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MODELING FREEWAY INTERCHANGE ACCIDENTS

By

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ABSTRACT

MODELING FREEWAY INTERCHANGE ACCIDENTS

By

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The accident frequency and rate for the various components of freeway interchanges were identified and compared using accident data from the State of Michigan for the years 1982 through 1984. The accident rates at various types of interchanges were compared, and accident predictive algorithms for freeway interchange elements were developed.

A master data file which was composed of geometric, accident and traffic data was constructed by merging existing data bases. The data were then classified into 3 area types (urban, rural and fringe) and further classified into different types of interchanges based on the interchange type. The interchange types were grouped into 12 homogeneous groups based on the accident rate and variance. Accident predictive linear regression models were constructed and tested against data not used in calibrating the models. An analysis was made of those interchange groups exhibiting a value greater than 0.7 in multiple R coefficient.

Based upon the results of this study, the average accident rates on the ramp units are greater than those on the mainline and crossroad units; the interchange is a very

important variable in predicting accidents; the average daily traffic (ADT) has the greatest explanatory power in predicting the accident frequency; and interchange lighting, freeway over or under the crossroad, and ramp control demonstrate the potential of being important variables if sufficient data are available to make additional stratifications.

To my mother, mother-in-law, brothers

and wife

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CHAPTER I

INTRODUCTION

Fundamentally, an interchange simply provides an opportunity for traffic to transfer from one road to another. As used in a modern freeway system, an interchange plays a very important role in providing greater capacity, maintaining higher operating speeds, and reducing the probability of vehicular conflicts during this transfer (7).

As the Interstate Highway System was constructed, a large number of freeway interchanges were designed and constructed. The design standards for these freeway interchanges, however, were not derived from an analysis of past experience, since there was very little past experience upon which the design engineer could draw. Instead, most designs were modifications of existing freeway interchanges, since substantive knowledge for redesign of freeway interchanges was rather limited in regard to the performance expected from individual elements in terms of efficient traffic movement and adequate safety (2). With many freeway systems approaching their design life, the data are now available to evaluate the safety attributes of various freeway configurations and various freeway elements under traffic conditions.

Some evaluation of the geometric design and operational characteristics of interchanges has been done using the rate of traffic accidents as an evaluation parameter (1). However, these safety analyses were not sufficiently detailed to allow freeway designers to select an optimal interchange design.

STATEMENT OF THE PROBLEM

In Michigan, freeway interchanges have been in use since the Davidson Freeway and the Ford Freeway were open to traffic in the early 1940's. There are approximately 700 interchanges in the state of Michigan. Of those interchanges, there are few, if any, exactly alike. The geometric interchange designs vary from the simple rural diamond interchange with at-grade intersections of the ramp with the crossroad to the urban multi-level directional freeway-to-freeway interchange with lane drops, multi-lane turning roadways, weaving lanes, and freeflow merges.

Research has indicated that accident rates are not uniform for the various interchange types or interchange elements. One study showed that the accident rate (346/100 mvm) for a rural exit ramp is more than twice that (161/100 mvm) of a rural entrance ramp (1). Interestingly enough, the reverse is true for urban interchanges with entrance ramps having an accident rate (718/100 mvm) that is twice that (378/100 mvm) of the exit ramp (1). While this study identified accident rates for various elements of a freeway interchange and compared those accident rates with each other, it did not compare the accident rate at various types of interchanges, nor did it establish predictive algorithms based on design features of the freeway interchange elements.

The Michigan Department of Transportation recently completed a geometric inventory of its freeway interchanges, and has assigned accidents to elements. Thus, the geometric data, accident data, and traffic data (such as traffic volumes, population, no. of ramp lanes) could now be used to develop standards based upon the minimization of accidents, if models were available that expressed the relationship among these variables.

The purpose of this analysis of interchanges in Michigan is to: compare the accident rates in Michigan with those from the Interstate System Accident Research Study, Interim Report II by Cirillo, J. A. (1); identify accident rates as they relate to parameters of the interchange elements; and, finally, to establish interchange accident predictive models based upon accident rates on the elements which comprise the interchange.

The results of this study will provide guidance as design decisions are made during the reconstruction of the freeway system in Michigan.

CHAPTER II

LITERATURE REVIEW

In an analysis of the effect of location on accident rates on the interstate highway system, Julie A. Cirillo (1) used data collected by 20 State Highway Departments to compare accident rates on various roadway elements. The initial categorization was between-interchange units and at-interchange units respectively. These were then further divided into urban and rural sections. Each mainline unit was described by its proximity to an interchange. Units which were located at the same distance from two interchanges were divided equally between the two study units (1).

From the results of the between-interchange accident rate analysis, the results shown in Table II.1 were reported. Some of the important conclusions from this study were:

. The accident rate increased on urban sections as the study unit was positioned closer to an exit ramp with the highest rate occurring in those sections located less than 0.2 mile from the exit ramp. Also, as a study unit was stationed closer to the entrance ramp area, the accident rate increased, although not uniformly.

. On rural sections, the change in accident rates was not significantly altered as a unit was positioned closer to the interchange and in the exit direction it remained constant

(1).

The results of the at-interchange accident rates as shown in Table II.2, indicated that:

. The accident rate for urban interchanges was substantially higher than for rural interchanges, as these areas carried more traffic, making merging and diverging maneuvers more difficult.

. The exceptionally high accident rate on entrance ramps in urban areas might be caused by inadequate acceleration lanes, or lack of them, on many sections, necessitating vehicles to stop at the bottom of the ramp before moving into the traffic stream.

. The accident rate on the mainline within the interchange area decreased after the deceleration lane had been passed (1).

The general conclusions of this study were that: sections in proximity of interchanges experienced a higher accident rate than other sections; ramps have much higher accident rates than speed-change lanes; and these, in turn, have generally higher rates than the other portions of the main roadways (1).

In a study of the relationship between interchange design features and traffic safety, Joseph C. Oppenlander and Robert

F. Dawson (2) found that:

. Relatively safer designs were produced when the mainline freeway passed over the minor facility and when the ramp terminals were at least 750 ft. from the structure.

. On-ramps became high accident locations in urban areas, while in rural areas the off-ramps represented the greatest accident rate locations.

. Entrance terminals were improved with geometric designs that provided auxiliary lanes or deceleration lanes of 800 ft. or more. This eliminated traffic friction on the through lanes which resulted in reduced accident rates.

. Adequate sight distances were essential at entrance and exit terminals.

. Geometric designs for weaving maneuvers should provide weaving sections that are at least 800 ft. in length.

In another study of accidents and design features at interchanges, R. L. Fisher (3) found that:

. There were no accidents that could be ascribed to the curvature on loops which had radii of over 100 ft.

. Speed-change lanes of adequate length together with careful treatment of the terminals practically eliminated accidents at interchanges.

. All of the left-hand entrances and exits had a poor accident record.

In a comparative freeway study concerning alignment and accidents at interchanges, John Vostrez and Richard A. Lundy (4) classified the ramp alignment into 6 types. These alignments, in order of low to high accident rates were straight level, straight upgrade, straight downgrade, curved level, curved upgrade, and curved downgrade respectively. They found that:

. With heavy truck traffic the straight upgrade was more detrimental than the straight downgrade while all of the curved classifications were the same.
. Fixed objects were involved in about 28 percent of all freeway interchange accidents. Piers, abutments and bridge rails were apparently the most vulnerable, with signs, guardrails, and light standards following in that order.
. Ramps associated with diamond-type interchanges were the safest type, and on-ramps generally had better accident rates than off-ramps. The downhill on-ramp was the safest type of on-ramp and the uphill off-ramp was the safest type off-ramp. Left-hand ramps (enters or leaves the freeway at high speed lane) had a higher accident rate than any other class.

In an analysis with regard to lighting of interchanges, M. S. Janoff, M. Freedman, and Decina, L. E. (5) reported that:

- Complete Interchange Lighting (CIL) systems perform better than Partial Interchange Lighting (PIL) systems consisting of one, two, or four luminaries.
- Either CIL or PIL normally perform better than no lighting.
- PIL systems with fewer luminaries (one or two) frequently perform better than PIL systems with a greater number of luminaries (four).
- There is a trade-off between cost and traffic operations and safety factors in the design of freeway interchange lighting systems.
- Existing CIL systems should not be reduced to PIL systems if safety and traffic flow are important considerations.

In an investigation of factors affecting the design and location of freeway ramps from an operational viewpoint, William E. Tipton and Charles Pinnel (6) indicated that:

- Standard interchange designs cannot always fulfill the various desired movements at different interchanges. To obtain the most efficient operation at a specific interchange, it may be desirable to use a diamond type, an X-type, or possibly a combination of both of these. The X-type interchange includes an on-ramp upstream of the arterial street and off-ramp down-stream of the arterial street for both the inbound and outbound directions of travel.

. The configuration of an off-ramp located upstream of an on-ramp has considerable advantages over the reverse configuration. The studies indicated that an approximately 50 to 70 percent increase in on-ramp capacity could be obtained by removing traffic in advance of adding traffic to the freeway.

. The construction of stacked ramps rather than an off-ramp upstream of an on-ramp was not generally feasible due to the high cost, the lack of potential for stage construction and the additional right-of-way required. The stacked ramps, however, offer the advantages of elimination of weaving on the frontage road and less distance (approximately 460 ft.) required along the freeway to fit in the design.

. The type of interchange layout which has an off-ramp located upstream of an on-ramp both upstream and downstream of the arterial street is the most desirable. The exception would exist when the freeway capacity is reduced by this design as the freeway crosses the arterial street.

In a study of safety and operational requirements for interchanges (7), it was found that:

. Simple ramps (such as the diamond ramp, the cloverleaf ramp with C-D roads, and direct connections) can reduce the accident rates as shown in Table II.3.

. Sufficient advance information on the type of interchange exit pattern ahead and path which a driver must follow to reach his desired destination should be provided.

. The relative safety of entrance terminals is enhanced with geometric designs that provide a long acceleration lane or auxiliary lanes, adequate sight distances for both freeway and ramp drivers, and freeway lanes on downgrades.

. The types of accidents that occur in the area of the exit terminal can be reduced if the design of entrance and exit terminals provides adequate speed-change lanes, control of access, and proper sight distances to encourage smooth traffic flow at proper operating speeds.

Based upon the literature review, the results are summarized as shown in Table II.4. An "X" represents that researches agree with each other on that factor. From the results in Table II.4, it might be summarized that:

. The accident rates for urban interchanges are higher than those for rural interchanges since urban areas carry more traffic, making merging and diverging maneuvers more difficult.

. While the accident rate on entrance ramps is higher than that on exit ramps in urban areas, the accident rate on exit ramps is higher than that on entrance ramps in rural areas.

. Ramps have much higher accident rates than the other elements of the interchange.

- Ramp terminals should be positioned at least 750 ft. from the structures.
- Speed-change lanes of 800 ft. or more in length should be provided to reduce the accident rates.
- Adequate sight distances should be maintained at entrance and exit terminals.
- Left-hand exits and entrances should be avoided if possible because of poor accident rates, and adequate signs in advance should be provided if they are absolutely needed.
- On-ramps on upgrade are more hazardous than those on downgrade. Vertical alignment should be considered in the design of interchanges.
- Ramp type should be simple to reduce accidents related to confusion with complex ramp types.
- Interchange lighting systems reduce the accident rates on freeway interchanges.

While these research studies provide some useful information for the freeway designer, they do not provide a sufficient basis for detailed design purposes. For instance, they have not developed analytical tools to assist the designer in making trade offs between the cost of various freeway elements and the difference in the number of accidents that could be expected with each choice. The studies were often based upon dichotomous data (i.e., speed-change lanes

< 800 ft. versus those > 800 ft.), and thus do not provide data on accidents related to continuous variables which would allow an analyst to develop predictive algorithms based upon design features of the freeway interchange elements.

For example, it may not be possible to extend a speed-change lane from 700 ft. to 800 ft., but it would still be desirable to know the effect of lengthening it to 750 ft. The past studies would not assist in this analysis, since both 700 ft. and 750 ft. are less than the dividing point used in the preceding analysis. The same is true for other design features (adequate sight distance versus inadequate sight distance, ramps with a radius greater than 100 ft. versus those with a radius less than 100 ft., greater than 750 ft. in distances between ramp terminals and structures versus less than 750 ft.).

The purpose of this research is to establish accident predictive algorithms based upon geometric design features of the freeway interchange elements, and traffic data (such as traffic volume, population, no. of ramp lanes).

Table II.1 Accident rate by proximity to interchange ahead or behind (1)

EXIT SIDE			ENTRANCE SIDE		
Distance to exit-ramp nose ahead	Accident	Accident rate[1]	Diatance to entrance-ramp nose behind	Accident	Accident rate[1]
URBAN			URBAN		
Less than 0.2 miles	722	131	Less than 0.2 miles	426	122
0.2 - 0.4 miles	1,209	127	0.2 - 0.4 miles	1,156	125
0.5 - 0.9 miles	786	110	0.4 - 0.9 miles	655	105
1.0 - 1.9 miles	280	75	1.0 - 1.9 miles	278	84
2.0 - 3.9 miles	166	63	2.0 - 3.9 miles	151	59
4.0 - 7.9 miles	19[2]	69	4.0 - 7.9 miles	200	75
More than 8 miles[3]	--	--	More than 8 miles[3]	--	--
Rural			Rural		
Less than 0.2 miles	160	76	Less than 0.2 miles	117	80
0.2 - 0.4 miles	459	75	0.2 - 0.4 miles	482	82
0.5 - 0.9 miles	559	69	0.4 - 0.9 miles	560	72
1.0 - 1.9 miles	479	69	1.0 - 1.9 miles	435	64
2.0 - 3.9 miles	222	68	2.0 - 3.9 miles	169	51
4.0 - 7.9 miles	46	62	4.0 - 7.9 miles	52	40
More than 8 miles[3]	--	--	More than 8 miles[3]	--	--

1 Number of Accidents per 100 million vehicle miles.
2 Small sample size.
3 No data available.

Table II.2 Accident rate by Interchange unit and area type (1)

Interchange Unit	Area type					
	Rural			Urban		
	Vehicle-miles 100 million	Accidents Number	Accident-rate[1]	Vehicle-miles 100 million	Accidents Number	Accident-rate[1]
Deceleration Lane	2.51	348	137	5.83	1,089	186
Exit Ramp	0.57	199	346	1.48	546	370
Area between speed-change lanes	6.52	554	85	11.87	1,982	167
Entrance Ramp	0.59	95	161	1.61	1,159	719
Acceleration Lane	3.68	280	76	8.40	1,461	174
Acceleration-Deceleration Lane	0.49	87	116	2.45	555	227
Total	14.36	1,563	109	31.64	6,792	214

1 Accident rate = number of accidents per 100 million vehicle-miles.

Table II.3 Accident rate by type of Freeway ramp (7)

Ramp Type	Accident rate[1]		
	On	Off	On & Off
1. Diamond ramps	0.40	0.67	0.53
2. Cloverleaf ramps with collector-distributor roads[2]	0.45	0.62	0.61
3. Direct connections	0.50	0.91	0.67
4. Cloverleaf loops with collector-distributor roads[2]	0.38	0.40	0.69
5. Buttonhook ramps	0.64	0.96	0.80
6. Loops without collector-distributor roads	0.78	0.88	0.83
7. Cloverleaf ramps without collector-distributor roads	0.72	0.95	0.84
8. Trumpet ramps	0.84	0.85	0.85
9. Scissors ramps	0.88	1.48	1.28
10. Left-side ramps	0.93	2.19	1.91
Average	0.59	0.95	0.79

1 Accidents per million vehicles.
2 Only the On & Off rate includes the accidents occurring on the collector-distributor roads.

Table II.4 Comparison of factors related to accidents on freeway interchanges

Factors	Cirillo	Oppenlander & Dawson	Fisher	Vostrez & Lundy	Janoff & Freedman	Tipton & Pinnel	Rowan
On-ramps are more hazardous than Off-ramps in urban area	X	X					X
Off-ramps are more hazardous than on-ramps in rural area	X	X					X
Off-ramps are more hazardous than on-ramps				X			
Simplicity in ramp type reduces accidents						X	X
Speed-change lanes of sufficient length are needed		X	X				X
Vertical alignment effects accidents				X			X
Adequate sight distance reduces accidents		X					X
Ramp terminal design effects the accident rate	X	X					X
Interchange lighting reduces accidents					X		
Longer weaving sections reduce accidents		X					X
Fixed object accidents are the most common type of accidents	X	X		X			X
Left-hand exits and entrances are hazardous			X	X			

X represents that researches agree with each other of that factor.

CHAPTER III

DATA ACQUISITION

III-1. Data Needed

The objectives of this research were to: 1) compare the accident rates in Michigan with those from the Interstate System Accident Research Study II, Interim Report II by J. A. Cirillo (1) and 2) develop and calibrate accident predictive models based upon accident rates on the elements which comprise a freeway interchange.

In the state of Michigan, there are approximately 700 freeway interchanges. The Michigan Department of Transportation recently completed a geometric inventory of its freeway interchanges, and merged the accident file to the geometric file to identify the number of accidents associated with each interchange element. Thus, the three types of data needed for this research were available from this file.

Geometric data: Data describing the elements of the freeway interchanges geometrically. The geometric data were collected from the Michigan Department of Transportation's Highway Accident Master Data file. The geometric data used in this study are:

1). Interchange Number

2). Interchange Element Code

3). Control Section

4). Milepoint

5). Prime Road (PR) Number

6). Beginning PR Milepoint

7). Ending PR Milepoint

8). Beginning Ramp Terminal Milepoint

9). Ending Ramp Terminal Milepoint

10). Geometric and Laneage Code

11). Ramp Terminal or Intersection Code

12). Ramp Terminal Lane Usage Code

13). Interchange Light Code

14). Interchange Type

15). Activity Density

16). Junction Type Code

Traffic data: Data describing the level of use of the freeway interchange elements. The traffic data are available from the Michigan Department of Transportation's TVM (Trunkline Vehicle Miles) Master Data file and Traffic Flow Map. The traffic data needed for this study are:

1). ADT (Average Daily Traffic) on Mainline

2). ADT (Average Daily Traffic) on Crossroad

3). ADT (Average Daily Traffic) on Ramp

4). Population of the county in which the interchange is located

<u>Accident data</u>: Data on accidents that occurred on the freeway interchanges in Michigan. The accident data were collected from the Michigan Department of Transportation's Highway Accident Master Data file. The accident data needed for this study are:

1). Miscellaneous single vehicle accident
2). Overturn accident
3). Hit train accident
4). Hit parked vehicle accident
5). Backing accident
6). Parking accident
7). Pedestrian accident
8). Fixed object accident
9). Other object accident
10). Animal accident
11). Bicycle accident
12). Head-on accident
13). Angle straight accident
14). Rear-end accident
15). Angle turn accident
16). Side swipe same direction accident
17). Rear-end left-turn accident
18). Rear-end right-turn accident

19). Other drive way related accident

20). Angle drive way related accident

21). Rear-end drive way related accident

22). Side swipe opposite direction accident

23). Head-on left-turn accident

24). Dual left-turn accident

25). Dual right-turn accident

The accident data used for this study were data from 1982 to 1984. The geometric data base used for this study was completed by 1984, but many parts of the data base had been partly created before 1984.

The geometric data base completed in 1984 was used since the geometry had not changed significantly. The traffic volume data for 1983 was used since traffic volumes are updated with a traffic growth factor every 3 years. The population data based on this same year was used.

The master data file comprises the geometric data and the accident data. Merging the traffic data into the master data file and analyzing those data was done by computer programs (that is, FORTRAN and SPSS).

III-2. Sample Size

The purpose of sampling is to gain information about the nature or distribution of elements in a particular population without studying the entire population. In determining a sample size, there are two major considerations:

First, assumptions must be made about the underlying distribution of these elements when selecting a sample size. One common assumption is that the population is normally distributed. Under the normal distribution the same proportion of observations will always lie between the mean and a specified number of standard deviations below or above the mean. For example, 68.26 percent of the area under the normal distribution will be within one standard deviation of the mean, and 95.46 percent, within two standard deviations for any normally distributed variable.

Second, some decision must be made about the acceptable limits of error for the sample. This is usually done by specifying that the sample mean for a data item should be within some value **d** of the true average for a certain percentage of samples which is called the **level of confidence.** This level of confidence is denoted as $100(1 - \alpha)$, where α is the fraction of the area under the normal distribution falling outside the confidence limits. Thus, in the case that $d = 2$ and $\alpha = 0.05$, ± 2 units around the true value will include the estimated value 95 percent of the time (8).

There are two types of equations considered for determining a sample size: **sampling with replacement** and **sampling without replacement. Sampling with replacement** assumes that the sample **n** is small relative to the total population size, but **sampling without replacement** does not. Under **sampling with replacement**, the equation for determining a sample size to achieve a precision of **d** units with 100(1 - **α**) percent confidence is

$$n = \frac{Z^2_{1-(1/2)\alpha}\sigma^2}{d^2}$$

where n = sample size

d = tolerable margin of error of mean value

σ = standard deviation of population distribution

α = fraction of area under normal curve representing events not within confidence level (thus, $1 - \alpha$ is desired level of confidence)

$Z_{1-(1/2)\alpha}$ = standard normal statistic corresponding to $1 - \alpha$ confidence level

If the standard deviation of the population distribution is unknown, **s**(standard deviation of sample distribution) might be used instead as follows:

$$n = \frac{Z^2_{1-(1/2)\alpha}S^2}{d^2}$$

where s = standard deviation of sample distribution

Under **sampling without replacement**, the equation considered for determining a sample size is

$$n_1 = \frac{n}{1 + n/N}$$

where n = number of sample observations with replacement

n_1 = adjusted number of observations

N = total population

In the state of Michigan, there are approximately 700 freeway interchanges. Suppose that there are an average of 4 ramps per freeway interchange. It is desired to know the number of accidents per ramp within **d** (tolerable margin of error) = 2, $\mathbf{s}^2$ (sample variance in accidents per ramp) = 100, and **Z** = 1.96, assuming 95 % confidence level. Then,

$$n = \frac{(1.96)^2 (100)}{(2)^2}$$

$$= 96.04$$

$$n_1 = \frac{96.04}{1 + 96.04/2800}$$

$$= 92.855$$

Thus, under **sampling with replacement**, the sample size is at least 97 ramps, and under **sampling without replacement**, the sample size is at least 93 ramps. The actual sample size to be used in this study will be determined following sufficient analysis to determine the probable value of the variance.

