle-miles per month Clear/Cloudy} = 100\% - (\% \text{ Rain} + \% \text{ Snow} + \% \text{ Fog})$$

By using these methods and averaging over the twelve months, the percentages obtained for 1956 were:

Clear/Cloudy	91.0
Rain	4.3
Snow	2.9
Fog	1.8
	100.0

Appendix B

TABLE 29

Segment	Eastbound 24-hr Count C_e	Length (ft) L_e	Vehicle-ft per Segment $\Sigma C_e L_e \cdot 10^4$	Westbound 24-hr Count C_w	Length (ft) L_w	Vehicle-ft per Segment $\Sigma C_w L_w \cdot 10^4$	$\frac{\Sigma C_e L_e + \Sigma C_w L_w}{10^4}$
	38,781	500		47,976	2,200		
	42,705	700		56,002	340		
1	48,765	1,340	1,146			1,246	2,392
	48,765	1,260		56,002	1,160		
2	53,158	1,280	1,295	60,865	1,380	1,490	2,785
	53,158	1,820		60,865	2,120		
3	56,177	720	1,372	64,178	420	1,560	2,932
	56,177	1,180		64,178	980		
	48,408	800		55,053	800		
4	53,357	560	1,349	58,827	760	1,516	2,865
	53,357	1,640		58,827	1,740		
5	49,581	900	1,321	50,029	800	1,424	2,745
	49,581	400		50,029	1,200		
	52,886	700		54,307	100		
	49,805	1,400		50,396	1,200		
6	54,149	40	1,287	54,770	40	1,281	2,568
	54,149	1,650		54,770	2,540		
7	49,553	890	1,334			1,391	2,725
	49,553	710		54,770	1,020		
	53,622	1,830		50,046	1,300		
8			1,333	57,134	220	1,335	2,668
	53,622	1,170		57,134	2,180		
	58,544	800		52,766	360		
9	54,668	570	1,407			1,435	2,842
	54,668	930		52,766	840		
	33,976	200		19,935	1,600		
	21,408	1,200		22,872	100		
	27,078	200					
10	30,016	10	890			785	1,675
	30,016	1,090		22,872	100		
	18,286	1,450		29,652	1,200		
11			592	15,279	1,240	568	1,160
	18,286	1,350		15,279	1,660		
12	18,882	1,190	472	15,462	880	390	862

TABLE 30

Segment	Σ C·L x 10^4	Observed Accidents	No. Accidents Normalized to Segment #1 = $\frac{2392}{\sum^{n} C \cdot L}$ x Accidents
1	2,392	33	33.0
2	2,785	24	20.6
3	2,932	25	20.4
4	2,865	77	64.2
5	2,745	34	29.6
6	2,568	55	51.1
7	2,725	62	54.4
8	2,668	72	64.5
9	2,842	67	56.3
10	1,675	46	65.6
11	1,160	39	80.4
12	862	13	36.1
			576.2

$a = \frac{576.2}{12} = 48$ normalized accidents per segment.

1. The first step was to divide the total length of an expressway into equal segments. A segment of approximately half a mile was chosen. (On the Ford, segment length was actually 2,540 ft, resulting in a total of 12 segments.)

2. The vehicle-ft carried on each segment was calculated as shown in Table 29, starting from the Wyoming end.

3. The number of accidents in each segment was counted.

4. The method of obtaining the number of expected accidents in a particular segment is illustrated in Table 30.

5. Repeat Table 30 for the other segments obtaining a different "a" and "c." For example, in calculating Segment #2, normalize in the last column by the relation

$$\frac{2785}{\sum^{n} C \cdot L} \text{ x Accidents}$$

Use a table of Poisson distribution such as Molina, E. C., "Poisson's Exponential Binomial Limit," D. Van Nostrand and Co., Inc., Table II—Cumulated Terms. Using column marked "a = 48" choose a number "c" where the table reads no more than 0.05. For instance, in this case "c" is between 60 and 61. Thus, by choosing c = 61, it can be said that the odds are less than 1 in 20 that chance alone would be the explanation for an observed number of accidents greater than 61 in this segment.