III-3. Unit of Analysis

In the Interstate System Accident Research Study II, Interim Report II by Cirillo, J. A. (1), the following analysis units of freeway interchange were included in the analysis:

- Deceleration lanes including taper
- Acceleration lanes including taper
- Exit ramps
- Entrance ramps
- Mainline units between speed-change lanes
- Combined acceleration-deceleration lanes

Each analysis unit was analyzed based on whether the analysis unit was within an urban or rural area. The accidents occurring between interchanges were coded as a distance from either the interchange ahead or behind based on the distances to the exit-ramp nose and the entrance-ramp nose, respectively. However, in this study all exit ramps were combined, regardless of length, ADT, number of lanes, type of interchange, etc. The same was true for entrance ramps and mainline sections. No analysis was made of accidents occurring on the cross roads. Thus, it is not possible to predict the total accident frequency or rate for an interchange.

The analysis units for this study will be further classified based on ADT, the interchange type and the length of the various elements. The population of the county in which the interchange exists will be used as a surrogate measure for activity density. The elements of the freeway interchanges will be considered in detail, and the following base analysis units will be included in this research:

- Mainline unit
- Crossroad unit
- On-ramp unit
- Off-ramp unit

The base units of analysis to be considered were defined as the following:

- Mainline units start at a point 500 ft. before the deceleration lane for the off-ramp and end at a point 500 ft. after the acceleration lane for the on-ramp;
- Crossroad units start at a point 250 ft. before the intersection of the on-ramp and the crossroad and end at a point 250 ft. after the intersection of the off-ramp and the crossroad;

. On-ramp units start at the point they meet the cross-road and end at the end of the acceleration lane;

. Off-ramp units start at the beginning of the deceleration lane on the freeway and end at the point the ramp meets the crossroad.

III-4. Mathematical Inspection

using the identified data, sample size, and units of analysis, models were constructed based upon the following analysis:

Linear model: The data were first analyzed using linear models. Suppose that interest lies in a certain (response) variable μ, which is thought to be dependent on the functionally independent variables Z_1, Z_2, ..., Z_s, that is, $\mu = f(Z_1, \ldots, Z_s)$. Then, it is said that μ obeys a linear model if

$$\mu = f(Z_1, \ldots, Z_s)$$

$$= \sum_{j=1}^{k} \beta_j X_j(Z_1, \ldots, Z_s)$$

where X_j = functions of the Z_j only

$\beta_1, \ldots, \beta_k$ = unknown parameters which enter into the above (9).

Regression Analysis: As a statistical tool that utilizes the relation between two or more quantitative variables, regression analysis is used to predict one variable from the other or others. Regression analysis is based on a linear regression model which fits the scattered observations on a straight line by the least square method. There are two types of linear regression models: simple linear regression models and multiple linear regression models. A linear regression model which contains only one independent variable is called a simple linear regression model, while the linear regression model which contains a number of independent variables is called a multiple linear regression model. Thus, the simple linear regression model can be stated as follows:

$$\mathbf{Y}_i = \beta_0 + \beta_1 \mathbf{X}_i + \epsilon_i$$

where Y_i = the value of the response variable in the **i**th trial β_0 and β_1 = parameters

X_i = a known constant, namely, the value of the independent variable in the **i**th trial

ϵ_i = a random error term with mean $\mathbf{E}(\epsilon_i) = 0$ and variance $\sigma^2(\epsilon_i) = \sigma^2$, ϵ_i and ϵ_j are uncorrelated so that the covariance $\sigma(\epsilon_i, \epsilon_j)$ for all i, j; i is not equal to j

$i = 1, \ldots, n$

Method of Least Square: In order to find good estimators of the regression parameters (i.e., β_0 and β_1), the method of least squares was employed. Suppose that there is a sample observation (X_i, Y_i). Then the method of least squares considers the deviation of Y_i from its expected value:

$$Y_i - (\beta_0 + \beta_1 X_i)$$

In particular, the method of least squares requires that the sum of the n squared deviations is considered. This criterion is denoted by Q:

$$Q = \sum_{i=1}^{n} \{Y_i - (\beta_0 + \beta_1 X_i)\}^2$$

Thus, the estimators of β_0 and β_1 are those values b_0 and b_1, respectively, that minimize the criterion Q for the given sample observations (X_i, Y_i) (<u>10</u>).

Regression Procedure: In selecting a regression procedure, there are three possible regression procedures which require the fitting of every possible regression equation. The **backward elimination** procedure which determines the "best" regression using all variables and then determines the best equation for each step in which the number of variables in the equation is reduced. The **forward selection** procedure inserts variables in turn until the regression equation is satisfactory. The **stepwise regression** procedure which is an improved version of **forward selection** procedure which examines the variables incorporated into the model at every stage of the regression, provides a judgement on the contribution made by each variable, and removes any variable which has a nonsignificant contribution at a later stage even if it may have been the best single variable at the early stage (11). The **stepwise regression** procedure was used for this study.

Using the geometric, traffic and accident data, the regression models were constructed for each unit of analysis. In the linear regression models, accident rates based on the different types of accident (i.e., total accident rate, injury accident rate, etc.) were the dependent variable, and the geometric and traffic data were the independent variables. In those instances where the relationship did not appear to be linear, the intrinsically linear regression model by transformation was used.

CHAPTER IV

PROCEDURE

This study concerned itself with the development of linear regression models for predicting accidents occurring on freeway interchanges. One of the questions investigated in this research was a determination of whether stratified data or nonstratified data would result in better accident prediction models.

The units of analysis for constructing the accident predictive models for the total freeway interchange were based on individual predictive models for the following elements:

- Mainline unit
- Crossroad unit
- Ramp unit

Mainline units include the freeway lanes from a point 500 ft. before the deceleration lane for the off-ramp to a point 500 ft. after the acceleration lane of the on-ramp. Crossroad units include the roadway from a point 250 ft. before the intersection of the on-ramp and the crossroad to a point 250 ft. after the intersection of the off-ramp and the crossroad. Ramp units include the on-ramp units from the intersection of the cross-road to the end of the acceleration lane and the off-ramp units from the beginning of the deceleration lane on the freeway to the intersection with the crossroad.

Models constructed before data stratification

Based upon the above units of analysis, a linear regression model was constructed using the total data based on the following formula:

Accidents = **f**(ADT, Population, Lane mileage, # of Ramps)

The best linear regression models of accident prediction on each unit of analysis was as follows:

Model for Mainline Unit

$$Y = -8.0362 + 0.00021658X_1 + 0.05523X_2 + 0.000008697X_3 + 3.39985X_4 - 1.86537X_5$$

where Y = Total number of accidents per unit

X_1 = Average Daily Traffic (ADT)

X_2 = Lane mileage

X_3 = Population

X_4 = Number of Off-ramps

X_5 = Number of On-ramps

For this model, the multiple regression coefficient (**R**) was 0.5624.

Model for Crossroad Unit

$$Y = 5.9372 + 0.00019387X_1 + 0.01979X_2 + 0.000004297X_3$$

where Y = Total number of accidents per unit

X_1 = Average Daily Traffic (ADT)

X_2 = Lane mileage

X_3 = Population

For this model, the multiple regression coefficient (**R**) was 0.386.

Model for Ramp Unit

$$Y = -0.8302 + 0.00001575X_1 + 0.02555X_2 + 0.000000671X_3 + 0.26683X_4$$

where Y = Total number of accidents per unit

X_1 = Average Daily Traffic (ADT)

X_2 = Ramp lane mileage

X_3 = Population

X_4 = Number of Off-ramps

For this model, the multiple regression coefficient (**R**) was 0.323.

It was obvious that there was more variance in the accident data than that which could be satisfactorily explained by these linear regression models. Thus, a systematic method of stratifying the interchanges to reduce the variance, and increase the explanatory power of the models was undertaken.

As a simple test to determine whether stratification might be useful, a model of nighttime accidents on cloverleaf freeway interchanges was developed as follows:

$$Y = -2.4229 + 0.00004974X_1 + 0.05896X_2$$

where Y = Dark accidents

X_1 = Average Daily Traffic (ADT)

X_2 = Lane mileage

For this model, the multiple regression coefficient (**R**) was 0.724. Thus, it appears that stratifying the data can lead to improved model reliability. The remaining question is whether the stratification procedure will result in useful data upon which design decisions can be made.

Data Stratification

IV-1. Data File Format

As described in the preceding section, the objectives of this research are to: 1) identify accident rates as they relate to parameters of the interchange elements; 2) compare the accident rates in Michigan with those from J. A. Cirillo; and 3) develop and calibrate interchange accident predictive models based on the accident rates on elements which comprise the interchange.

With the above objectives, the data needed were obtained from the databases of the Michigan Department of Transportation. After data were obtained, they were merged into the master data file using Fortran programs. The master data file contains elements from the geometric data file, the accident data file and the traffic data file. This master data file also includes a category code. Thus, the master data file can be sorted into specific data file sets as needed for research.

From the master data file, the categories used to format the data file sets needed for this research were:

- Activity Density
- Interchange Type
- Interchange Element

1). Data file set by Activity Density

For the activity density, the master data file was classified into 3 area types of activity density: urban; rural; and fringe. The number of interchanges and the percentage of each area type are:

- Urban: 28.07 % (185 out of 659)
- Rural: 49.47 % (326 out of 659)
- Fringe: 22.46 % (148 out of 659)

2). Data file set by Interchange Type

For the freeway interchange type, the master data file was divided into 30 interchange types with the percentage and the total number of interchanges for each interchange type:

- Diamond: 19.12 % (126 out of 659)
- Tight diamond: 11.68 % (77 out of 659)
- Modified diamond: 4.10 % (27 out of 659)
- Modified tight diamond: 4.10 % (27 out of 659)
- Partial diamond: 2.73 % (18 out of 659)
- Partial tight diamond: 4.70 % (31 out of 659)
- Split diamond: 2.28 % (15 out of 659)
- Diamond plus 1 loop: 2.88 % (19 out of 659)
- Parclo A: 2.73 % (18 out of 659)
- Parclo A 4 quad: 6.98 % (46 out of 659)
- Parclo B: 3.03 % (20 out of 659)
- Parclo B 4 quad: 1.67 % (11 out of 659)

- Parclo AB: 4.10 % (27 out of 659)
- Parclo AB 4 quad: 1.82 % (12 out of 659)
- Cloverleaf: 1.37 % (9 out of 659)
- Cloverleaf with CD roads: 1.21 % (8 out of 659)
- Cloverleaf minus 1 loop: 0.46 % (3 out of 659)
- Trumpet A: 1.37 % (9 out of 659)
- Trumpet B: 1.37 % (9 out of 659)
- Full directional: 1.52 % (10 out of 659)
- Partial directional: 2.12 % (14 out of 659)
- Directional Y: 1.21 % (8 out of 659)
- General Directional: 0.76 % (5 out of 659)
- Partial directional Y: 4.40 % (29 out of 659)
- Directional with loops: 1.37 % (9 out of 659)
- General: 1.52 % (10 out of 659)
- Urban diamond: 6.68 % (44 out of 659)
- SRI-A: 0.15 % (1 out of 659)
- SRI-B: 0.45 % (3 out 659)
- Other: 2.12 % (14 out of 659)

These freeway interchange types represent the total interchanges in Michigan. Based upon the above freeway interchange types, data files for each interchange type were created, and the total number of accidents and the average number of accidents for each data file was found as shown in Table IV.1. Since many of the sample sizes were too small, these data files were collapsed into a smaller number of groups based upon a similar mean accident rate and variance. These groups are shown in Table IV.2. The interchange types comprising each group are as follows:

- Group 1: Diamond
- Group 2: Tight diamond, Urban diamond
- Group 3: Modified diamond, Modified tight diamond, Parclo A 4 quad
- Group 4: Partial diamond, Partial tight diamond, Trumpet A, Partial Directional Y
- Group 5: Split diamond, General directional, Other
- Group 6: Diamond plus 1 loop, Parclo B 4 quad, Trumpet B, Directional Y
- Group 7: Parclo AB, Partial directional
- Group 8: Cloverleaf, Cloverleaf with CD roads, Cloverleaf minus 1 loop, Directional with loops
- Group 9: Parclo A, Parclo B, Parclo AB 4 quad
- Group 10: Full directional, General
- Group 11: SRI-A
- Group 12: SRI-B

A "t" test was run to determine if these groups were statistically significantly different. While not all groups were different from all other groups, all groups were different from at least one other group. The result of this analysis is shown in Table IV.3.

3). Data file set by Interchange Element

For the freeway interchange element, the master data file was classified into 33 elements of the freeway interchange as follows:

- NB mainline
- SB mainline
- EB mainline
- WB mainline
- Crossroad
- Spread on ramp from crossroad to freeway
- Spread off ramp from freeway to crossroad
- Tight on ramp from crossroad to freeway
- Tight off ramp from freeway to crossroad
- Loop on ramp from crossroad to freeway
- Loop off ramp from freeway to crossroad
- Collector distributor
- On ramp from service road to freeway
- Off ramp from freeway to service road
- Service road from off ramp to crossroad
- Service road from crossroad to on ramp
- On ramp from crossroad to CD
- Off ramp from CD
- Ramp from CD to CD
- Off ramp from CD to service road
- On ramp from service road to CD

- Directional loop ramp
- Directional ramp
- Loop ramp from CD to CD
- Loop ramp from CD to crossroad
- Loop ramp from crossroad to CD
- Off ramp from freeway to CD
- On ramp from CD to freeway
- Turning roadway
- Loop ramp from freeway to CD
- Ramp from service road to service road
- Service road
- Other

These freeway interchange elements represent the freeway interchange in total. For this research the freeway interchange elements were collapsed into 4 analysis units based on the role on the freeway interchange:

- Mainline unit - NB mainline
  SB mainline
  EB mainline
  WB mainline
- Crossroad unit - Crossroad
- On-ramp unit - Spread on ramp from crossroad to freeway
  Tight on ramp from crossroad to freeway
  Loop on ramp from crossroad to freeway

On ramp from service road to freeway

On ramp from CD to freeway

- Off-ramp unit - Spread off ramp from freeway to crossroad

  Tight off ramp from freeway to crossroad

  Loop off ramp from freeway to crossroad

  Off ramp from freeway to service road

  Off ramp from freeway to CD

  Loop ramp from freeway to CD

The total number of accidents by each element and each group of elements is shown in Table IV.4 and IV.5 respectively.

4). Data file set by Accident Type

With the above-described data file set, the types of accidents available on the accident data file were:

- Miscellaneous single vehicle
- Overturn
- Hit train
- Hit parked vehicle
- Backing
- Parking
- Pedestrian
- Fixed object
- Other object

- Animal
- Bicycle
- Head-on
- Angle straight
- Rear-end
- Angle turn
- Side swipe same
- Rear-end left turn
- Rear-end right turn
- Other drive
- Angle drive
- Rear-end drive
- Side swipe opposite
- Head-on left turn
- Dual left turn
- Dual right turn

The number of accidents by type for each interchange element is shown in Table IV.6a through IV.6e. The number of accidents by collapsed interchange elements is shown in Table IV.7.

5). Data file set by Interchange groups with Activity density

Based upon the above interchange types and activity densities, the following combined data file sets were created:

Urban Groups

- Urban group 1
- Urban group 2
- Urban group 3
- Urban group 4
- Urban group 5
- Urban group 6
- Urban group 7
- Urban group 8
- Urban group 9
- Urban group 10
- Urban group 11
- Urban group 12

Rural Groups

- Rural group 1
- Rural group 2
- Rural group 3
- Rural group 4
- Rural group 5
- Rural group 6
- Rural group 7
- Rural group 8
- Rural group 9
- Rural group 10

Fringe Groups

- Fringe group 1
- Fringe group 2
- Fringe group 3
- Fringe group 4
- Fringe group 5
- Fringe group 6
- Fringe group 7
- Fringe group 8
- Fringe group 9
- Fringe group 10

These data file sets represent the total data file by freeway interchange type and the analysis units considered. The total number of accidents in each cell based upon these categories was found, and the accident rate (accidents per interchange) for each analysis unit was also determined as shown in Table IV.8 through IV.38.

IV-2. Summary of Results by Groups

1). Summary of accident types by collapsed interchange elements

Based upon the accident types and the interchange elements described, the total number of accidents for each accident type by each interchange element is shown in Table IV.39 through IV.41. From the results shown in these tables, the average number of accidents that occurred on the analysis units is shown in Table IV.42.

Mainline unit: 4464 accidents out of the total 9534 accidents that occurred on those analysis units occurred on the mainline unit (46.82 percent). The major types of accidents and the percentage of each major accident type were:

- Rear-end: 39.83 % (1778 out of 4464)
- Fixed object: 27.76 % (1239 out of 4464)
- Animal: 12.25 % (547 out of 4464)
- Overturn: 8.2 % (364 out of 4464)
- Miscellaneous single vehicle: 3.3 % (148 out of 4464)

These major types of accidents represent 91.31 percent of the total accidents on the mainline unit.

Crossroad unit: 2536 accidents out of the total 9534 that occurred on those analysis units occurred on the crossroad unit (26.60 percent). The major types of accidents and the percentage of each major accident type were:

- Rear-end: 29.77 % (755 out of 2536)
- Fixed object: 16.56 % (420 out of 2536)
- Angle straight: 9.62 % (244 out of 2536)
- Angle turn: 8.16 % (207 out of 2536)

- Rear-end drive: 4.53 % (115 out of 2536)
- Head-on left turn: 3.94 % (100 out of 2536)

These major types of accidents represent 72.59 percent of all accidents on the crossroad unit.

On-ramp unit: 919 accidents out of the total 9534 accidents that occurred on those analysis units occurred on the on-ramp unit (9.64 percent). The major types of accidents and the percentage of each accident type were:

- Fixed object: 36.02 % (331 out of 919)
- Rear-end: 33.51 % (308 out of 919)
- Overturn: 16.32 % (150 out of 919)

These major types of accidents represent 85.85 percent of the total accidents on the on-ramp unit.

Off-ramp unit: 1615 accidents out of the total 9534 accidents that occurred on those analysis units occurred on the off-ramp unit (16.94 percent). The major types of accidents and the percentage of each accident type were:

- Rear-end: 41.24 % (666 out of 1615)
- Fixed object: 30.4 % (491 out of 1615)
- Overturn: 10.46 % (169 out of 1615)

These major types of accidents represent 82.11 percent of all accidents on the off-ramp unit.

2). Summary of Urban Groups based on Analysis Units

Following stratification, some of the groups were too small to be modeled. An analysis of the sample size for each group is discussed below:

Urban Group 1: As shown in Table IV.8, the total number of accidents was small and the number of interchanges was 5. This group was excluded from further analysis.

Urban Group 2: As shown in Table IV.9, the number of interchanges was 50. The accident rate for the mainline unit was 5.86 accidents per interchange, and the major types of accidents were rear-end and fixed object. The accident rate for the crossroad unit was 3.66, and the major types of accidents were rear-end, angle straight, angle turn, fixed object, other drive, and angle drive. The accident rate for the on-ramp unit was 2.26, and the major types of accidents were rear-end and fixed object. For the off-ramp unit the accident rate was 2.04, and the major types of accident were rear-end and fixed object.

Urban Group 3: As shown in Table IV.10, the number of interchanges was 17. The accident rate for the mainline unit was 9.53 accidents per interchange, and the major types of accidents were rear-end and fixed object. The accident rate for the crossroad unit was 6.18, and the major types of accidents were rear-end and angle turn. The accident rate for the on-ramp unit was 3.41, and the major types of accidents were fixed object and rear-end. For the off-ramp unit the accident rate was 4.82, and the major types of accident were rear-end and fixed object.

Urban Group 4: As shown in Table IV.11, the number of interchanges was 38. The accident rate for the mainline unit was 5.24 accidents per interchange (the lowest value among the urban groups), and the major types of accidents were rear-end and fixed object. The accident rate for the crossroad unit was 3.37 (the lowest value among the urban groups), and the major types of accidents were angle straight, rear-end and hit parked vehicle. The accident rate for the on-ramp unit was 1 (the lowest value among the urban groups), and the major types of accidents were rear-end and fixed object. For the off-ramp unit the accident rate was 1.63, and the major types of accident were rear-end and fixed object (the off-ramp value is also the lowest among the urban groups).

Urban Group 5: As shown in Table IV.12, the number of interchanges was 21. The accident rate for the mainline unit was 8.90 accidents per interchange, and the major types of accidents were rear-end and fixed object. The accident rate for the crossroad unit was 5.52, and the major types of accidents were rear-end, angle straight, fixed object, and rear-end drive. The accident rate for the on-ramp unit was

2.14, and the major types of accidents were rear-end and fixed object. For the off-ramp unit the accident rate was 2.71, and the major types of accident were rear-end and fixed object.

Urban Group 6: As shown in Table IV.13, the number of interchanges was 10. The accident rate for the mainline unit was 11 accidents per interchange, and the major types of accidents were rear-end and fixed object. The accident rate for the crossroad unit was 6, and the major type of accident was rear-end. The accident rate for the on-ramp unit was 3.5 (the highest value among the urban groups), and the major types of accidents were rear-end and fixed object. For the off-ramp unit the accident rate was 6, and the major types of accident were rear-end and fixed object (the off-ramp value is the highest among the urban groups).

Urban Group 7: As shown in Table IV.14, the number of interchanges was 12. The accident rate for the mainline unit was 7.75 accidents per interchange, and the major types of accidents were rear-end and fixed object. The accident rate for the crossroad unit was 6.5, and the major type of accident was rear-end. The accident rate for the on-ramp unit was 1.83, and the major type of accident was fixed object. For the off-ramp unit the accident rate was 2.5, and the major type of accident was rear-end.

Urban Group 8: As shown in Table IV.15, the number of interchanges was 7. This group was excluded from further analysis.

Urban Group 9: As shown in Table IV.16, the number of interchanges was 8. This group was excluded from further analysis.

Urban Group 10: As shown in Table IV.17, the number of interchanges was 11. The accident rate for the mainline unit was 15.0 accidents per interchange (the highest value for any urban group), and the major types of accidents were rear-end and fixed object. The accident rate for the crossroad unit was 7.09 (the highest value for any urban group), and the major types of accidents were rear-end, fixed object and angle straight. The accident rate for the on-ramp unit was 1.27, and the major type of accident was rear-end. For the off-ramp unit the accident rate was 2.82, and the major types of accidents were rear-end and fixed object.

Urban Group 11: As shown in Table IV.18, the number of interchanges was 1. This group was excluded from further analysis.

Urban Group 12: As shown in Table IV.19, the number of interchanges was 3. This group was excluded from further analysis.

The highest and lowest accident rates for each analysis unit in the urban groups are:

- Group 10 had the highest mainline accident rate (13.75)
- Group 4 had the lowest mainline accident rate (5.24)
- Group 10 had the highest crossroad accident rate (6.5)

- Group 4 had the lowest crossroad accident rate (3.37)
- Group 6 had the highest on-ramp accident rate (3.5)
- Group 4 had the lowest on-ramp accident rate (1)
- Group 6 had the highest off-ramp accident rate (6.0)
- Group 4 had the lowest off-ramp accident rate (1.63)

3). Summary of Rural Groups based upon Analysis Units

Rural Group 1: As shown in Table IV.20, the total number of interchanges was 106. The accident rate of the mainline unit was 5.03, and the major types of accidents were animal, fixed object, rear-end, and overturn. The accident rate for the crossroad unit was 2.25, and the major types of accidents were fixed object, animal, rear-end, angle straight, angle turn, and head-on. The accident rate for the on-ramp unit was 0.4 (the lowest value among the rural groups), and the major types of accidents were fixed object and overturn. For the off-ramp the accident rate was 1.18, and the major types of accidents were fixed object, rear-end, overturn, and animal.

Rural Group 2: As shown in Table IV.21, the number of interchanges was 47. The accident rate for the mainline unit was 5.57 accidents per interchange, and the major types of accidents were animal, fixed object and rear-end. The accident rate for the crossroad unit was 2.74, and the major types of accidents were fixed object, rear-end, angle straight, animal, angle turn. The accident rate for the on-ramp unit was 0.60, and the major type of accident was fixed object. For the off-ramp unit the accident rate was 1.57, and the major types of accident were rear-end and fixed object.

Rural Group 3: As shown in Table IV.22, the number of interchanges was 43. The accident rate for the mainline unit was 5.93 accidents per interchange, and the major types of accidents were rear-end, fixed object, animal, and overturn. The accident rate for the crossroad unit was 4.19, and the major types of accidents were rear-end and fixed object. The accident rate for the on-ramp unit was 1.07, and the major types of accidents were fixed object, overturn and rear-end. For the off-ramp unit the accident rate was 2.47, and the major types of accident were rear-end and fixed object.

Rural Group 4: As shown in Table IV.23, the number of interchanges was 36. The accident rate for the mainline unit was 4.97 accidents per interchange (the lowest value among the rural groups), and the major types of accidents were rear-end, fixed object, animal and overturn. The accident rate for the crossroad unit was 1.06 (the lowest value among the rural groups), and the major types of accidents were fixed object and rear-end. The accident rate for the on-ramp unit was 0.44, and the major type of accident was fixed object. For the off-ramp unit the accident rate was 0.56 (the lowest value among the rural groups), and the major type of accident was fixed object.

Rural Group 5: As shown in Table IV.24, the number of

interchanges was 7. This group was excluded from further analysis.

Rural Group 6: As shown in Table IV.25, the number of interchanges was 27. The accident rate for the mainline unit was 7.41 accidents per interchange (the highest value among the rural groups), and the major types of accidents were rear-end, fixed object, animal and overturn. The accident rate for the crossroad unit was 2.96, and the major types of accidents were rear-end and fixed object. The accident rate for the on-ramp unit was 0.74, and the major types of accidents were overturn and fixed object. For the off-ramp unit the accident rate was 1.74, and the major types of accidents were rear-end and fixed object.

Rural Group 7: As shown in Table IV.26, the number of interchanges was 17. The accident rate for the mainline unit was 6.94 accidents per interchange, and the major types of accidents were fixed object, rear-end, animal and overturn. The accident rate for the crossroad unit was 4.24, and the major types of accidents were rear-end and fixed object. The accident rate for the on-ramp unit was 1.18 (the highest value among the rural groups), and the major types of accidents were overturn and fixed object. For the off-ramp unit the accident rate was 2.53 (the highest value among the rural groups), and the major types of accidents were rear-end and fixed object.

Rural Group 8: As shown in Table IV.27, the number of interchanges was 8. This group was excluded from further analysis.

Rural Group 9: As shown in Table IV.28, the number of interchanges was 29. The accident rate for the mainline unit was 6 accidents per interchange, and the major types of accidents were fixed object, rear-end, animal and overturn. The accident rate for the crossroad unit was 4.34 (the highest value among the rural groups), and the major types of accidents were fixed object and rear-end. The accident rate for the on-ramp unit was 0.90, and the major types of accidents were fixed object and overturn. For the off-ramp unit the accident rate was 2.31, and the major types of accidents were fixed object, rear-end, and overturn.

Rural Group 10: As shown in Table IV.29, the number of interchanges was 6. This group was excluded from further analysis.

The highest and lowest accident rates for each analysis unit in the rural groups are:

- Group 6 had the highest mainline accident rate (7.41)
- Group 4 had the lowest mainline accident rate (4.84)
- Group 9 had the highest crossroad accident rate (4.5)
- Group 4 had the lowest crossroad accident rate (1.03)
- Group 7 had the highest on-ramp accident rate (1.18)
- Group 1 had the lowest on-ramp accident rate (0.39)
- Group 7 had the highest off-ramp accident rate (2.53)

• Group 4 had the lowest off-ramp accident rate (0.54)

4). Summary of Fringe Groups based on Analysis Units

Fringe Group 1: As shown in Table IV.30, the total number of interchanges was 13. The accident rate of the mainline unit was 6, and the major types of accidents were animal, fixed object and rear-end. The accident rate for the crossroad unit was 3.85, and the major types of accidents were fixed object, rear-end, angle straight and angle turn. The accident rate for the on-ramp unit was 1.38, and the major types of accident were fixed object and overturn. For the off-ramp unit the accident rate was 3.23, and the major types of accidents were rear-end, fixed object and overturn.

Fringe Group 2: As shown in Table IV.31, the number of interchanges was 25. The accident rate for the mainline unit was 6.6 accidents per interchange, and the major types of accidents were rear-end, fixed object, overturn and animal. The accident rate for the crossroad unit was 3.6, and the major types of accidents were rear-end, fixed object, angle straight and angle turn. The accident rate for the on-ramp unit was 1.24 (the lowest value among the fringe groups), and the major types of accidents were fixed object and rear-end. For the off-ramp unit the accident rate was 3.36, and the major types of accident were rear-end and fixed object.

Fringe Group 3: As shown in Table IV.32, the number of interchanges was 40. The accident rate for the mainline unit was 7.48 accidents per interchange, and the major types of accidents were rear-end, fixed object, overturn and animal. The accident rate for the crossroad unit was 5.98 (the highest value among the fringe groups), and the major types of accidents were rear-end, fixed object, angle turn, angle straight and rear-end drive. The accident rate for the on-ramp unit was 2.18, and the major types of accidents were fixed object, rear-end and overturn. For the off-ramp unit the accident rate was 3.75, and the major types of accident were rear-end, fixed object and overturn.

Fringe Group 4: As shown in Table IV.33, the number of interchanges was 12. The accident rate for the mainline unit was 5.5 accidents per interchange (the lowest value among the fringe groups), and the major types of accidents were rear-end and fixed object. The accident rate for the crossroad unit was 1.5 (the lowest value among the fringe groups), and the major type of accident was nothing to be considered. The accident rate for the on-ramp unit was 1.25, and the major types of accidents were rear-end and fixed object. For the off-ramp unit the accident rate was 1.25 (the lowest value among the fringe groups), and the major types of accident were rear-end and fixed object.

Fringe Group 5: As shown in Table IV.34, the number of interchanges was 6. This group was excluded from further analysis.

Fringe Group 6: As shown in Table IV.35, the number of interchanges was 11. The accident rate for the mainline unit was 7.27 accidents per interchange, and the major types of accidents were fixed object and rear-end. The accident rate for the crossroad unit was 4.82, and the major types of accidents were rear-end and fixed object. The accident rate for the on-ramp unit was 1.73, and the major type of accident was fixed object. For the off-ramp unit the accident rate was 4.36, and the major types of accidents were rear-end, fixed object and overturn.

Fringe Group 7: As shown in Table IV.36, the number of interchanges was 12. The accident rate for the mainline unit was 5.92 accidents per interchange, and the major types of accidents were rear-end and fixed object. The accident rate for the crossroad unit was 3.67, and the major type of accident was fixed object. The accident rate for the on-ramp unit was 1.25, and the major type of accident was fixed object. For the off-ramp unit the accident rate was 2.5, and the major types of accidents were fixed object and rear-end.

Fringe Group 8: As shown in Table IV.37, the number of interchanges was 14. The accident rate for the mainline unit was 13.71 accidents per interchange (the highest value among the fringe groups), and the major types of accidents were rear-end and fixed object. The accident rate for the crossroad unit was 5.71, and the major types of accidents were rear-end and fixed object. The accident rate for the on-ramp unit was

2.93 (the highest value among the fringe groups), and the major types of accidents were rear-end and fixed object. For the off-ramp unit the accident rate was 3.79, and the major types of accidents were rear-end and fixed object.

Fringe Group 9: As shown in Table IV.38, the number of interchanges was 12. The accident rate for the mainline unit was 6.92 accidents per interchange, and the major types of accidents were rear-end, fixed object and animal. The accident rate for the crossroad unit was 4.83, and the major type of accident was rear-end. The accident rate for the on-ramp unit was 1.92, and the major type of accident was fixed object. For the off-ramp unit the accident rate was 4.58 (the highest value among the fringe groups), and the major types of accidents were fixed object and rear-end.

Fringe Group 10: As shown in Table IV.39, the number of interchanges was 2. This group was excluded from further analysis.

The highest and lowest accident rates for each analysis unit in the fringe groups are:

- Group 8 had the highest mainline accident rate (12.8)
- Group 4 had the lowest mainline accident rate (5.5)
- Group 3 had the highest crossroad accident rate (5.98)
- Group 4 had the lowest crossroad accident rate (1.5)
- Group 8 had the highest on-ramp accident rate (2.73)

- Group 4 had the lowest on-ramp accident rate (1.29)
- Group 6 had the highest off-ramp accident rate (4.8)
- Group 4 had the lowest off-ramp accident rate (1.25)

5). Comparison of the accident rates

From the results of the urban groups, group 4 had the lowest accident rates for any analysis units, whereas group 6 had the highest accident rates for the ramp units and group 10 had the highest accident rates for the mainline and crossroad units. In the rural groups, group 4 again had the lowest accident rates for any analysis units excluding the on-ramp unit for which group 1 had the lowest accident rate. Group 6, group 7 and group 9 had the highest accident rates for the mainline unit, the ramp units and the crossroad unit, respectively. For the fringe groups, group 4 once again had the lowest accident rates for the same analysis units as the rural groups excluding the on-ramp unit for which group 2 had the lowest accident rate. Group 3, group 8 and group 9 had the highest accident rates for the crossroad unit, the mainline and on-ramp units, and the off-ramp unit, respectively. These groups by the analysis units can be compared as shown in Table IV.45.

IV-3. Summary of Results

Based upon the results from each group of some sample interchanges, the average number of accidents on the mainline unit were generally higher than those on the other units as shown in Table IV.46. However, the accident rates on the ramp units were higher than those on the mainline unit as shown in Table IV.47 when the traffic volumes were considered with those average accidents.

The data file set to be used in modelling will be selected based on the Charts 4.1 through 4.4. The groups with less than 10 interchanges were excluded from the analysis. In the charts, the groups included for further analysis were marked by **. The sample data file is shown in Table IV.44.

Table IV.1 Mean accident rate and Variance by Interchange Type

Interchange Type	Mean Accident Rate	Variance	Number of Interchanges
1. Diamond	2.41	14.07	126
2. Tight Diamond	3.72	27.07	77
3. Modified Diamond	3.73	74.75	27
4. Modified Tight Diamond	4.80	75.31	27
5. Partial Diamond	0.91	0.30	18
6. Partial Tight Diamond	1.12	0.91	31
7. Split Diamond	4.96	20.69	15
8. Diamond plus 1 loop	2.91	7.08	19
9. Parclo A	3.01	3.57	18
10. Parclo A 4 Quad	4.44	74.24	46
11. Parclo B	2.21	3.57	20
12. Parclo B 4 Quad	3.78	6.97	11
13. Parclo AB	4.51	42.60	27
14. Parclo AB 4 Quad	3.23	6.73	12
15. Cloverleaf	4.21	2.91	9
16. Cloverleaf with C-D Roads	4.48	3.30	8
17. Cloverleaf minus 1 loop	4.43	1.97	3
18. Trumpet A	2.65	1.30	9
19. Trumpet B	2.17	5.82	9
20. Full Directional	14.29	449.47	10
21. Partial Directional	5.66	36.41	14
22. Directional Y	3.97	7.49	8
23. General Directional	4.94	18.42	5
24. Partial Directional Y	1.17	1.34	29
25. Directional with loops	4.23	3.57	9
26. General	6.26	283.70	10
27. Urban Diamond	3.32	27.65	44
28. SRI-A	4.07	.	1
29. SRI-B	6.93	3.13	3
30. Other	4.11	20.41	14
Total			659

Table IV.2 Mean accident rate and Variance by Interchange Group

Interchange Group	Mean Accident Rate	Variance	Number of Interchanges
1. Group 1	2.41	14.07	126
2. Group 2	3.58	27.04	121
3. Group 3	4.34	73.27	100
4. Group 4	1.25	1.17	87
5. Group 5	4.61	19.27	34
6. Group 6	3.15	6.86	47
7. Group 7	4.90	39.82	41
8. Group 8	4.31	2.82	29
9. Group 9	2.75	4.41	50
10. Group 10	10.27	364.43	20
11. Group 11	4.07	.	1
12. Group 12	6.93	3.13	3
Total			659

Table IV.3 Classification of significance between Groups based on t-test

GROUP	GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5	GROUP 6	GROUP 7	GROUP 8	GROUP 9	GROUP 10	GROUP 11	GROUP 12
GROUP 1		S	S	S	S	NS	S	S	NS	S	NS	S
GROUP 2	S		NS	S	NS	NS	NS	NS	NS	S	NS	NS
GROUP 3	S	NS		S	NS	NS	NS	NS	NS	S	NS	NS
GROUP 4	S	S	S		S	S	S	S	S	S	S	S
GROUP 5	S	NS	NS	S		S	NS	NS	S	NS	NS	NS
GROUP 6	NS	NS	NS	S	S		S	S	NS	S	NS	S
GROUP 7	S	NS	NS	S	NS	S		NS	S	NS	NS	NS
GROUP 8	S	NS	NS	S	NS	S	NS		S	S	NS	S
GROUP 9	NS	NS	NS	S	S	NS	S	S		S	NS	S
GROUP 10	S	S	S	S	NS	S	NS	S	S		NS	NS
GROUP 11	NS	NS	NS	S	NS	NS	NS	NS	NS	NS		NS
GROUP 12	S	NS	NS	S	NS	S	NS	S	S	NS	NS	

S represents that the mean accident rates between groups considered are significantly different at 5 % level of significance.
NS represents that the mean accident rates between groups considered are not significantly different at 95 % level of significance.

Table IV.4 Total number of Accidents by Uncollapsed Interchange Elements

INTERCHANGE ELEMENTS	TOTAL NUMBER OF ACCIDENTS
01 NB MAINLINE	1215
02 SB MAINLINE	1165
03 EB MAINLINE	1040
04 WB MAINLINE	1044
09 CROSSROAD	2536
10 SPREAD ON RAMP FROM CROSSROAD TO FWY	308
11 SPREAD OFF RAMP FROM FWY TO CROSSROAD	716
12 TIGHT ON RAMP FROM CROSSROAD TO FWY	223
13 TIGHT OFF RAMP FROM FWY TO CROSSROAD	376
14 LOOP ON RAMP FROM CROSSROAD TO FWY	202
15 LOOP OFF RAMP FROM FWY TO CROSSROAD	254
16 COLLECTOR DISTRIBUTOR	120
17 ON RAMP FROM SERVICE RD TO FWY	155
18 OFF RAMP FROM FWY TO SERVICE RD	229
19 SERVICE RD FROM OFF RAMP TO CROSSROAD	484
20 SERVICE RD FROM CROSSROAD TO ON RAMP	408
21 ON RAMP FROM CROSSROAD TO CD	44
22 OFF RAMP FROM CD	36
23 RAMP FROM CD TO CD	12
24 OFF RAMP FROM CD TO SERVICE RD	3
25 ON RAMP FROM SERVICE RD TO CD	2
26 DIRECTIONAL LOOP RAMP	62
27 DIRECTIONAL RAMP	561
28 LOOP RAMP FROM CD TO CD	8
33 LOOP RAMP FROM CD TO CROSSROAD	11
34 LOOP RAMP FROM CROSSROAD TO CD	19
35 OFF RAMP FROM FWY TO CD	37
36 ON RAMP FROM CD TO FWY	31
37 TURNING ROADWAY	13
38 LOOP RAMP FROM FWY TO CD	3
39 RAMP FROM SERVICE RD TO SERVICE RD	8
41 SERVICE RD	164
42 OTHER	19
TOTAL NUMBER OF ACCIDENTS	11508

Table IV.5 Total number of Accidents by Collapsed interchange elements

COLLAPSED INTERCHANGE ELEMENTS	TOTAL NUMBER OF ACCIDENTS
MAINLINE UNIT	4464
CROSSROAD UNIT	2536
ON-RAMP UNIT	919
OFF-RAMP UNIT	1615
TOTAL NUMBER OF ACCIDENTS	9534

MAINLINE UNIT: NB MAINLINE
SB MAINLINE
EB MAINLINE
WB MAINLINE

CROSSROAD UNIT: CROSSROAD

ON-RAMP UNIT: SPREAD ON RAMP FROM CROSSROAD TO FWY
TIGHT ON RAMP FROM CROSSROAD TO FWY
LOOP ON RAMP FROM CROSSROAD TO FWY
ON RAMP FROM SERVICE RD TO FWY
ON RAMP FROM CD TO FWY

OFF-RAMP UNIT: SPREAD OFF RAMP FROM FWY TO CROSSROAD
TIGHT OFF RAMP FROM FWY TO CROSSROAD
LOOP OFF RAMP FROM FWY TO CROSSROAD
OFF RAMP FROM FWY TO SERVICE RD
OFF RAMP FROM FWY TO CD
LOOP RAMP FROM FWY TO CD

Table IV.6a Total number of Accidents by Each type of Accidents and Interchange Elements

INTERCHANGE ELEMENTS	MISCELLANEOUS	OVERTURN	HIT TRAIN	HIT PARKED VEH.	BACKING
01 NB MAINLINE	30	103		20	2
02 SB MAINLINE	47	120		20	2
03 EB MAINLINE	31	73		24	
04 WB MAINLINE	40	68		23	2
09 CROSSROAD	19	78		48	19
10 SPREAD ON RAMP FROM CROSSROAD TO FWY	10	78		9	3
11 SPREAD OFF RAMP FROM FWY TO CROSSROAD	20	76		17	19
12 TIGHT ON RAMP FROM CROSSROAD TO FWY	5	20		2	5
13 TIGHT OFF RAMP FROM FWY TO CROSSROAD	8	22		4	6
14 LOOP ON RAMP FROM CROSSROAD TO FWY	7	41		2	3
15 LOOP OFF RAMP FROM FWY TO CROSSROAD	13	55		3	
16 COLLECTOR DISTRIBUTOR	1	8		1	1
17 ON RAMP FROM SERVICE RD TO FWY	1	8		1	3
18 OFF RAMP FROM FWY TO SERVICE RD	4	11		1	4
19 SERVICE RD FROM OFF RAMP TO CROSSROAD	2	6		6	13
20 SERVICE RD FROM CROSSROAD TO ON RAMP		5		15	8
21 ON RAMP FROM CROSSROAD TO CD		3		1	
22 OFF RAMP FROM CD		2			3
23 RAMP FROM CD TO CD	1	2			1
24 OFF RAMP FROM CD TO SERVICE RD					
25 ON RAMP FROM SERVICE RD TO CD					
26 DIRECTIONAL LOOP RAMP	1	14		2	
27 DIRECTIONAL RAMP	7	57		11	7
28 LOOP RAMP FROM CD TO CD					1
33 LOOP RAMP FROM CD TO CROSSROAD		1			1
34 LOOP RAMP FROM CROSSROAD TO CD		3			
35 OFF RAMP FROM FWY TO CD		5		1	
36 ON RAMP FROM CD TO FWY		3		1	
37 TURNING ROADWAY				1	
38 LOOP RAMP FROM FWY TO CD	1				
39 RAMP FROM SERVICE RD TO SERVICE RD					
41 SERVICE RD				4	1
42 OTHER					
TOTAL NUMBER OF ACCIDENTS	248	862		217	103

Table IV.6b Total number of Accidents by Each type of Accidents and Interchange Elements

INTERCHANGE ELEMENTS	PARKING	PEDESTRIAN	FIXED OBJECT	OTHER OBJECT	ANIMAL
01 NB MAINLINE	2	4	329	15	176
02 SB MAINLINE	3	3	324	14	150
03 EB MAINLINE	2	1	301	21	105
04 WB MAINLINE	4	1	285	13	116
09 CROSSROAD	16	18	420	5	94
10 SPREAD ON RAMP FROM CROSSROAD TO FWY		1	118	4	7
11 SPREAD OFF RAMP FROM FWY TO CROSSROAD		5	231	3	22
12 TIGHT ON RAMP FROM CROSSROAD TO FWY	2	2	83	2	1
13 TIGHT OFF RAMP FROM FWY TO CROSSROAD		3	96	2	2
14 LOOP ON RAMP FROM CROSSROAD TO FWY	1	2	88	1	1
15 LOOP OFF RAMP FROM FWY TO CROSSROAD		2	92	1	4
16 COLLECTOR DISTRIBUTOR	1		38		1
17 ON RAMP FROM SERVICE RD TO FWY		1	29		
18 OFF RAMP FROM FWY TO SERVICE RD		4	65	1	
19 SERVICE RD FROM OFF RAMP TO CROSSROAD	1	1	63		2
20 SERVICE RD FROM CROSSROAD TO ON RAMP	3	8	49	1	
21 ON RAMP FROM CROSSROAD TO CD			12	1	
22 OFF RAMP FROM CD			13		
23 RAMP FROM CD TO CD			4		1
24 OFF RAMP FROM CD TO SERVICE RD			2	1	
25 ON RAMP FROM SERVICE RD TO CD					
26 DIRECTIONAL LOOP RAMP			35		
27 DIRECTIONAL RAMP		1	215	4	9
28 LOOP RAMP FROM CD TO CD			4		
33 LOOP RAMP FROM CD TO CROSSROAD			4		
34 LOOP RAMP FROM CROSSROAD TO CD			8		
35 OFF RAMP FROM FWY TO CD			6		2
36 ON RAMP FROM CD TO FWY			13		
37 TURNING ROADWAY			6		
38 LOOP RAMP FROM FWY TO CD			1		
39 RAMP FROM SERVICE RD TO SERVICE RD			2		
41 SERVICE RD		1	14		
42 OTHER			5		
TOTAL NUMBER OF ACCIDENTS	35	58	2955	89	693

Table IV.6c Total number of Accidents by Each type of Accidents and Interchange Elements

	INTERCHANGE ELEMENTS	BICYCLE	HEAD-ON	ANGLE STRAIGHT	REAR-END	ANGLE TURN
01	NB MAINLINE	1	16	19	466	1
02	SB MAINLINE	1	11	9	437	3
03	EB MAINLINE		8	4	446	4
04	WB MAINLINE		11	16	429	6
09	CROSSROAD	22	67	244	755	207
10	SPREAD ON RAMP FROM CROSSROAD TO FWY		1	4	64	2
11	SPREAD OFF RAMP FROM FWY TO CROSSROAD	1	9	8	266	13
12	TIGHT ON RAMP FROM CROSSROAD TO FWY		2	7	79	2
13	TIGHT OFF RAMP FROM FWY TO CROSSROAD	2	2	9	192	6
14	LOOP ON RAMP FROM CROSSROAD TO FWY		1		50	1
15	LOOP OFF RAMP FROM FWY TO CROSSROAD	2	6	3	64	1
16	COLLECTOR DISTRIBUTOR			5	55	2
17	ON RAMP FROM SERVICE RD TO FWY			6	105	
18	OFF RAMP FROM FWY TO SERVICE RD		2	5	123	1
19	SERVICE RD FROM OFF RAMP TO CROSSROAD	1	2	95	188	26
20	SERVICE RD FROM CROSSROAD TO ON RAMP	6		81	134	24
21	ON RAMP FROM CROSSROAD TO CD			1	24	
22	OFF RAMP FROM CD			1	16	
23	RAMP FROM CD TO CD				3	
24	OFF RAMP FROM CD TO SERVICE RD					
25	ON RAMP FROM SERVICE RD TO CD				2	
26	DIRECTIONAL LOOP RAMP		1		7	
27	DIRECTIONAL RAMP	1	6	15	207	4
28	LOOP RAMP FROM CD TO CD				3	
33	LOOP RAMP FROM CD TO CROSSROAD		1		4	
34	LOOP RAMP FROM CROSSROAD TO CD			1	7	
35	OFF RAMP FROM FWY TO CD			1	20	1
36	ON RAMP FROM CD TO FWY				10	1
37	TURNING ROADWAY			1	4	
38	LOOP RAMP FROM FWY TO CD				1	
39	RAMP FROM SERVICE RD TO SERVICE RD				6	
41	SERVICE RD	3		28	78	11
42	OTHER			4	6	1
	TOTAL NUMBER OF ACCIDENTS	40	146	567	4251	317

Table IV.6d Total number of Accidents by Each type of Accidents and Interchange Elements

	INTERCHANGE ELEMENTS	SIDESWIPE SAME	REAR-END LEFT	REAR-END RIGHT	OTHER DRIVE	ANGLE DRIVE
01	NB MAINLINE	21	1	1	3	1
02	SB MAINLINE	8	6	2	1	1
03	EB MAINLINE	9	7	2		
04	WB MAINLINE	14	4	6	1	
09	CROSSROAD	8	95	34	62	84
10	SPREAD ON RAMP FROM CROSSROAD TO FWY		1	1		
11	SPREAD OFF RAMP FROM FWY TO CROSSROAD	1	2	11		
12	TIGHT ON RAMP FROM CROSSROAD TO FWY	4	2	1		
13	TIGHT OFF RAMP FROM FWY TO CROSSROAD	4	1	13		
14	LOOP ON RAMP FROM CROSSROAD TO FWY			1		
15	LOOP OFF RAMP FROM FWY TO CROSSROAD	1	1	4		
16	COLLECTOR DISTRIBUTOR	2	3			
17	ON RAMP FROM SERVICE RD TO FWY	1				
18	OFF RAMP FROM FWY TO SERVICE RD	1	2	4		
19	SERVICE RD FROM OFF RAMP TO CROSSROAD	11	21	13	3	6
20	SERVICE RD FROM CROSSROAD TO ON RAMP	4	25	13	3	2
21	ON RAMP FROM CROSSROAD TO CD	1	1			
22	OFF RAMP FROM CD		1			
23	RAMP FROM CD TO CD					
24	OFF RAMP FROM CD TO SERVICE RD					
25	ON RAMP FROM SERVICE RD TO CD					
26	DIRECTIONAL LOOP RAMP	1	1			
27	DIRECTIONAL RAMP	5	3	1	2	
28	LOOP RAMP FROM CD TO CD					
33	LOOP RAMP FROM CD TO CROSSROAD					
34	LOOP RAMP FROM CROSSROAD TO CD					
35	OFF RAMP FROM FWY TO CD	1				
36	ON RAMP FROM CD TO FWY	1		1		
37	TURNING ROADWAY					
38	LOOP RAMP FROM FWY TO CD					
39	RAMP FROM SERVICE RD TO SERVICE RD					
41	SERVICE RD		8	8		1
42	OTHER		3			
TOTAL NUMBER OF ACCIDENTS		98	188	116	75	95

Table IV.6e Total number of Accidents by Each type of Accidents and Interchange Elements

	INTERCHANGE ELEMENTS	REAR-END DRIVE	SIDESWIPE OPPO.	HEAD-ON LEFT-TN	DUAL LEFT-TURN	DUAL RIGHT-TURN
01	NB MAINLINE	2	1		1	
02	SB MAINLINE		2	1		
03	EB MAINLINE		1	1		
04	WB MAINLINE		3	2		
09	CROSSROAD	115	6	100	10	10
10	SPREAD ON RAMP FROM CROSSROAD TO FWY	2		2		1
11	SPREAD OFF RAMP FROM FWY TO CROSSROAD		2	1	1	8
12	TIGHT ON RAMP FROM CROSSROAD TO FWY	1		2	1	
13	TIGHT OFF RAMP FROM FWY TO CROSSROAD			1	1	2
14	LOOP ON RAMP FROM CROSSROAD TO FWY			1		2
15	LOOP OFF RAMP FROM FWY TO CROSSROAD					2
16	COLLECTOR DISTRIBUTOR	2				1
17	ON RAMP FROM SERVICE RD TO FWY					
18	OFF RAMP FROM FWY TO SERVICE RD				1	
19	SERVICE RD FROM OFF RAMP TO CROSSROAD	7	1	7	7	2
20	SERVICE RD FROM CROSSROAD TO ON RAMP	8		10	8	1
21	ON RAMP FROM CROSSROAD TO CD					
22	OFF RAMP FROM CD					
23	RAMP FROM CD TO CD					
24	OFF RAMP FROM CD TO SERVICE RD					
25	ON RAMP FROM SERVICE RD TO CD					
26	DIRECTIONAL LOOP RAMP					
27	DIRECTIONAL RAMP	2	4			
28	LOOP RAMP FROM CD TO CD					
33	LOOP RAMP FROM CD TO CROSSROAD					
34	LOOP RAMP FROM CROSSROAD TO CD					
35	OFF RAMP FROM FWY TO CD				1	
36	ON RAMP FROM CD TO FWY				1	
37	TURNING ROADWAY					
38	LOOP RAMP FROM FWY TO CD					
39	RAMP FROM SERVICE RD TO SERVICE RD					
41	SERVICE RD	1		2	3	1
42	OTHER					
	TOTAL NUMBER OF ACCIDENTS	140	20	130	35	30

Table IV.7 Accident types by Collapsed interchange elements

ACCIDENT TYPES	MAINLINE UNIT	CROSSROAD UNIT	ON-RAMP UNIT	OFF-RAMP UNIT
000 MISCELLANEOUS SINGLE VEHICLE	148	19	23	46
010 OVERTURN	364	78	150	169
020 HIT TRAIN				
030 HIT PARKED VEHICLE	87	48	15	26
048 BACKING	6	19	14	29
049 PARKING	11	16	3	
050 PEDESTRIAN	9	18	6	14
060 FIXED OBJECT	1239	420	331	491
070 OTHER OBJECT	63	5	7	7
080 ANIMAL	547	94	9	30
090 BICYCLE	2	22		5
141 HEAD-ON	46	67	4	19
144 ANGLE STRAIGHT	48	244	17	26
147 REAR-END	1778	755	308	666
244 ANGLE TURN	14	207	6	22
342 SIDESWIPE SAME	52	8	6	8
345 REAR-END LEFT TURN	18	95	3	6
346 REAR-END RIGHT TURN	11	34	4	32
440 OTHER DRIVE	5	62		
444 ANGLE DRIVE	2	84		
447 REAR-END DRIVE	2	115	3	
543 SIDESWIPE OPPOSITE	7	6		2
545 HEAD-ON LEFT TURN	4	100	5	2
645 DUAL LEFT TURN	1	10	2	3
646 DUAL RIGHT TURN		10	3	12
TOTAL NUMBER OF ACCIDENTS	4464	2536	919	1616

Table IV.8 Accident types by Collapsed interchange elements of Urban group 1

ACCIDENT TYPES	MAINLINE UNIT	CROSSROAD UNIT	ON-RAMP UNIT	OFF-RAMP UNIT
000 MISCELLANEOUS SINGLE VEHICLE	2	1		1
010 OVERTURN	3			
020 HIT TRAIN				
030 HIT PARKED VEHICLE	1			
048 BACKING				
049 PARKING	1			
050 PEDESTRIAN				1
060 FIXED OBJECT	6	3	3	4
070 OTHER OBJECT				1
080 ANIMAL	8			1
090 BICYCLE				
141 HEAD-ON				
144 ANGLE STRAIGHT		1		
147 REAR-END	4	3		4
244 ANGLE TURN	1	5		
342 SIDESWIPE SAME				
345 REAR-END LEFT TURN		2		
346 REAR-END RIGHT TURN				
440 OTHER DRIVE				
444 ANGLE DRIVE				
447 REAR-END DRIVE				
543 SIDESWIPE OPPOSITE				1
545 HEAD-ON LEFT TURN				
645 DUAL LEFT TURN				
646 DUAL RIGHT TURN				
TOTAL NUMBER OF ACCIDENTS	26	15	3	13
NUMBER OF INTERCHANGES = 5				
# OF ACCIDENTS / # OF INTERCHANGES	5.2	3	0.6	2.6

Table IV.9 Accident types by Collapsed interchange elements of Urban group 2

ACCIDENT TYPES	MAINLINE UNIT	CROSSROAD UNIT	ON-RAMP UNIT	OFF-RAMP UNIT
000 MISCELLANEOUS SINGLE VEHICLE	8		1	5
010 OVERTURN	6	1	4	3
020 HIT TRAIN				
030 HIT PARKED VEHICLE	4	7	1	
048 BACKING			3	1
049 PARKING	1	2		
050 PEDESTRIAN	1	4	1	3
060 FIXED OBJECT	56	12	23	36
070 OTHER OBJECT	4			1
080 ANIMAL	2			
090 BICYCLE	1	2		2
141 HEAD-ON	4	3		1
144 ANGLE STRAIGHT	11	28	1	1
147 REAR-END	183	63	72	88
244 ANGLE TURN	2	14		1
342 SIDESWIPE SAME	6	2	4	2
345 REAR-END LEFT TURN	1	8	1	3
346 REAR-END RIGHT TURN	3	3		4
440 OTHER DRIVE		3		
444 ANGLE DRIVE		12		
447 REAR-END DRIVE		12	1	
543 SIDESWIPE OPPOSITE				1
545 HEAD-ON LEFT TURN		6	1	
645 DUAL LEFT TURN				1
646 DUAL RIGHT TURN		1		
TOTAL NUMBER OF ACCIDENTS	293	183	113	152
NUMBER OF INTERCHANGES = 50				
# OF ACCIDENTS / # OF INTERCHANGES	5.86	3.66	2.66	2.04

Table IV.10 Accident types by Collapsed interchange elements of Urban group 3

ACCIDENT TYPES	MAINLINE UNIT	CROSSROAD UNIT	ON-RAMP UNIT	OFF-RAMP UNIT
000 MISCELLANEOUS SINGLE VEHICLE	2		1	1
010 OVERTURN	4	1	9	2
020 HIT TRAIN				
030 HIT PARKED VEHICLE	2	3	1	2
048 BACKING		2	2	2
049 PARKING				
050 PEDESTRIAN				1
060 FIXED OBJECT	40	6	27	26
070 OTHER OBJECT	2		2	
080 ANIMAL	6			
090 BICYCLE		3		
141 HEAD-ON	2	1		2
144 ANGLE STRAIGHT	1	7		3
147 REAR-END	100	55	16	38
244 ANGLE TURN		10		3
342 SIDESWIPE SAME	2			1
345 REAR-END LEFT TURN		2		
346 REAR-END RIGHT TURN		3		
440 OTHER DRIVE				
444 ANGLE DRIVE		3		
447 REAR-END DRIVE		3		
543 SIDESWIPE OPPOSITE	1			
545 HEAD-ON LEFT TURN		3		
645 DUAL LEFT TURN				
646 DUAL RIGHT TURN		3		1
TOTAL NUMBER OF ACCIDENTS	162	105	58	82
NUMBER OF INTERCHANGES = 17				
# OF ACCIDENTS / # OF INTERCHANGES	9.53	6.18	3.41	4.82

Table IV.11 Accident types by Collapsed interchange elements of Urban group 4

ACCIDENT TYPES	MAINLINE UNIT	CROSSROAD UNIT	ON-RAMP UNIT	OFF-RAMP UNIT
000 MISCELLANEOUS SINGLE VEHICLE	9	1		1
010 OVERTURN	6	5	1	3
020 HIT TRAIN				
030 HIT PARKED VEHICLE	2	12		1
048 BACKING		1		2
049 PARKING	1	7	1	
050 PEDESTRIAN		1		1
060 FIXED OBJECT	49	8	11	17
070 OTHER OBJECT	1			1
080 ANIMAL	1			
090 BICYCLE				
141 HEAD-ON		1	1	
144 ANGLE STRAIGHT	2	34	2	
147 REAR-END	122	24	21	33
244 ANGLE TURN	2	4		
342 SIDESWIPE SAME	4			
345 REAR-END LEFT TURN		7		
346 REAR-END RIGHT TURN		3		3
440 OTHER DRIVE		4		
444 ANGLE DRIVE		3		
447 REAR-END DRIVE		4		
543 SIDESWIPE OPPOSITE		1		
545 HEAD-ON LEFT TURN		7		
645 DUAL LEFT TURN		1	1	
646 DUAL RIGHT TURN				
TOTAL NUMBER OF ACCIDENTS	199	128	38	62
NUMBER OF INTERCHANGES = 38				
# OF ACCIDENTS / # OF INTERCHANGES	5.24	3.37	1	1.63

Table IV.12 Accident types by Collapsed interchange elements of Urban group 5

ACCIDENT TYPES	MAINLINE UNIT	CROSSROAD UNIT	ON-RAMP UNIT	OFF-RAMP UNIT
000 MISCELLANEOUS SINGLE VEHICLE	5		1	
010 OVERTURN	12		3	6
020 HIT TRAIN				
030 HIT PARKED VEHICLE	5	5	1	
048 BACKING		4	1	
049 PARKING		1		
050 PEDESTRIAN		2		
060 FIXED OBJECT	54	13	8	11
070 OTHER OBJECT	1			
080 ANIMAL	1			
090 BICYCLE				
141 HEAD-ON	2	2		
144 ANGLE STRAIGHT	3	21	1	2
147 REAR-END	101	40	29	36
244 ANGLE TURN		4	1	
342 SIDESWIPE SAME	2			1
345 REAR-END LEFT TURN		6		
346 REAR-END RIGHT TURN				1
440 OTHER DRIVE		2		
444 ANGLE DRIVE		1		
447 REAR-END DRIVE		10		
543 SIDESWIPE OPPOSITE	1			
545 HEAD-ON LEFT TURN		5		
645 DUAL LEFT TURN				
646 DUAL RIGHT TURN				
TOTAL NUMBER OF ACCIDENTS	187	116	45	57
NUMBER OF INTERCHANGES = 22				
# OF ACCIDENTS / # OF INTERCHANGES	8.50	5.27	2.05	2.59

Table IV.13 Accident types by Collapsed interchange elements of Urban group 6

ACCIDENT TYPES	MAINLINE UNIT	CROSSROAD UNIT	ON-RAMP UNIT	OFF-RAMP UNIT
000 MISCELLANEOUS SINGLE VEHICLE	6			
010 OVERTURN	4		5	5
020 HIT TRAIN				
030 HIT PARKED VEHICLE			1	3
048 BACKING			1	1
049 PARKING		2		
050 PEDESTRIAN	1	2		1
060 FIXED OBJECT	31	8	12	13
070 OTHER OBJECT	1	1		1
080 ANIMAL	5			
090 BICYCLE		1		
141 HEAD-ON	3	1		3
144 ANGLE STRAIGHT		8	2	1
147 REAR-END	53	19	11	29
244 ANGLE TURN		2	1	2
342 SIDESWIPE SAME	2		1	
345 REAR-END LEFT TURN	2	1		
346 REAR-END RIGHT TURN		1		1
440 OTHER DRIVE		1		
444 ANGLE DRIVE		3		
447 REAR-END DRIVE		2		
543 SIDESWIPE OPPOSITE	2			
545 HEAD-ON LEFT TURN		7	1	
645 DUAL LEFT TURN				
646 DUAL RIGHT TURN		1		
TOTAL NUMBER OF ACCIDENTS	110	60	35	60
NUMBER OF INTERCHANGES = 10				
# OF ACCIDENTS / # OF INTERCHANGES	11	6	3.5	6

Table IV.14 Accident types by Collapsed interchange elements of Urban group 7

ACCIDENT TYPES	MAINLINE UNIT	CROSSROAD UNIT	ON-RAMP UNIT	OFF-RAMP UNIT
000 MISCELLANEOUS SINGLE VEHICLE	4	1		1
010 OVERTURN	2	1	2	5
020 HIT TRAIN				
030 HIT PARKED VEHICLE	1	1		1
048 BACKING				
049 PARKING				
050 PEDESTRIAN				
060 FIXED OBJECT	24	6	11	6
070 OTHER OBJECT				
080 ANIMAL	5			
090 BICYCLE	1	1		
141 HEAD-ON		1		1
144 ANGLE STRAIGHT	1	5	1	
147 REAR-END	53	38	8	13
244 ANGLE TURN		8		
342 SIDESWIPE SAME				
345 REAR-END LEFT TURN		2		
346 REAR-END RIGHT TURN	2	3		2
440 OTHER DRIVE		3		
444 ANGLE DRIVE		5		
447 REAR-END DRIVE		1		
543 SIDESWIPE OPPOSITE				
545 HEAD-ON LEFT TURN		1		1
645 DUAL LEFT TURN		1		
646 DUAL RIGHT TURN				
TOTAL NUMBER OF ACCIDENTS	93	78	22	30
NUMBER OF INTERCHANGES = 12				
# OF ACCIDENTS / # OF INTERCHANGES	7.75	6.5	1.83	2.5

Table IV.15 Accident types by Collapsed interchange elements of Urban group 8

ACCIDENT TYPES	MAINLINE UNIT	CROSSROAD UNIT	ON-RAMP UNIT	OFF-RAMP UNIT
000 MISCELLANEOUS SINGLE VEHICLE	3		1	
010 OVERTURN	5	3	7	2
020 HIT TRAIN				
030 HIT PARKED VEHICLE	1			1
048 BACKING		1		
049 PARKING			1	
050 PEDESTRIAN				
060 FIXED OBJECT	21	16	11	5
070 OTHER OBJECT	1			
080 ANIMAL	3			
090 BICYCLE				
141 HEAD-ON				
144 ANGLE STRAIGHT	1	2		
147 REAR-END	35	38	3	9
244 ANGLE TURN		2		1
342 SIDESWIPE SAME				
345 REAR-END LEFT TURN				
346 REAR-END RIGHT TURN	1		1	1
440 OTHER DRIVE				
444 ANGLE DRIVE		1		
447 REAR-END DRIVE		1		
543 SIDESWIPE OPPOSITE				
545 HEAD-ON LEFT TURN	1	1		
645 DUAL LEFT TURN				
646 DUAL RIGHT TURN				
TOTAL NUMBER OF ACCIDENTS	72	65	24	19
NUMBER OF INTERCHANGES = 7				
# OF ACCIDENTS / # OF INTERCHANGES	10.3	9.29	3.43	2.71

Table IV.16 Accident types by Collapsed interchange elements of Urban group 9

ACCIDENT TYPES	MAINLINE UNIT	CROSSROAD UNIT	ON-RAMP UNIT	OFF-RAMP UNIT
000 MISCELLANEOUS SINGLE VEHICLE	1			3
010 OVERTURN	1		4	5
020 HIT TRAIN				
030 HIT PARKED VEHICLE	2		1	
048 BACKING		1	1	
049 PARKING				
050 PEDESTRIAN				
060 FIXED OBJECT	20	5	13	8
070 OTHER OBJECT	3		1	1
080 ANIMAL	1			
090 BICYCLE				1
141 HEAD-ON	1			3
144 ANGLE STRAIGHT	1	4		1
147 REAR-END	37	26	14	17
244 ANGLE TURN		7	2	1
342 SIDESWIPE SAME	1	1		1
345 REAR-END LEFT TURN	1	2	1	
346 REAR-END RIGHT TURN		2		
440 OTHER DRIVE		3		
444 ANGLE DRIVE				
447 REAR-END DRIVE		1	1	
543 SIDESWIPE OPPOSITE				
545 HEAD-ON LEFT TURN	1	4		
645 DUAL LEFT TURN				
646 DUAL RIGHT TURN				
TOTAL NUMBER OF ACCIDENTS	70	56	38	41
NUMBER OF INTERCHANGES = 8				
# OF ACCIDENTS / # OF INTERCHANGES	8.75	7	4.75	5.13

Table IV.17 Accident types by Collapsed interchange elements of Urban group 10

ACCIDENT TYPES	MAINLINE UNIT	CROSSROAD UNIT	ON-RAMP UNIT	OFF-RAMP UNIT
000 MISCELLANEOUS SINGLE VEHICLE	4			1
010 OVERTURN	8	2	2	
020 HIT TRAIN				
030 HIT PARKED VEHICLE	1	2		1
048 BACKING				
049 PARKING	2			
050 PEDESTRIAN				1
060 FIXED OBJECT	39	13	2	10
070 OTHER OBJECT	2			
080 ANIMAL				
090 BICYCLE				
141 HEAD-ON	1	1		2
144 ANGLE STRAIGHT	1	12	1	5
147 REAR-END	97	33	9	11
244 ANGLE TURN		6		
342 SIDESWIPE SAME	8			
345 REAR-END LEFT TURN		4		
346 REAR-END RIGHT TURN	1			
440 OTHER DRIVE		1		
444 ANGLE DRIVE		1		
447 REAR-END DRIVE				
543 SIDESWIPE OPPOSITE	1			
545 HEAD-ON LEFT TURN		2		
645 DUAL LEFT TURN		1		
646 DUAL RIGHT TURN				
TOTAL NUMBER OF ACCIDENTS	165	78	14	31
NUMBER OF INTERCHANGES = 12				
# OF ACCIDENTS / # OF INTERCHANGES	13.75	6.50	1.17	2.58

Table IV.18 Accident types by Collapsed interchange elements of Urban group 11

ACCIDENT TYPES	MAINLINE UNIT	CROSSROAD UNIT	ON-RAMP UNIT	OFF-RAMP UNIT
000 MISCELLANEOUS SINGLE VEHICLE				1
010 OVERTURN		1		
020 HIT TRAIN				
030 HIT PARKED VEHICLE				
048 BACKING				
049 PARKING				
050 PEDESTRIAN				
060 FIXED OBJECT		1	1	
070 OTHER OBJECT	2			
080 ANIMAL				
090 BICYCLE				
141 HEAD-ON				
144 ANGLE STRAIGHT				
147 REAR-END	4	4		4
244 ANGLE TURN				
342 SIDESWIPE SAME				
345 REAR-END LEFT TURN				
346 REAR-END RIGHT TURN				
440 OTHER DRIVE				
444 ANGLE DRIVE				
447 REAR-END DRIVE				
543 SIDESWIPE OPPOSITE				
545 HEAD-ON LEFT TURN				
645 DUAL LEFT TURN				
646 DUAL RIGHT TURN				
TOTAL NUMBER OF ACCIDENTS	6	6	1	5
NUMBER OF INTERCHANGES = 1				
# OF ACCIDENTS / # OF INTERCHANGES	6	6	1	5

Table IV.18 Accident types by Collapsed interchange elements of Urban group 11

ACCIDENT TYPES	MAINLINE UNIT	CROSSROAD UNIT	ON-RAMP UNIT	OFF-RAMP UNIT
000 MISCELLANEOUS SINGLE VEHICLE				1
010 OVERTURN		1		
020 HIT TRAIN				
030 HIT PARKED VEHICLE				
048 BACKING				
049 PARKING				
050 PEDESTRIAN				
060 FIXED OBJECT		1	1	
070 OTHER OBJECT	2			
080 ANIMAL				
090 BICYCLE				
141 HEAD-ON				
144 ANGLE STRAIGHT				
147 REAR-END	4	4		4
244 ANGLE TURN				
342 SIDESWIPE SAME				
345 REAR-END LEFT TURN				
346 REAR-END RIGHT TURN				
440 OTHER DRIVE				
444 ANGLE DRIVE				
447 REAR-END DRIVE				
543 SIDESWIPE OPPOSITE				
545 HEAD-ON LEFT TURN				
645 DUAL LEFT TURN				
646 DUAL RIGHT TURN				
TOTAL NUMBER OF ACCIDENTS	6	6	1	5
NUMBER OF INTERCHANGES = 1				
# OF ACCIDENTS / # OF INTERCHANGES	6	6	1	5

Table IV.19 Accident types by Collapsed interchange elements of Urban group 12

ACCIDENT TYPES	MAINLINE UNIT	CROSSROAD UNIT	ON-RAMP UNIT	OFF-RAMP UNIT
000 MISCELLANEOUS SINGLE VEHICLE				
010 OVERTURN	2	2	1	
020 HIT TRAIN				
030 HIT PARKED VEHICLE	1	1		
048 BACKING				
049 PARKING		1		
050 PEDESTRIAN				
060 FIXED OBJECT	3	3	2	5
070 OTHER OBJECT				
080 ANIMAL				
090 BICYCLE				
141 HEAD-ON				
144 ANGLE STRAIGHT	1		3	
147 REAR-END	22	16	13	5
244 ANGLE TURN		4		
342 SIDESWIPE SAME		1		
345 REAR-END LEFT TURN		1		
346 REAR-END RIGHT TURN				
440 OTHER DRIVE		2		
444 ANGLE DRIVE		1		
447 REAR-END DRIVE				
543 SIDESWIPE OPPOSITE				
545 HEAD-ON LEFT TURN				
645 DUAL LEFT TURN	1	1		
646 DUAL RIGHT TURN				
TOTAL NUMBER OF ACCIDENTS	30	33	19	10
NUMBER OF INTERCHANGES = 3				
# OF ACCIDENTS / # OF INTERCHANGES	10	11	6.33	3.33

Table IV.20 Accident types by Collapsed interchange elements of Rural group 1

ACCIDENT TYPES	MAINLINE UNIT	CROSSROAD UNIT	ON-RAMP UNIT	OFF-RAMP UNIT
000 MISCELLANEOUS SINGLE VEHICLE	17		3	6
010 OVERTURN	88	13	12	19
020 HIT TRAIN				
030 HIT PARKED VEHICLE	5	4	1	3
048 BACKING				4
049 PARKING	1			
050 PEDESTRIAN	2	1		1
060 FIXED OBJECT	126	74	17	45
070 OTHER OBJECT	7		1	
080 ANIMAL	184	37	4	11
090 BICYCLE		1		
141 HEAD-ON		11		
144 ANGLE STRAIGHT	1	17	2	
147 REAR-END	93	35	1	30
244 ANGLE TURN	1	13		
342 SIDESWIPE SAME	5			1
345 REAR-END LEFT TURN	2	9		
346 REAR-END RIGHT TURN		1		3
440 OTHER DRIVE	1	2		
444 ANGLE DRIVE		6		
447 REAR-END DRIVE		7		
543 SIDESWIPE OPPOSITE				1
545 HEAD-ON LEFT TURN		8		
645 DUAL LEFT TURN				
646 DUAL RIGHT TURN			1	1
TOTAL NUMBER OF ACCIDENTS	533	239	42	125
NUMBER OF INTERCHANGES = 108				
# OF ACCIDENTS / # OF INTERCHANGES	4.94	2.21	0.39	1.16

Table IV.21 Accident types by Collapsed interchange elements of Rural group 2

ACCIDENT TYPES	MAINLINE UNIT	CROSSROAD UNIT	ON-RAMP UNIT	OFF-RAMP UNIT
000 MISCELLANEOUS SINGLE VEHICLE	12	1	2	2
010 OVERTURN	31	4	3	7
020 HIT TRAIN				
030 HIT PARKED VEHICLE	10	3		
048 BACKING		2		1
049 PARKING			1	
050 PEDESTRIAN				
060 FIXED OBJECT	71	21	13	29
070 OTHER OBJECT	9			
080 ANIMAL	64	15	1	1
090 BICYCLE		3		
141 HEAD-ON	4	5	1	
144 ANGLE STRAIGHT	2	16		
147 REAR-END	56	19	6	29
244 ANGLE TURN	1	13		1
342 SIDESWIPE SAME				1
345 REAR-END LEFT TURN	2	3		
346 REAR-END RIGHT TURN		1		3
440 OTHER DRIVE		5		
444 ANGLE DRIVE		3		
447 REAR-END DRIVE		5		
543 SIDESWIPE OPPOSITE		1		
545 HEAD-ON LEFT TURN		8	1	
645 DUAL LEFT TURN		1		
646 DUAL RIGHT TURN				
TOTAL NUMBER OF ACCIDENTS	262	129	28	74
NUMBER OF INTERCHANGES = 47				
# OF ACCIDENTS / # OF INTERCHANGES	5.57	2.74	0.60	1.57

Table IV.22 Accident types by Collapsed interchange elements of Rural group 3

ACCIDENT TYPES	MAINLINE UNIT	CROSSROAD UNIT	ON-RAMP UNIT	OFF-RAMP UNIT
000 MISCELLANEOUS SINGLE VEHICLE	9	2	2	2
010 OVERTURN	23	8	13	13
020 HIT TRAIN				
030 HIT PARKED VEHICLE	7	4		5
048 BACKING		1		4
049 PARKING	1	2		
050 PEDESTRIAN		2	1	
060 FIXED OBJECT	75	33	18	34
070 OTHER OBJECT	2	1		
080 ANIMAL	41	10	1	2
090 BICYCLE		1		1
141 HEAD-ON	3	9		
144 ANGLE STRAIGHT	4	14		1
147 REAR-END	85	40	11	37
244 ANGLE TURN		9		
342 SIDESWIPE SAME	2			
345 REAR-END LEFT TURN	1	9		1
346 REAR-END RIGHT TURN		2		3
440 OTHER DRIVE	1	8		
444 ANGLE DRIVE		6		
447 REAR-END DRIVE	1	10		
543 SIDESWIPE OPPOSITE		1		
545 HEAD-ON LEFT TURN		7		
645 DUAL LEFT TURN				
646 DUAL RIGHT TURN		1		3
TOTAL NUMBER OF ACCIDENTS	255	180	46	106
NUMBER OF INTERCHANGES = 43				
# OF ACCIDENTS / # OF INTERCHANGES	5.93	4.19	1.07	2.47

Table IV.23 Accident types by Collapsed interchange elements of Rural group 4

ACCIDENT TYPES	MAINLINE UNIT	CROSSROAD UNIT	ON-RAMP UNIT	OFF-RAMP UNIT
000 MISCELLANEOUS SINGLE VEHICLE	7		1	
010 OVERTURN	16	3	4	7
020 HIT TRAIN				
030 HIT PARKED VEHICLE	3			1
048 BACKING	2	1		
049 PARKING				
050 PEDESTRIAN				
060 FIXED OBJECT	57	14	9	10
070 OTHER OBJECT	2			
080 ANIMAL	28	4		
090 BICYCLE				
141 HEAD-ON	1	1		
144 ANGLE STRAIGHT		1		
147 REAR-END	57	10	2	2
244 ANGLE TURN		1		
342 SIDESWIPE SAME	3			
345 REAR-END LEFT TURN	3	2		
346 REAR-END RIGHT TURN				
440 OTHER DRIVE				
444 ANGLE DRIVE				
447 REAR-END DRIVE		1		
543 SIDESWIPE OPPOSITE				
545 HEAD-ON LEFT TURN				
645 DUAL LEFT TURN				
646 DUAL RIGHT TURN				
TOTAL NUMBER OF ACCIDENTS	179	38	16	20
NUMBER OF INTERCHANGES = 37				
# OF ACCIDENTS / # OF INTERCHANGES	4.84	1.03	0.43	0.54

Table IV.24 Accident types by Collapsed interchange elements of Rural group 5

ACCIDENT TYPES	MAINLINE UNIT	CROSSROAD UNIT	ON-RAMP UNIT	OFF-RAMP UNIT
000 MISCELLANEOUS SINGLE VEHICLE	4			
010 OVERTURN	1			3
020 HIT TRAIN				
030 HIT PARKED VEHICLE	1			
048 BACKING		1		
049 PARKING				
050 PEDESTRIAN	1			
060 FIXED OBJECT	21	2	1	5
070 OTHER OBJECT			1	
080 ANIMAL	6	2		
090 BICYCLE				
141 HEAD-ON	1			
144 ANGLE STRAIGHT	1	4		
147 REAR-END	12	5		3
244 ANGLE TURN		2		
342 SIDESWIPE SAME				
345 REAR-END LEFT TURN	1			
346 REAR-END RIGHT TURN	1			
440 OTHER DRIVE				
444 ANGLE DRIVE		1		
447 REAR-END DRIVE		2		
543 SIDESWIPE OPPOSITE				
545 HEAD-ON LEFT TURN				
645 DUAL LEFT TURN		1		
646 DUAL RIGHT TURN				
TOTAL NUMBER OF ACCIDENTS	50	20	2	11
NUMBER OF INTERCHANGES = 6				
# OF ACCIDENTS / # OF INTERCHANGES	8.33	3.33	0.33	1.83

Table IV.25 Accident types by Collapsed interchange elements of Rural group 6

ACCIDENT TYPES	MAINLINE UNIT	CROSSROAD UNIT	ON-RAMP UNIT	OFF-RAMP UNIT
000 MISCELLANEOUS SINGLE VEHICLE	7	2	2	2
010 OVERTURN	24	5	7	6
020 HIT TRAIN				
030 HIT PARKED VEHICLE	6			1
048 BACKING				
049 PARKING				
050 PEDESTRIAN	2			
060 FIXED OBJECT	56	14	6	14
070 OTHER OBJECT	2			
080 ANIMAL	36	3	1	4
090 BICYCLE				
141 HEAD-ON	1	3		
144 ANGLE STRAIGHT	3	9		3
147 REAR-END	58	18	3	16
244 ANGLE TURN		5		
342 SIDESWIPE SAME	3			
345 REAR-END LEFT TURN	1	6	1	
346 REAR-END RIGHT TURN		1		
440 OTHER DRIVE		5		
444 ANGLE DRIVE		5		
447 REAR-END DRIVE		3		
543 SIDESWIPE OPPOSITE	1			
545 HEAD-ON LEFT TURN		1		
645 DUAL LEFT TURN				
646 DUAL RIGHT TURN				1
TOTAL NUMBER OF ACCIDENTS	200	80	20	47
NUMBER OF INTERCHANGES = 27				
# OF ACCIDENTS / # OF INTERCHANGES	7.41	2.96	0.74	1.74

Table IV.26 Accident types by Collapsed interchange elements of Rural group 7

ACCIDENT TYPES	MAINLINE UNIT	CROSSROAD UNIT	ON-RAMP UNIT	OFF-RAMP UNIT
000 MISCELLANEOUS SINGLE VEHICLE	1	1		
010 OVERTURN	11	2	9	4
020 HIT TRAIN				
030 HIT PARKED VEHICLE	2			
048 BACKING		1	1	
049 PARKING				
050 PEDESTRIAN				
060 FIXED OBJECT	39	13	5	23
070 OTHER OBJECT	5			1
080 ANIMAL	18	1		
090 BICYCLE				
141 HEAD-ON	4	4		1
144 ANGLE STRAIGHT		1	1	2
147 REAR-END	36	20	3	11
244 ANGLE TURN		9		1
342 SIDESWIPE SAME	1			
345 REAR-END LEFT TURN		4		
346 REAR-END RIGHT TURN	1	1		
440 OTHER DRIVE		1		
444 ANGLE DRIVE		2		
447 REAR-END DRIVE		8		
543 SIDESWIPE OPPOSITE				
545 HEAD-ON LEFT TURN		4	1	
645 DUAL LEFT TURN				
646 DUAL RIGHT TURN				
TOTAL NUMBER OF ACCIDENTS	118	72	20	43
NUMBER OF INTERCHANGES = 17				
# OF ACCIDENTS / # OF INTERCHANGES	6.94	4.24	1.18	2.53

Table IV.27 Accident types by Collapsed interchange elements of Rural group 8

ACCIDENT TYPES	MAINLINE UNIT	CROSSROAD UNIT	ON-RAMP UNIT	OFF-RAMP UNIT
000 MISCELLANEOUS SINGLE VEHICLE	1	2		4
010 OVERTURN	9		9	14
020 HIT TRAIN				
030 HIT PARKED VEHICLE	2		4	
048 BACKING				
049 PARKING				
050 PEDESTRIAN				1
060 FIXED OBJECT	48	11	14	17
070 OTHER OBJECT				
080 ANIMAL	9	2		2
090 BICYCLE				
141 HEAD-ON	1			
144 ANGLE STRAIGHT	1	4		
147 REAR-END	47	16	8	8
244 ANGLE TURN	1	3	1	
342 SIDESWIPE SAME	2	1		
345 REAR-END LEFT TURN		1		
346 REAR-END RIGHT TURN	1			
440 OTHER DRIVE		2		
444 ANGLE DRIVE		2		
447 REAR-END DRIVE				
543 SIDESWIPE OPPOSITE				
545 HEAD-ON LEFT TURN				
645 DUAL LEFT TURN				
646 DUAL RIGHT TURN				
TOTAL NUMBER OF ACCIDENTS	122	44	36	46
NUMBER OF INTERCHANGES = 7				
# OF ACCIDENTS / # OF INTERCHANGES	17.43	6.29	5.14	6.57

Table IV.28 Accident types by Collapsed interchange elements of Rural group 9

ACCIDENT TYPES	MAINLINE UNIT	CROSSROAD UNIT	ON-RAMP UNIT	OFF-RAMP UNIT
000 MISCELLANEOUS SINGLE VEHICLE	11	2	3	1
010 OVERTURN	17	7	7	10
020 HIT TRAIN				
030 HIT PARKED VEHICLE	4	2		2
048 BACKING			1	
049 PARKING	1			
050 PEDESTRIAN				1
060 FIXED OBJECT	51	32	11	27
070 OTHER OBJECT	5			
080 ANIMAL	38	4		2
090 BICYCLE		2		
141 HEAD-ON	5	6	1	
144 ANGLE STRAIGHT		3		2
147 REAR-END	40	28	2	18
244 ANGLE TURN		8		1
342 SIDESWIPE SAME				
345 REAR-END LEFT TURN	1	6		1
346 REAR-END RIGHT TURN		3		1
440 OTHER DRIVE		6		
444 ANGLE DRIVE	1	3		
447 REAR-END DRIVE		7		
543 SIDESWIPE OPPOSITE		1		
545 HEAD-ON LEFT TURN		6		
645 DUAL LEFT TURN				
646 DUAL RIGHT TURN			1	1
TOTAL NUMBER OF ACCIDENTS	174	126	26	67
NUMBER OF INTERCHANGES = 28				
# OF ACCIDENTS / # OF INTERCHANGES	6.21	4.50	0.93	2.39

Table IV.29 Accident types by Collapsed interchange elements of Rural group 10

ACCIDENT TYPES	MAINLINE UNIT	CROSSROAD UNIT	ON-RAMP UNIT	OFF-RAMP UNIT
000 MISCELLANEOUS SINGLE VEHICLE	4			
010 OVERTURN				
020 HIT TRAIN				
030 HIT PARKED VEHICLE	1			
048 BACKING				
049 PARKING				
050 PEDESTRIAN				
060 FIXED OBJECT	9	1	2	4
070 OTHER OBJECT		1		
080 ANIMAL	5	2		
090 BICYCLE				
141 HEAD-ON	2			
144 ANGLE STRAIGHT				
147 REAR-END	7	3		
244 ANGLE TURN		1		1
342 SIDESWIPE SAME				
345 REAR-END LEFT TURN				
346 REAR-END RIGHT TURN				
440 OTHER DRIVE				
444 ANGLE DRIVE		1		
447 REAR-END DRIVE		1		
543 SIDESWIPE OPPOSITE				
545 HEAD-ON LEFT TURN				
645 DUAL LEFT TURN				
646 DUAL RIGHT TURN				
TOTAL NUMBER OF ACCIDENTS	28	10	2	5
NUMBER OF INTERCHANGES = 6				
# OF ACCIDENTS / # OF INTERCHANGES	4.67	1.67	0.33	0.83

Table IV.30 Accident types by Collapsed interchange elements of Fringe group 1

ACCIDENT TYPES	MAINLINE UNIT	CROSSROAD UNIT	ON-RAMP UNIT	OFF-RAMP UNIT
000 MISCELLANEOUS SINGLE VEHICLE	3			
010 OVERTURN	4		5	5
020 HIT TRAIN				
030 HIT PARKED VEHICLE	4			
048 BACKING		1		2
049 PARKING	1			
050 PEDESTRIAN				
060 FIXED OBJECT	21	14	9	7
070 OTHER OBJECT	1			
080 ANIMAL	22	5		
090 BICYCLE				
141 HEAD-ON				
144 ANGLE STRAIGHT	1	7	1	1
147 REAR-END	21	8	3	26
244 ANGLE TURN		7		
342 SIDESWIPE SAME		1		
345 REAR-END LEFT TURN		3		
346 REAR-END RIGHT TURN		1		1
440 OTHER DRIVE		1		
444 ANGLE DRIVE		1		
447 REAR-END DRIVE		1		
543 SIDESWIPE OPPOSITE				
545 HEAD-ON LEFT TURN				
645 DUAL LEFT TURN				
646 DUAL RIGHT TURN				
TOTAL NUMBER OF ACCIDENTS	78	50	18	42
NUMBER OF INTERCHANGES = 13				
# OF ACCIDENTS / # OF INTERCHANGES	6	3.85	1.38	3.23

Table IV.31 Accident types by Collapsed interchange elements of Fringe group 2

ACCIDENT TYPES	MAINLINE UNIT	CROSSROAD UNIT	ON-RAMP UNIT	OFF-RAMP UNIT
000 MISCELLANEOUS SINGLE VEHICLE	3	3		1
010 OVERTURN	18		4	4
020 HIT TRAIN				
030 HIT PARKED VEHICLE	1	2	1	1
048 BACKING	2	1	1	3
049 PARKING				
050 PEDESTRIAN				
060 FIXED OBJECT	49	14	12	22
070 OTHER OBJECT	2	1		
080 ANIMAL	11	3		
090 BICYCLE		3		
141 HEAD-ON	4	1		1
144 ANGLE STRAIGHT		11	1	1
147 REAR-END	72	26	11	46
244 ANGLE TURN	1	10	1	2
342 SIDESWIPE SAME	1			
345 REAR-END LEFT TURN		3		
346 REAR-END RIGHT TURN	1			2
440 OTHER DRIVE		2		
444 ANGLE DRIVE		2		
447 REAR-END DRIVE		4		
543 SIDESWIPE OPPOSITE				
545 HEAD-ON LEFT TURN		3		
645 DUAL LEFT TURN		1		1
646 DUAL RIGHT TURN				
TOTAL NUMBER OF ACCIDENTS	165	90	31	84
NUMBER OF INTERCHANGES = 24				
# OF ACCIDENTS / # OF INTERCHANGES	6.88	3.75	1.29	3.50

Table IV.32 Accident types by Collapsed interchange elements of Fringe group 3

ACCIDENT TYPES	MAINLINE UNIT	CROSSROAD UNIT	ON-RAMP UNIT	OFF-RAMP UNIT
000 MISCELLANEOUS SINGLE VEHICLE	14		2	3
010 OVERTURN	29	8	21	15
020 HIT TRAIN				
030 HIT PARKED VEHICLE	6		3	4
048 BACKING	1	1		4
049 PARKING	2			
050 PEDESTRIAN		4	2	
060 FIXED OBJECT	78	31	31	38
070 OTHER OBJECT	7		1	1
080 ANIMAL	15	2	1	3
090 BICYCLE		4		
141 HEAD-ON	3	9	1	1
144 ANGLE STRAIGHT	1	20	1	
147 REAR-END	138	87	22	69
244 ANGLE TURN	1	29		2
342 SIDESWIPE SAME	2	1		
345 REAR-END LEFT TURN	1	4		1
346 REAR-END RIGHT TURN		4	2	4
440 OTHER DRIVE		4		
444 ANGLE DRIVE		9		
447 REAR-END DRIVE		10		
543 SIDESWIPE OPPOSITE		3		
545 HEAD-ON LEFT TURN	1	8		
645 DUAL LEFT TURN		1		1
646 DUAL RIGHT TURN		1		4
TOTAL NUMBER OF ACCIDENTS	299	239	87	150
NUMBER OF INTERCHANGES = 40				
# OF ACCIDENTS / # OF INTERCHANGES	7.48	5.98	2.18	3.75

Table IV.33 Accident types by Collapsed interchange elements of Fringe group 4

ACCIDENT TYPES	MAINLINE UNIT	CROSSROAD UNIT	ON-RAMP UNIT	OFF-RAMP UNIT
000 MISCELLANEOUS SINGLE VEHICLE	1			
010 OVERTURN	5	1	1	2
020 HIT TRAIN				
030 HIT PARKED VEHICLE	1	2		
048 BACKING			1	1
049 PARKING				
050 PEDESTRIAN		1	1	1
060 FIXED OBJECT	24		5	4
070 OTHER OBJECT	1			
080 ANIMAL	2			
090 BICYCLE		1		
141 HEAD-ON				1
144 ANGLE STRAIGHT	2	3		
147 REAR-END	26	4	6	5
244 ANGLE TURN		2		
342 SIDESWIPE SAME	3			1
345 REAR-END LEFT TURN	1	1		
346 REAR-END RIGHT TURN				
440 OTHER DRIVE		1		
444 ANGLE DRIVE				
447 REAR-END DRIVE		2		
543 SIDESWIPE OPPOSITE				
545 HEAD-ON LEFT TURN				
645 DUAL LEFT TURN			1	
646 DUAL RIGHT TURN				
TOTAL NUMBER OF ACCIDENTS	66	18	15	15
NUMBER OF INTERCHANGES = 12				
# OF ACCIDENTS / # OF INTERCHANGES	5.5	1.5	1.25	1.25

Table IV.34 Accident types by Collapsed interchange elements of Fringe group 5

ACCIDENT TYPES	MAINLINE UNIT	CROSSROAD UNIT	ON-RAMP UNIT	OFF-RAMP UNIT
000 MISCELLANEOUS SINGLE VEHICLE				1
010 OVERTURN	4	1		2
020 HIT TRAIN				
030 HIT PARKED VEHICLE	1		1	
048 BACKING			1	
049 PARKING				
050 PEDESTRIAN				
060 FIXED OBJECT	21	3	8	8
070 OTHER OBJECT				
080 ANIMAL	1			
090 BICYCLE				
141 HEAD-ON		1		
144 ANGLE STRAIGHT		2		
147 REAR-END	28	12	5	11
244 ANGLE TURN		5		2
342 SIDESWIPE SAME				
345 REAR-END LEFT TURN		2		
346 REAR-END RIGHT TURN				1
440 OTHER DRIVE		1		
444 ANGLE DRIVE		1		
447 REAR-END DRIVE		3		
543 SIDESWIPE OPPOSITE				
545 HEAD-ON LEFT TURN		4		1
645 DUAL LEFT TURN			1	
646 DUAL RIGHT TURN				1
TOTAL NUMBER OF ACCIDENTS	55	35	15	27
NUMBER OF INTERCHANGES = 6				
# OF ACCIDENTS / # OF INTERCHANGES	9.17	5.83	2.5	4.5

Table IV.35 Accident types by Collapsed interchange elements of Fringe group 6

ACCIDENT TYPES	MAINLINE UNIT	CROSSROAD UNIT	ON-RAMP UNIT	OFF-RAMP UNIT
000 MISCELLANEOUS SINGLE VEHICLE	4			
010 OVERTURN	6	1		10
020 HIT TRAIN				
030 HIT PARKED VEHICLE	3			
048 BACKING				2
049 PARKING				
050 PEDESTRIAN			1	
060 FIXED OBJECT	26	8	15	15
070 OTHER OBJECT	1			
080 ANIMAL	9	2		
090 BICYCLE				
141 HEAD-ON		3		1
144 ANGLE STRAIGHT	5	4		1
147 REAR-END	24	13	2	18
244 ANGLE TURN		5		1
342 SIDESWIPE SAME				
345 REAR-END LEFT TURN	1	3		
346 REAR-END RIGHT TURN		2		
440 OTHER DRIVE		1		
444 ANGLE DRIVE		2		
447 REAR-END DRIVE		5		
543 SIDESWIPE OPPOSITE	1			
545 HEAD-ON LEFT TURN		4		
645 DUAL LEFT TURN		1		
646 DUAL RIGHT TURN				
TOTAL NUMBER OF ACCIDENTS	80	53	19	48
NUMBER OF INTERCHANGES = 10				
# OF ACCIDENTS / # OF INTERCHANGES	8.00	5.30	1.90	4.80

Table IV.36 Accident types by Collapsed interchange elements of Fringe group 7

ACCIDENT TYPES	MAINLINE UNIT	CROSSROAD UNIT	ON-RAMP UNIT	OFF-RAMP UNIT
000 MISCELLANEOUS SINGLE VEHICLE	1		1	4
010 OVERTURN	9	3	3	4
020 HIT TRAIN				
030 HIT PARKED VEHICLE	3			
048 BACKING				1
049 PARKING				
050 PEDESTRIAN	2	1		
060 FIXED OBJECT	19	12	5	11
070 OTHER OBJECT				
080 ANIMAL	6			1
090 BICYCLE				
141 HEAD-ON	1	1		2
144 ANGLE STRAIGHT		2		
147 REAR-END	30	6	3	7
244 ANGLE TURN		7		
342 SIDESWIPE SAME				
345 REAR-END LEFT TURN		1		
346 REAR-END RIGHT TURN			1	
440 OTHER DRIVE		2		
444 ANGLE DRIVE				
447 REAR-END DRIVE		3		
543 SIDESWIPE OPPOSITE				
545 HEAD-ON LEFT TURN		4	1	
645 DUAL LEFT TURN		1		
646 DUAL RIGHT TURN		1	1	
TOTAL NUMBER OF ACCIDENTS	71	44	15	30
NUMBER OF INTERCHANGES = 12				
# OF ACCIDENTS / # OF INTERCHANGES	5.92	3.67	1.25	2.5

Table IV.37 Accident types by Collapsed interchange elements of Fringe group 8

ACCIDENT TYPES	MAINLINE UNIT	CROSSROAD UNIT	ON-RAMP UNIT	OFF-RAMP UNIT
000 MISCELLANEOUS SINGLE VEHICLE	5	3		3
010 OVERTURN	9	5	8	5
020 HIT TRAIN				
030 HIT PARKED VEHICLE	5			
048 BACKING	1			
049 PARKING				
050 PEDESTRIAN				1
060 FIXED OBJECT	65	21	13	14
070 OTHER OBJECT	1			
080 ANIMAL	9	2	1	1
090 BICYCLE				1
141 HEAD-ON	2	1		
144 ANGLE STRAIGHT	4	1		1
147 REAR-END	79	32	19	25
244 ANGLE TURN	3	3		
342 SIDESWIPE SAME	3			
345 REAR-END LEFT TURN		1		
346 REAR-END RIGHT TURN		1		2
440 OTHER DRIVE	3			
444 ANGLE DRIVE	1	3		
447 REAR-END DRIVE	1	3		
543 SIDESWIPE OPPOSITE				
545 HEAD-ON LEFT TURN	1	2		
645 DUAL LEFT TURN				
646 DUAL RIGHT TURN		2		
TOTAL NUMBER OF ACCIDENTS	192	80	41	53
NUMBER OF INTERCHANGES = 15				
# OF ACCIDENTS / # OF INTERCHANGES	12.80	5.33	2.73	3.53

Table IV.38 Accident types by Collapsed interchange elements of Fringe group 9

ACCIDENT TYPES	MAINLINE UNIT	CROSSROAD UNIT	ON-RAMP UNIT	OFF-RAMP UNIT
000 MISCELLANEOUS SINGLE VEHICLE	4		3	4
010 OVERTURN	3	2	4	6
020 HIT TRAIN				
030 HIT PARKED VEHICLE	1			
048 BACKING		1	1	1
049 PARKING		1		
050 PEDESTRIAN				1
060 FIXED OBJECT	28	7	13	21
070 OTHER OBJECT	1	1		
080 ANIMAL	10			2
090 BICYCLE				
141 HEAD-ON	1	1		
144 ANGLE STRAIGHT		2		
147 REAR-END	32	13	2	17
244 ANGLE TURN	1	7		3
342 SIDESWIPE SAME	2	1		
345 REAR-END LEFT TURN		2		
346 REAR-END RIGHT TURN				
440 OTHER DRIVE		2		
444 ANGLE DRIVE		7		
447 REAR-END DRIVE		6		
543 SIDESWIPE OPPOSITE				
545 HEAD-ON LEFT TURN		5		
645 DUAL LEFT TURN				
646 DUAL RIGHT TURN				
TOTAL NUMBER OF ACCIDENTS	83	53	23	55
NUMBER OF INTERCHANGES = 14				
# OF ACCIDENTS / # OF INTERCHANGES	5.93	3.79	1.64	3.93

Table IV.39 Accident types by Collapsed interchange elements of Fringe group 10

ACCIDENT TYPES	MAINLINE UNIT	CROSSROAD UNIT	ON-RAMP UNIT	OFF-RAMP UNIT
000 MISCELLANEOUS SINGLE VEHICLE				
010 OVERTURN			1	1
020 HIT TRAIN				
030 HIT PARKED VEHICLE	1			
048 BACKING				
049 PARKING				
050 PEDESTRIAN				
060 FIXED OBJECT	12	1		2
070 OTHER OBJECT			1	
080 ANIMAL	1			
090 BICYCLE				
141 HEAD-ON		1		
144 ANGLE STRAIGHT	1	1		1
147 REAR-END	26	1	3	1
244 ANGLE TURN		2		
342 SIDESWIPE SAME			1	
345 REAR-END LEFT TURN				
346 REAR-END RIGHT TURN		2		
440 OTHER DRIVE				
444 ANGLE DRIVE				
447 REAR-END DRIVE			1	
543 SIDESWIPE OPPOSITE				
545 HEAD-ON LEFT TURN				
645 DUAL LEFT TURN				
646 DUAL RIGHT TURN				
TOTAL NUMBER OF ACCIDENTS	41	8	7	5
NUMBER OF INTERCHANGES = 2				
# OF ACCIDENTS / # OF INTERCHANGES	20.5	4	3.5	2.5

Table IV.40 Accident types by Urban groups

	ACCIDENT TYPES	GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5	GROUP 6	GROUP 7	GROUP 8	GROUP 9	GROUP 10	GROUP 11	GROUP 12
000	MISCELLANEOUS SINGLE VEHICLE	3	15	4	11	8	6	7	4	4	6	1	
010	OVERTURN	4	18	16	15	29	16	13	25	12	27	1	5
020	HIT TRAIN												
030	HIT PARKED VEHICLE	2	25	8	18	16	6	3	4	3	9		3
048	BACKING		14	6	5	12	2	1	4	3	6		
049	PARKING	1	3		10	3	2		1		2		2
050	PEDESTRIAN	1	12	1	4	5	5				2		
060	FIXED OBJECT	25	189	101	96	124	68	83	90	60	135	4	20
070	OTHER OBJECT	1	7	4	2	1	3		2	5	3	2	
080	ANIMAL	9	2	6	2	1	5	5	3	1			
090	BICYCLE		11	4	1	3	1	2		1			
141	HEAD-ON		9	5	2	5	7	3		4	9		
144	ANGLE STRAIGHT	1	119	12	65	80	13	19	6	11	32	1	11
147	REAR-END	16	587	216	245	303	133	157	131	106	249	19	85
244	ANGLE TURN	6	43	14	14	17	7	12	3	10	8		5
342	SIDESWIPE SAME		20	3	7	7	3	2		3	12		2
345	REAR-END LEFT TURN	3	40	2	15	19	3	3		4	5		2
346	REAR-END RIGHT TURN		23	4	11	7	3	8	3	3	4		
440	OTHER DRIVE		4		5	4	1	3		3	1		2
444	ANGLE DRIVE		16	3	4	1	3	5	1		1		2
447	REAR-END DRIVE		19	3	5	12	3	2	3	2			3
543	SIDESWIPE OPPOSITE	1		1	1	1	2	2			1		
545	HEAD-ON LEFT TURN		16	4	7	8	8	3	2	5	4		
645	DUAL LEFT TURN		11		4	2	2	2			1	2	2
646	DUAL RIGHT TURN		2	4	1	1	2						
	TOTAL NUMBER OF ACCIDENTS	73	1205	421	550	669	304	335	282	240	517	30	144

Table IV.41 Accident types by Rural groups

	ACCIDENT TYPES	GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5	GROUP 6	GROUP 7	GROUP 8	GROUP 9	GROUP 10	GROUP 11	GROUP 12
000	MISCELLANEOUS SINGLE VEHICLE	26	17	15	10	4	13	3	7	17			
010	OVERTURN	132	45	57	38	4	49	29	35	41	5		
020	HIT TRAIN												
030	HIT PARKED VEHICLE	13	13	16	5	1	7	2	7	8	1		
048	BACKING	5	3	5	3	1		2		1			
049	PARKING	1	1	3						1			
050	PEDESTRIAN	4		3		1	2		1	1			
060	FIXED OBJECT	263	135	161	119	35	104	87	106	122	17		
070	OTHER OBJECT	8	9	3	3	1	2	7		5	1		
080	ANIMAL	236	81	54	35	9	45	20	15	45	7		
090	BICYCLE	1	3	2						2			
141	HEAD-ON	11	10	12	2	1	4	9	1	12	2		
144	ANGLE STRAIGHT	22	19	21	3	6	18	4	5	6			
147	REAR-END	160	112	173	86	25	100	73	83	88	11		
244	ANGLE TURN	14	15	9	2	2	5	10	6	9	2		
342	SIDESWIPE SAME	6	1	2	3		4	1	3		1		
345	REAR-END LEFT TURN	11	5	12	6	1	10	4	1	8			
346	REAR-END RIGHT TURN	4	4	5		1	1	2	1	4			
440	OTHER DRIVE	3	5	9	2		5	1	2	6			
444	ANGLE DRIVE	6	4	6		1	5	2	2	4	1		
447	REAR-END DRIVE	7	5	11	3	2	3	8		7	1		
543	SIDESWIPE OPPOSITE	1	1	1	1		1			1			
545	HEAD-ON LEFT TURN	11	9	7			1	5		6			
645	DUAL LEFT TURN		1			1							
646	DUAL RIGHT TURN	2		4			1			2			
TOTAL NUMBER OF ACCIDENTS		947	498	591	321	96	380	269	275	396	49		

Table IV.42 Accident types by Fringe groups

	ACCIDENT TYPES	GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5	GROUP 6	GROUP 7	GROUP 8	GROUP 9	GROUP 10	GROUP 11	GROUP 12
000	MISCELLANEOUS SINGLE VEHICLE	3	7	19	1	1	4	6	14	11	1		
010	OVERTURN	14	33	73	9	11	17	21	50	15	3		
020	HIT TRAIN												
030	HIT PARKED VEHICLE	4	5	13	4	4	3	3	9	1	1		
048	BACKING	4	8	6	2	2	2	1	2	3			
049	PARKING	1		2					1	1			
050	PEDESTRIAN			6	3		1	3	2	1			
060	FIXED OBJECT	52	115	178	39	57	65	47	164	69	25		
070	OTHER OBJECT	1	3	9	1		1		2	2	1		
080	ANIMAL	27	14	22	3	1	11	7	14	12	1		
090	BICYCLE		3	4	1				1				
141	HEAD-ON		6	14	1	1	6	4	3	2	1		
144	ANGLE STRAIGHT	12	22	22	8	4	12	2	6	2	3		
147	REAR-END	59	183	317	46	66	67	47	202	64	42		
244	ANGLE TURN	9	18	34	3	8	6	7	6	11	2		
342	SIDESWIPE SAME	1	1	3	4				5	3	1		
345	REAR-END LEFT TURN	4	7	6	5	3	4	1	2	2			
346	REAR-END RIGHT TURN	5	4	10		1	2	1	3		2		
440	OTHER DRIVE	1	3	4	1	1	1	2	4	2			
444	ANGLE DRIVE	1	4	9		1	2		4	7			
447	REAR-END DRIVE	1	5	10	2	3	5	3	5	6	1		
543	SIDESWIPE OPPOSITE		1	2		1	1						
545	HEAD-ON LEFT TURN		3	9		5	4	5	3	5			
645	DUAL LEFT TURN		2	2	1		1	1					
646	DUAL RIGHT TURN	1		5		1		2	2				
TOTAL NUMBER OF ACCIDENTS		200	447	779	134	171	215	163	504	219	84		

Table IV.43 The average number of Accidents per interchange by units used

GROUP	MAINLINE	CROSSROAD	ON-RAMP	OFF-RAMP
URBAN GROUP 1	LSS	LSS	LSS	LSS
URBAN GROUP 2	5.86	3.66	2.26	2.04
URBAN GROUP 3	9.53	6.18	3.41	4.82
URBAN GROUP 4	5.24	3.37	1.00	1.63
URBAN GROUP 5	8.50	5.27	2.05	2.59
URBAN GROUP 6	11.00	6.00	3.50	6.00
URBAN GROUP 7	7.75	6.50	1.83	2.50
URBAN GROUP 8	LSS	LSS	LSS	LSS
URBAN GROUP 9	LSS	LSS	LSS	LSS
URBAN GROUP 10	13.75	6.50	1.17	2.58
URBAN GROUP 11	LSS	LSS	LSS	LSS
URBAN GROUP 12	LSS	LSS	LSS	LSS
RURAL GROUP 1	4.94	2.21	0.39	1.16
RURAL GROUP 2	5.57	2.74	0.60	1.57
RURAL GROUP 3	5.93	4.19	1.07	2.47
RURAL GROUP 4	4.84	1.03	0.43	0.54
RURAL GROUP 5	LSS	LSS	LSS	LSS
RURAL GROUP 6	7.41	2.96	0.74	1.74
RURAL GROUP 7	6.94	4.24	1.18	2.53
RURAL GROUP 8	LSS	LSS	LSS	LSS
RURAL GROUP 9	6.21	4.50	0.93	2.39
RURAL GROUP 10	LSS	LSS	LSS	LSS
FRINGE GROUP 1	6.00	3.85	1.38	3.23
FRINGE GROUP 2	6.88	3.75	1.29	3.50
FRINGE GROUP 3	7.48	5.98	2.18	3.75
FRINGE GROUP 4	5.50	1.50	1.25	1.25
FRINGE GROUP 5	LSS	LSS	LSS	LSS
FRINGE GROUP 6	8.00	5.30	1.90	4.80
FRINGE GROUP 7	5.92	3.67	1.25	2.50
FRINGE GROUP 8	12.80	5.33	2.73	3.53
FRINGE GROUP 9	5.93	3.79	1.64	3.93
FRINGE GROUP 10	LSS	LSS	LSS	LSS

LSS means the sample size is less than 10 interchanges.

Table IV.44 Sample Data File

261	3	50	2210	2298	8	4	0	13	2	2	1	19600	687583	176	1	0	0	0
261	4	50	2198	2286	8	4	0	13	2	2	1	19600	687583	176	12	2	0	4
728	1	33	658	770	8	2	0	13	2	2	1	10600	275341	224	11	2	0	2
728	2	33	665	776	8	2	0	13	2	2	1	10600	275341	222	14	3	0	1
729	1	33	970	1076	8	4	0	13	2	2	1	10600	275341	212	9	1	0	0
729	2	33	979	1084	8	4	0	13	2	2	1	10600	275341	210	7	1	0	0

Column Range	Descriptions
1 - 4	Interchange No.
5 - 6	Interchange Element
8 - 9	County No.
11 - 14	Beginning Milepoint
17 - 20	Ending Milepoint
23 - 24	Geometric and Laneage Code
25 - 26	Ramp Terminal or Intersection Code
29 - 30	Interchange Lighting Code
33 - 34	Interchange Type
35	Activity Density
36 - 38	Number of On-ramps
39 - 41	Number of Off-ramps
42 - 44	Freeway crossing over or under the crossroad
45 - 51	Average Daily Traffic
52 - 58	Population of the county
59 - 65	Lane mileage (in 1/100 mile unit)
66 - 68	Total accidents
69 - 71	Fixed object accidents
72 - 74	Angle turn accidents
75 - 77	Rear-end accidents

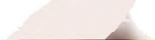


Table IV.45 Comparison of the analysis units by groups based on the highest and lowest accident rates

Groups	Highest Mn	Highest Cr	Highest On	Highest Of	Lowest Mn	Lowest Cr	Lowest On	Lowest Of
Urban Group 4					*	*	*	*
Urban Group 6			*	*				
Urban Group 10	*	*						
Rural Group 1							*	
Rural Group 4					*	*		*
Rural Group 6	*							
Rural Group 7			*	*				
Rural Group 9		*						
Fringe Group 2								
Fringe Group 3		*						
Fringe Group 4					*	*	*	*
Fringe Group 6				*				
Fringe Group 8	*		*					

Mn: Mainline Rate
Cr: Crossroad Rate
On: On-ramp Rate
Of: Off-ramp Rate

Table IV.46 The average number of accidents per interchange by sample units

Group	Accidents/Int. on Mainline	Accidents/Int. on Crossroad	Accidents/Int. on On-ramp	Accidents/Int. on Off-ramp
UGROUP 2	6	2.5	1.67	4.5
UGROUP 3	11	6	6	4
UGROUP 6	12	6	4	5
UGROUP 9	6	4.5	2	3
FGROUP 2	10.67	5	4	5.67

Table IV.47 The average accident rate per interchange by sample units

Group	Accident Rate on Mainline	Accident Rate on Crossroad	Accident Rate on On-ramp	Accident Rate on Off-ramp
UGROUP 2	0.058	0.098	0.181	0.425
UGROUP 3	0.127	0.172	0.307	0.522
UGROUP 6	0.169	0.240	0.531	4.374
UGROUP 9	0.102	0.117	0.265	0.937
FGROUP 2	0.118	0.133	0.210	0.317

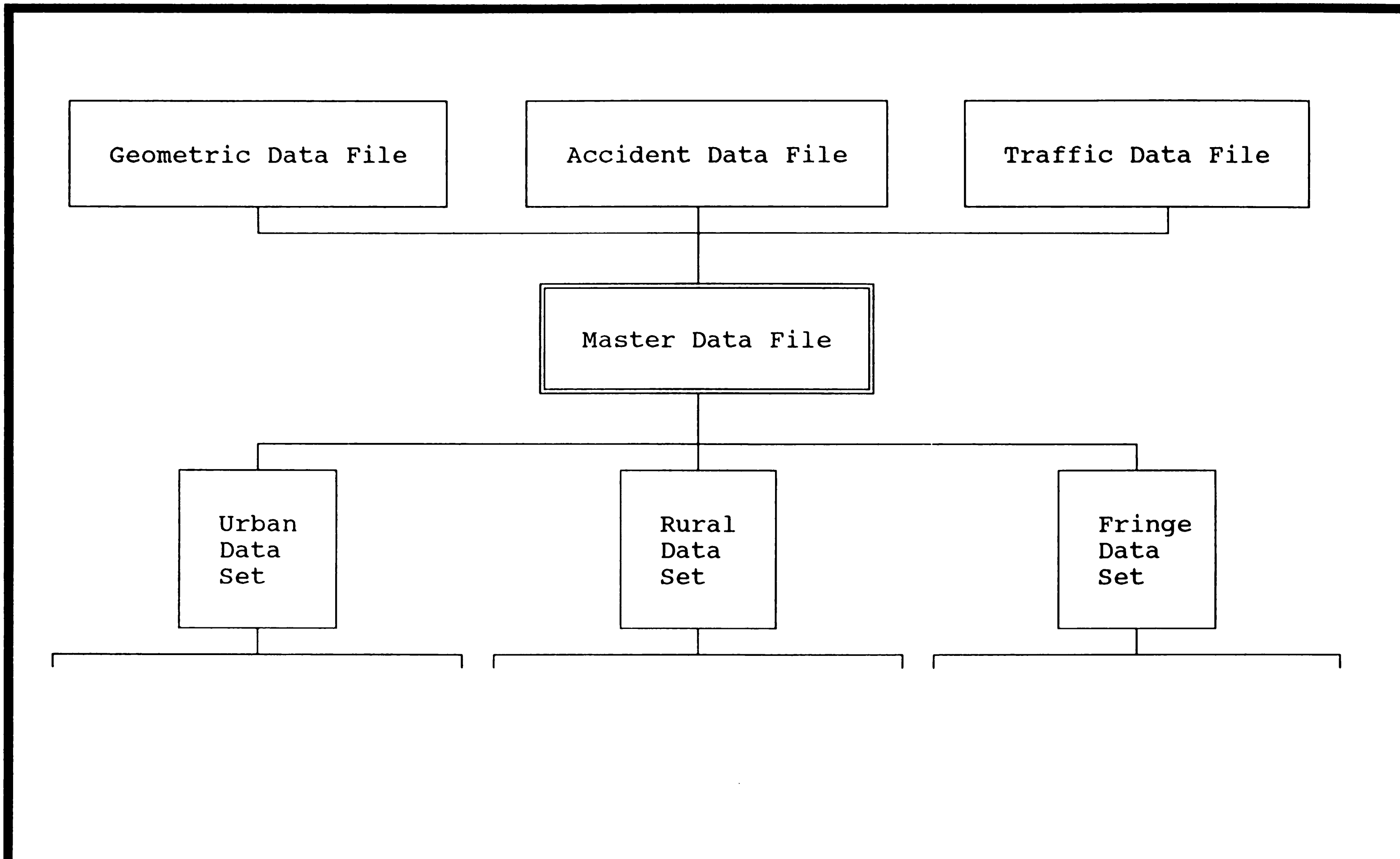


Chart 4.1 Data File Format Chart

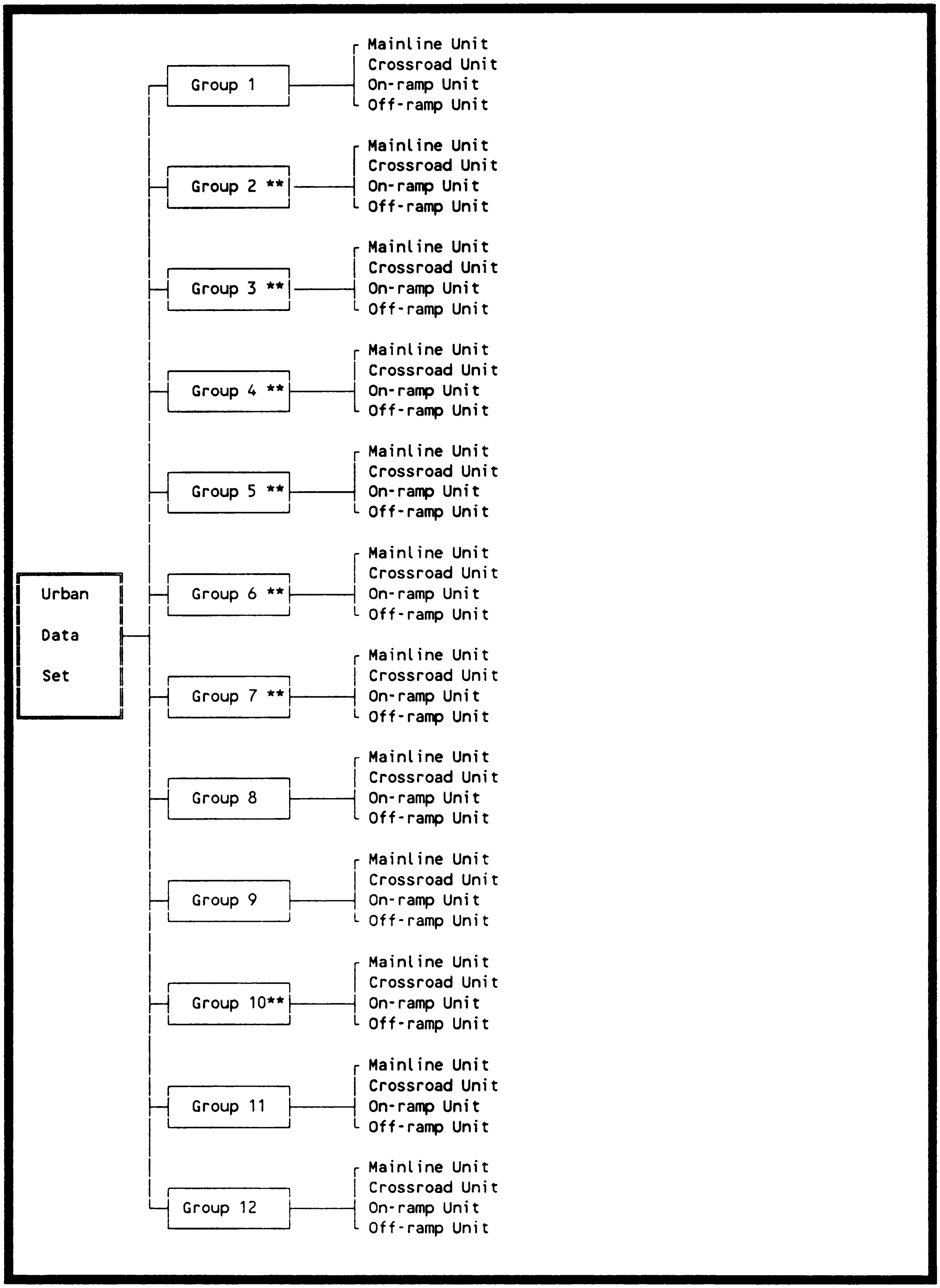


Chart 4.2 Data file set by Urban Groups

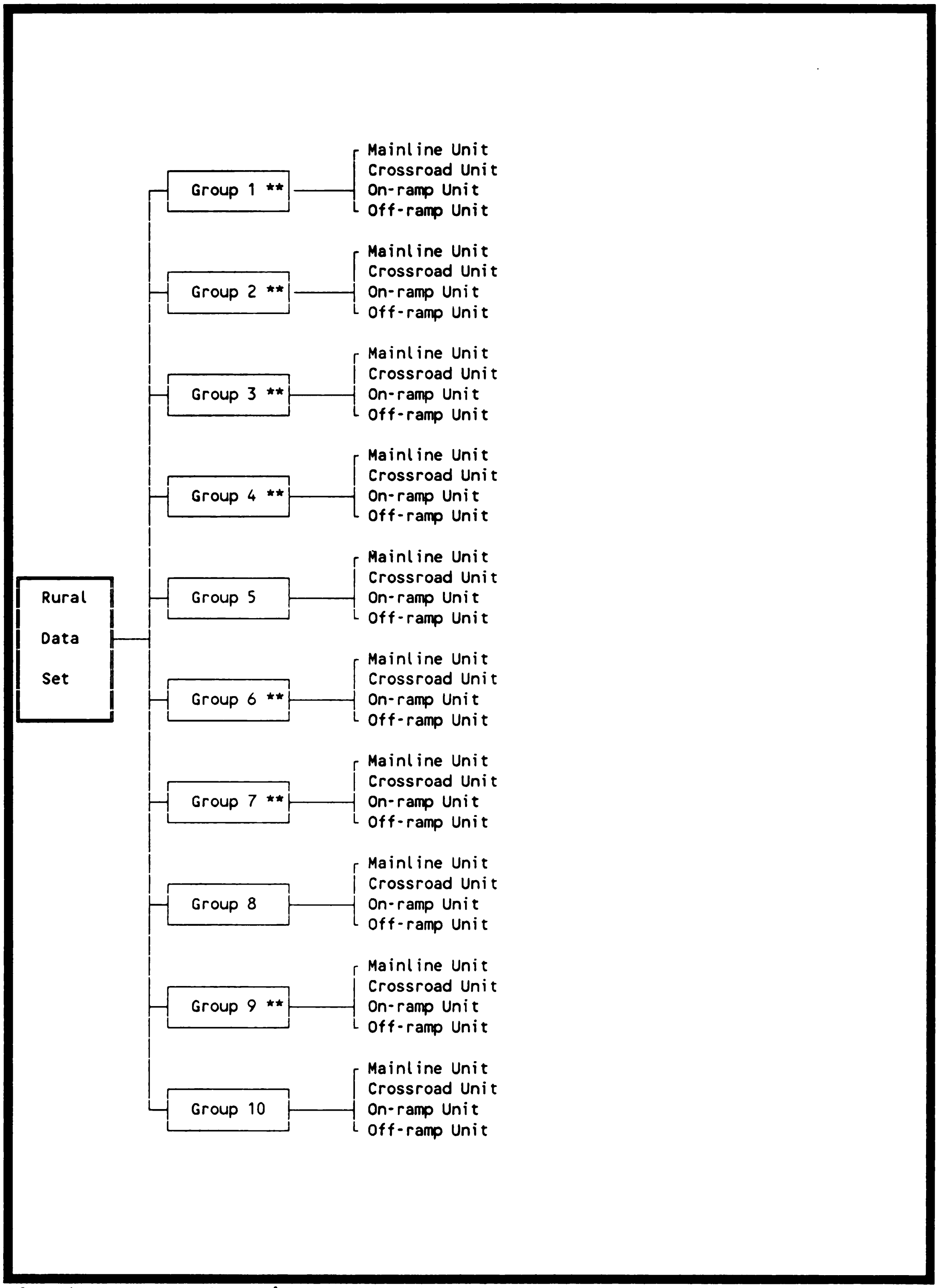


Chart 4.3 Data file set by Rural Groups

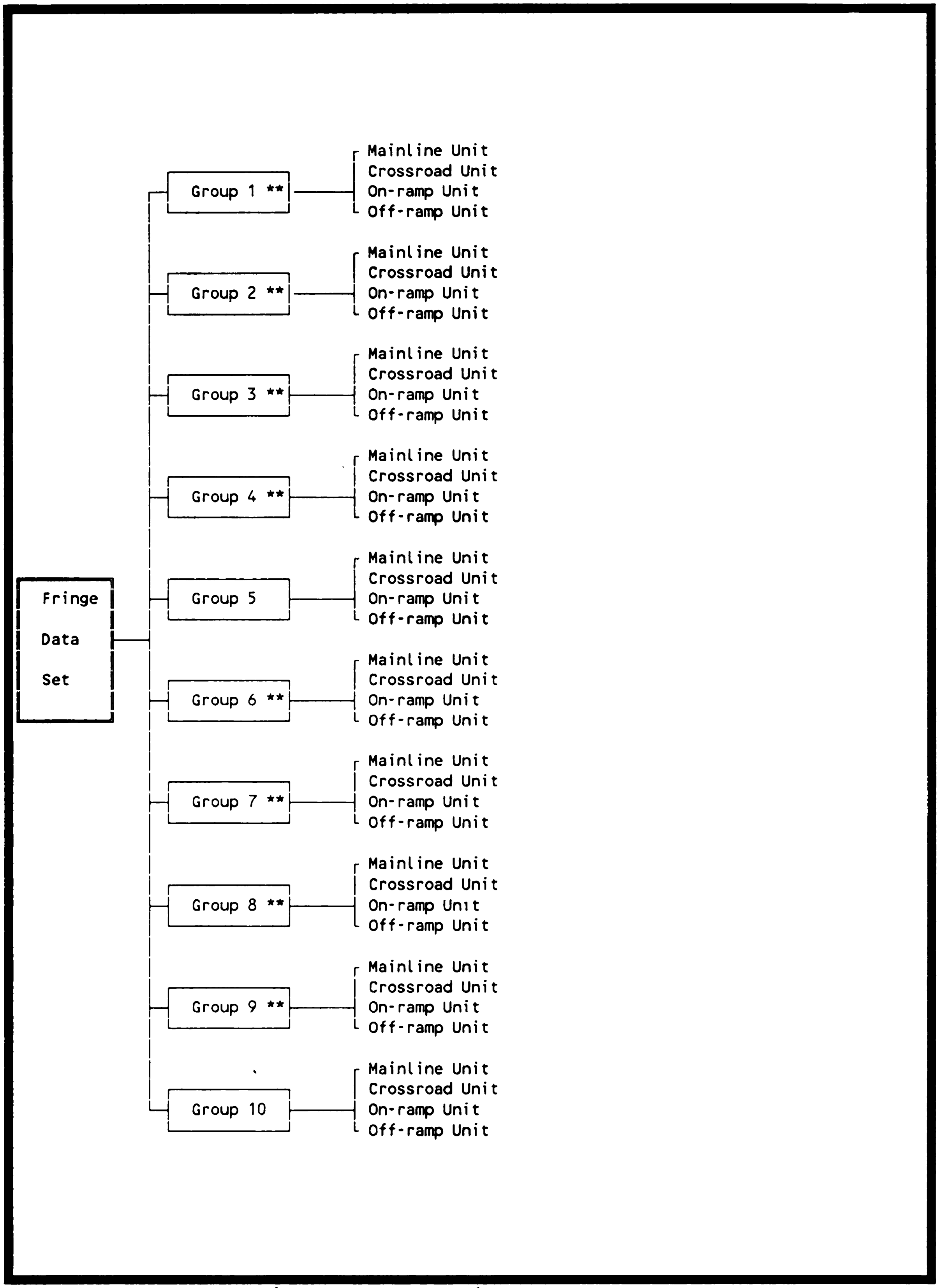


Chart 4.4 Data file set by Fringe Groups

CHAPTER V

MODELS

Having determined that models constructed on the total data base did not produce results sufficiently reliable to use in selecting alternative design parameters, the stratified data set was used for further analyses. As described in chapter IV, the data had been stratified by activity density (urban, rural and fringe) and by interchange design groups. The data records were divided into cells representing this two way classification, and models were constructed for each of the analysis units within a cell. Only those cells with at least 10 interchanges were modeled. These models were based upon the following formula:

$$Y = \mathbf{f}(X_1, X_2, X_3, X_4, X_5)$$

where Y = Number of accidents on road segment (i)

X_1 = Population (in 1000's) of the county

X_2 = Lane mileage of the analysis unit (in 0.01 mile units)

X_3 = Number of on-ramps

X_4 = Number of off-ramps

X_5 = Average Daily Traffic (ADT)

<u>V.1 Models constructed on the Mainline Unit</u>

Using stepwise linear regression, the following models provided the highest (R^2) value for each group.

A. Models constructed based on the total accidents on the mainline units

1. Model of urban group 2

$$Y = -19.910 + 0.000816X_5$$

where Y = Total number of Accidents on road segment (i)

X_5 = Average Daily Traffic (ADT)

From the above linear regression model, the multiple regression coefficient (**R**) was 0.5441, based on 19 interchanges (38 road segments).

2. Model of urban group 3

$$Y = -14.551 + 0.00115X_5$$

where Y = Total number of accidents on road segment (i)

X_5 = Average Daily Traffic (ADT)

From the above linear regression model, the multiple regression coefficient (**R**) was 0.9025, based on 11 interchanges (22 road segments).

3. Model of urban group 5

$$Y = -42.267 - 0.038X_1 + 0.00215X_5$$

where Y = Total number of accidents on road segment (i)

X_1 = Population (in 1000's) of the county

X_5 = Average Daily Traffic (ADT)

From the above linear regression model, the multiple regression coefficient (**R**) was 0.7839, based on 11 interchanges (28 road segments).

4. Model of rural group 1

$$Y = 0.937 - 0.00880X_1 + 0.000657X_5$$

where Y = Total number of accidents on road segment (i)

X_1 = Population (in 1000's) of the county

X_5 = Average Daily Traffic (ADT)

From the above linear regression model, the multiple regression coefficient (**R**) was 0.7336, based on 50 interchanges (99 road segments).

5. Model of rural group 2

$$Y = 4.650 + 0.000258X_5$$

where Y = Total number of accidents on road segment (i)

X_5 = Average Daily Traffic (ADT)

From the above linear regression model, the multiple regression coefficient (**R**) was 0.3547, based on 27 interchanges (54 road segments).

6. Model of rural group 3

$$Y = -5.007 + 0.030X_2 + 0.000354X_5$$

where Y = Total number of accidents on road segment (i)

X_2 = Lane mileage

X_5 = Average Daily Traffic (ADT)

From the above linear regression model, the multiple regression coefficient (**R**) was 0.7150, based on 25 interchanges (49 road segments).

7. Model of rural group 4

$$Y = 3.435 + 0.060X_2 - 8.534X_3 + 0.000289X_5$$

where Y = Total number of accidents on road segment (i)

X_2 = Lane mileage

X_3 = Number of on-ramps

X_5 = Average Daily Traffic (ADT)

From the above linear regression model, the multiple regression coefficient (**R**) was 0.8262, based on 23 interchanges (55 road segments).

8. Model of rural group 6

$$Y = 0.182 + 0.000410X_5$$

where Y = Total number of accidents on road segment (i)

X_5 = Average Daily Traffic (ADT)

From the above linear regression model, the multiple regression coefficient (**R**) was 0.4087, based on 18 interchanges (48 road segments).

9. Model of rural group 7

$$Y = -6.247 + 0.069X_2 + 0.000316X_5$$

where Y = Total number of accidents on road segment (i)

X_2 = Lane mileage

X_5 = Average Daily Traffic (ADT)

From the above linear regression model, the multiple regression coefficient (**R**) was 0.6497, based on 12 interchanges (26 road segments).

9. Model of rural group 9

$$Y = -27.865 + 11.561X_3 + 0.000585X_5$$

where Y = Total number of accidents on road segment (i)

X_3 = Number of on-ramps

X_5 = Average Daily Traffic (ADT)

From the above linear regression model, the multiple regression coefficient (**R**) was 0.6290, based on 19 interchanges (38 road segments).

10. Model of fringe group 2

$$Y = 7.932 - 0.067X_2 + 0.000685X_5$$

where Y = Total number of accidents on road segment (i)

X_2 = Lane mileage

X_5 = Average Daily Traffic (ADT)

From the above linear regression model, the multiple regression coefficient (**R**) was 0.8200, based on 14

interchanges (28 road segments).

11. Model of fringe group 3

$$Y = -9.340 - 0.00629X_1 + 0.062X_2 + 0.000566X_5$$

where Y = Total number of accidents on road segment (i)

X_1 = Population (in 1000's) of the county

X_2 = Lane mileage

X_5 = Average Daily Traffic (ADT)

From the above linear regression model, the multiple regression coefficient (**R**) was 0.6872, based on 26 interchanges (52 road segments).

12. Model of fringe group 8

$$Y = -7.127 + 0.149X_2$$

where Y = Total number of accidents on road segment (i)

X_2 = Lane mileage

From the above linear regression model, the multiple regression coefficient (**R**) was 0.7452, based on 10 interchanges (26 road segments).

13. Model of fringe group 9

$$Y = 5.488 + 0.077X_2$$

where Y = Total number of accidents on road segment (i)

X_2 = Lane mileage

From the above linear regression model, the multiple regression coefficient (**R**) was 0.7162, based on 10 interchanges (20 road segments).

<u>V.2 Models constructed on the crossroad unit</u>

Using stepwise linear regression, the following models provided the highest (**R^2**) value for each group.

<u>A. Models constructed based on the total accidents on the crossroad units</u>

1. Model of urban group 3

$$Y = -57.966 + 0.553X_2 + 0.00257X_5$$

where Y = Total number of accidents on road segment (i)

X_2 = Lane mileage

X_5 = Average Daily Traffic (ADT)

From the above linear regression model, the multiple regression coefficient (**R**) was 0.8590, based on 11 interchanges (11 road segments).

2. Model of urban group 4

$$Y = -21.355 + 0.425X_2 + 0.00167X_5$$

where Y = Total number of accidents on road segment (i)

X_2 = Lane mileage

X_5 = Average Daily Traffic (ADT)

From the above linear regression model, the multiple regression coefficient (**R**) was 0.8656, based on 11 interchanges (11 road segments).

3. Model of rural group 1

$$Y = -3.654 + 0.00348X_5$$

where Y = Total number of accidents on road segment (i)

X_5 = Average Daily Traffic (ADT)

From the above linear regression model, the multiple regression coefficient (**R**) was 0.7063, based on 50 interchanges (50 road segments).

4. Model of rural group 2

$$Y = 1.959 + 0.00246X_5$$

where Y = Total number of accidents on road segment (i)

X_5 = Average Daily Traffic (ADT)

From the above linear regression model, the multiple regression coefficient (**R**) was 0.6711, based on 27 interchanges (27 road segments).

5. Model of rural group 3

$$Y = 0.257 + 0.00235X_5$$

where Y = Total number of accidents on road segment (i)

X_5 = Average Daily Traffic (ADT)

From the above linear regression model, the multiple regression coefficient (**R**) was 0.8034, based on 25 interchanges (25 road segments).

6. Model of rural group 6

$$Y = -175.947 + 0.373X_2 + 48.619X_4$$

where Y = Total number of accidents on road segment (i)

X_2 = Lane mileage

X_4 = Number of off-ramps

From the above linear regression model, the multiple regression coefficient (**R**) was 0.8795, based on 12 interchanges (12 road segments).

7. Model of rural group 7

$$Y = 4.597 + 0.00144X_5$$

where Y = Total number of accidents on road segment (i)

X_5 = Average Daily Traffic (ADT)

From the above linear regression model, the multiple regression coefficient (**R**) was 0.8525, based on 10 interchanges (10 road segments).

8. Model of rural group 9

$$Y = -0.514 + 0.00384X_5$$

where Y = Total number of accidents on road segment (i)

X_5 = Average Daily Traffic (ADT)

From the above linear regression model, the multiple regression coefficient (**R**) was 0.8356, based on 19 interchanges (19 road segments).

9. Model of fringe group 2

$$Y = 4.077 + 0.00283X_5$$

where Y = Total number of accidents on road segment (i)

X_5 = Average Daily Traffic (ADT)

From the above linear regression model, the multiple regression coefficient (**R**) was 0.7534, based on 14 interchanges (14 road segments).

V.3 Models constructed on the on-ramp units

Using stepwise linear regression, the following models provided the highest ($\mathbf{R}^2$) value for each group.

A. Model constructed based on the total accidents on the on-ramp units

1. Model of urban group 2

$$Y = 4.723 - 0.00118X_5$$

where Y = Total number of accidents on road segment (i)

X_5 = Average Daily Traffic (ADT)

From the above linear regression model, the multiple regression coefficient (**R**) was 0.5051, based on 17 interchanges (18 on-ramps).

<u>B. Models constructed based on the fixed object accidents on the on-ramp units</u>

1. Model of urban group 2

$$Y = 0.883 + 0.039X_2 - 0.000605X_5$$

where Y = Total number of accidents on road segment (i)

X_2 = Lane mileage

X_5 = Average Daily Traffic (ADT)

From the above linear regression model, the multiple regression coefficient (**R**) was 0.7388, based on 17 interchanges (18 on-ramps).

V.4 Models constructed on the off-ramp unit

Using stepwise linear regression, the following models provided the highest (R^2) value for each group.

A. Model constructed based on the total accident rate on the off-ramp units

1. Model of urban group 2

$$Y = 8.236 - 0.00236X_1 + 0.271X_2 - 0.000565X_5$$

where Y = Total number of accidents on road segment (i)

X_1 = Population (in 1000's) of the county

X_2 = Lane mileage

X_5 = Average Daily Traffic (ADT)

From the above linear regression model, the multiple regression coefficient (R) was 0.9091, based on 17 interchanges (19 off-ramps).

B. Models constructed based on the fixed object accidents on the off-ramp units

1. Model of urban group 2

$$Y = 3.226 - 0.00102X_1$$

where Y = Total number of accidents on road segment (i)

X_1 = Population (in 1000's) of the county

From the above linear regression model, the multiple regression coefficient (**R**) was 0.5034, based on 17 interchanges (19 off-ramps).

C. Models constructed based on the rear-end accidents on the off-ramp units

1. Model of urban group 2

$$Y = -0.267 + 0.152X_2$$

where Y = Total number of accidents on road segment (i)

X_2 = Lane mileage

From the above linear regression model, the multiple regression coefficient (**R**) was 0.6195, based on 17 interchanges (19 off-ramps).

Summary of Results

Based upon the above models, the sign of each variable term was recorded for each group as shown in Table V.1. Some general observations that resulted from a review of these models were as follows:

1. On the mainline unit of urban freeway interchanges, all the models have a positive sign in the average daily traffic term as would be expected.

2. On the mainline unit of rural freeway interchanges, all the models again have a positive sign in the average daily traffic term. Also, all the models have a positive sign in the lane mileage term. This indicates that the number of accidents increases with the length of the road segment. Most of the models have a positive sign in the number of on-ramps term, indicating that the number of accidents on the rural mainline unit increases where there are more on-ramps.

3. On the mainline unit of fringe freeway interchanges, all the models again have a positive sign in the average daily traffic term. This is consistent with the results in the urban and rural areas. Also, most of the models have a positive sign in the lane mileage term, indicating that the number of accidents is greater for the longer fringe mainline units.

4. On the crossroad unit of urban freeway interchanges, all the models have a positive sign in the lane mileage and average daily traffic terms, indicating that the number of accidents increases with the longer crossroad units and increased traffic.

5. On the crossroad unit of rural and fringe freeway interchanges, all the models have a positive sign in the average daily traffic term.

6. There were an insufficient number of models of the on-ramp

and off-ramp accident frequency to draw any general conclusions.

7. Attempts to model specific accident types (fixed object accidents, rear-end accidents) did not improve the model accuracy (**R^2** value). Therefore, models built on predicting total accidents were retained for further testing.

8. Relatively high values of **R** were achieved for group 3 interchange mainline and crossroad units in all three categories (urban, rural and fringe). Group 3 interchanges include Modified Diamond, Modified Tight Diamond and Parclo A 4 Quad. Thus, it may be possible to accurately predict the accidents to be expected at these interchanges.

9. Group 2 interchanges (Tight Diamond and Urban Diamond) were not easily modeled, with low values of **R** resulting from the urban and rural mainline models. The fringe area model fit the data better, with an **R** value of 0.8200.

10. In the rural area, group 4 interchange (Partial Diamond, Partial Tight Diamond, Trumpet A and Partial Directional Y) models showed a good fit for both the crossroad and the mainline segments. There was an insignificant sample of this interchange group in the urban and fringe areas, so no models were constructed for this interchange groups.

Table V.1 Classification of signs of variable terms used in the models constructed

Variables used	UM		RM		FM		UC		RC		FC		ONR		OFR	
	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-
Population		1		1	1	1								1		2
Lane mileage			5		4	1	3		1				1		2	
Number of On-ramps			2	1												
Number of Off-ramps									1							
Avg. Daily Traffic	5		9		2		3		6		1			1		1

UM means Urban Mainline.
RM means Rural Mainline.
FM means Fringe Mainline.
UC means Urban Crossroad.
RC means Rural Crossroad.
FC means Fringe Crossroad.
ONR means On-ramps.
OFR means Off-ramps.

Table V.2 Number of interchanges for each group of the analysis unit

UNIT GROUP	MAINLINE			CROSSROAD				ON-RAMP			OFF-RAMP		
	TA	FA	RA	TA	FA	RA	AA	TA	FA	RA	TA	FA	RA
URBAN GROUP 2	19							17	17		17	17	17
URBAN GROUP 3	11	11	11	11									
URBAN GROUP 4				11	11		11						
URBAN GROUP 5	11												
RURAL GROUP 1	50			50			50						
RURAL GROUP 2	27			27									
RURAL GROUP 3	25			25									
RURAL GROUP 4	23	23	23										
RURAL GROUP 6	18			12									
RURAL GROUP 7	12			10									
RURAL GROUP 9	19			19									
FRINGE GROUP 2	14												
FRINGE GROUP 3	26			26									
FRINGE GROUP 8	10		10										
FRINGE GROUP 9	10												

Table V.3 Multiple R Coefficient for Each group of Analysis Unit

UNIT GROUP	MAINLINE			CROSSROAD				ON-RAMP			OFF-RAMP		
	TA	FA	RA	TA	FA	RA	AA	TA	FA	RA	TA	FA	RA
URBAN GROUP 2	0.5441							0.5051	0.7388		0.9091	0.5034	0.6195
URBAN GROUP 3	0.9025	0.7480	0.8134	0.8590									
URBAN GROUP 4				0.8656	0.6144		0.6170						
URBAN GROUP 5	0.7839												
RURAL GROUP 1	0.7336			0.7063			0.6283						
RURAL GROUP 2	0.3547			0.6711									
RURAL GROUP 3	0.7150			0.8034									
RURAL GROUP 4	0.8262	0.7661	0.8054										
RURAL GROUP 6	0.4087			0.8795									
RURAL GROUP 7	0.6497			0.8525									
RURAL GROUP 9	0.6290			0.8356									
FRINGE GROUP 2	0.8200			0.7534									
FRINGE GROUP 3	0.6872												
FRINGE GROUP 8	0.7452		0.8416										
FRINGE GROUP 9	0.7162												

CHAPTER VI

CALIBRATION

In order to test the above models, all models which had a multiple **R** coefficient greater than 0.7 and were based on more than 10 interchanges for the mainline and crossroad units were considered. However, all the groups for the ramp units were considered during the calibration procedure since samples of ramp data collected were so small. The linear regression models were constructed for each group of mainline, crossroad and ramp units based on population (1000's) of the county (X_1), lane mileage (in 0.01 mile unit) of the analysis unit (X_2) , number of on-ramps (X_3), number of off-ramps (X_4), average daily traffic (ADT) (X_5) and the total number of accidents.

VI. 1 Models for the Mainline Unit

1. Model of urban group 3

$$Y = -14.551 + 0.00115X_5$$

From the above linear regression model, the predicted values for each interchange not used in constructing the model for this group were found, and these were compared with the actual values as shown in Table VI.1.

2. Model of urban group 5

$$Y = -42.267 - 0.038X_1 + 0.00215X_5$$

From the above linear regression model, the predicted values and the actual values are shown in Table VI.2.

3. Model of rural group 1

$$Y = 0.937 - 0.00880X_1 + 0.000657X_5$$

From the above linear regression model, the predicted values and the actual values are shown in Table VI.3.

4. Model of rural group 3

$$Y = -5.007 + 0.030X_2 + 0.000354X_5$$

From the above linear regression model, the predicted values and the actual values are shown in Table VI.4.

5. Model of rural group 4

$$Y = 3.435 + 0.060X_2 - 8.534X_3 + 0.000289X_5$$

From the above linear regression model, the predicted values

and the actual values are shown in Table VI.5.

6. Model of fringe group 2

$$Y = 7.932 - 0.067X_2 + 0.000685X_5$$

From the above linear regression model, the predicted values and the actual values are shown in Table VI.6.

7. Model of fringe group 8

$$Y = -7.127 + 0.149X_2$$

From the above linear regression model, the predicted values and the actual values are shown in Table VI.7.

8. Model of fringe group 9

$$Y = 5.488 + 0.077X_2$$

From the above linear regression model, the predicted values and the actual values are shown in Table VI.8.

V.2 Models for the crossroad unit

1. Model of urban group 3

$$Y = -57.966 + 0.553X_2 + 0.00257X_5$$

From the above linear regression model, the predicted values and the actual values are shown in Table VI.9.

2. Model of urban group 4

$$Y = -21.355 + 0.425X_2 + 0.00167X_5$$

From the above linear regression model, the predicted values and the actual values are shown in Table VI.10.

3. Model of rural group 1

$$Y = -3.654 + 0.00348X_5$$

From the above linear regression model, the predicted values and the actual values are shown in Table VI.11.

4. Model of rural group 3

$$Y = 0.257 + 0.00235X_5$$

From the above linear regression model, the predicted values and the actual values are shown in Table VI.12.

5. Model of rural group 6

$$Y = -175.947 + 0.373X_2 + 48.619X_4$$

From the above linear regression model, the predicted values and the actual values are shown in Table VI.13.

6. Model of rural group 7

$$Y = 4.597 + 0.00144X_5$$

From the above linear regression model, the predicted values and the actual values are shown in Table VI.14.

7. Model of rural group 9

$$Y = -0.514 + 0.00384X_5$$

From the above linear regression model, the predicted values and the actual values are shown in Table VI.15.

8. Model of fringe group 2

$$Y = 4.077 + 0.00283X_5$$

From the above linear regression model, the predicted values

and the actual values are shown in Table VI.16.

V.3 Models for the on-ramp unit

1. Model of urban group 2

$$Y = 4.723 - 0.00118X_1$$

From the above linear regression model, the predicted values and the actual values are shown in Table VI.17.

V.4 Models for the off-ramp unit

1. Model of urban group 2

$$Y = 8.236 - 0.00236X_1 + 0.271X_2 - 0.000565X_5$$

From the above linear regression model, the predicted values and the actual values are shown in Table VI.18.

Summary of Results

Based upon the results of model calibration, the following conclusions were drawn:

1. Out of the urban and rural mainline groups, group 3 which

comprises the interchange types of Modified Diamond, Modified Tight Diamond and Parclo A 4 Quad predicts the observed values well as shown in Graphs 1 and 4. These models indicate that the number of accidents on the urban freeway interchanges of Modified Diamond, Modified Tight Diamond and Parclo A 4 Quad types depends primarily on the average daily traffic (ADT) and increases with increased traffic. However, models to predict the number of accidents on the rural freeway interchanges of the same types also include the lane mileage variable with the accident frequency increasing with the length of the road segment.

2. Out of the fringe mainline groups, group 2 and group 8 demonstrated good prediction capability as shown in Graphs 6 and 7. Group 2 comprises Tight Diamond and Urban Diamond types. Group 8 comprises Cloverleaf, Cloverleaf with CD roads, Cloverleaf minus 1 loop and Directional with loops types. In group 2, the models indicate that the number of accidents on these types of interchanges depend on the lane mileage and average daily traffic (ADT). However, in group 8, the number of accidents on these types of interchanges depends only on the lane mileage and increases with the length of road segment.

3. Out of the rural crossroad groups, group 3 and group 7 predict the observed values well as shown in Graphs 12 and 14. Group 3 comprises Modified Diamond, Modified Tight Diamond and Parclo A 4 Quad. Group 7 comprises Parclo AB and Partial

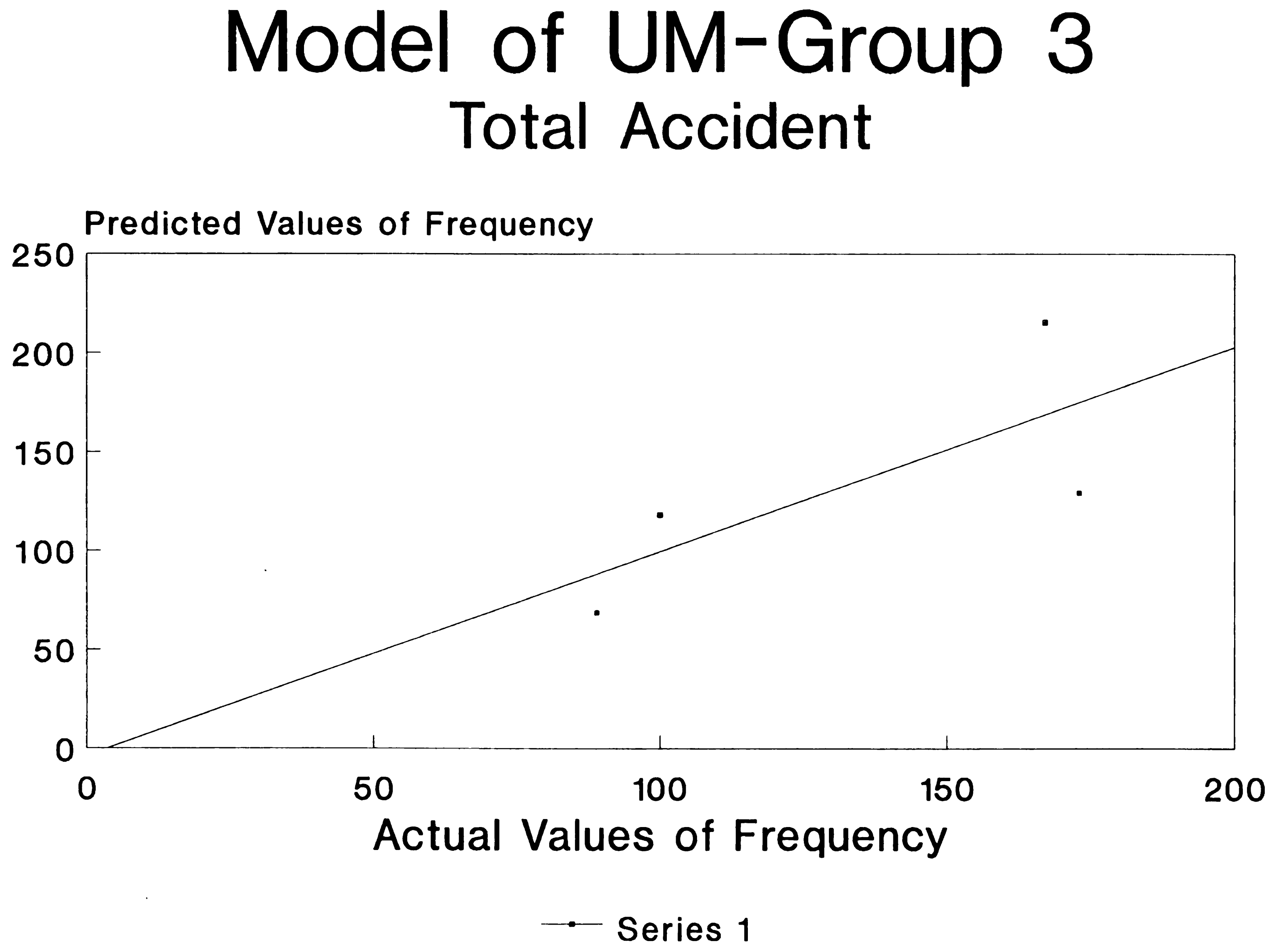
Directional. The number of accidents on these types of interchanges depends on the average daily traffic (ADT) and increases with the increased traffic. This is consistent with the results of other groups.

4. Out of the urban off-ramp groups, group 2 which comprises Modified Diamond, Modified Tight Diamond and Parclo A 4 Quad types has a good prediction for the observed values as shown in Graph 18. The number of accidents on these types of interchanges depends on the population, lane mileage and average daily traffic (ADT), and increases with less population, longer length and reduced traffic.

5. Out of the remaining groups, 3 groups had at least one negative predicted value and most of the remaining groups gave poor predictions for the observed values. This might be result of the existence of outliers within the data. If the outliers are removed, better predictions for the remaining groups could be expected.

Table VI.1 Comparison of Actual and Predicted values of Total accident frequency in UM-Group 3

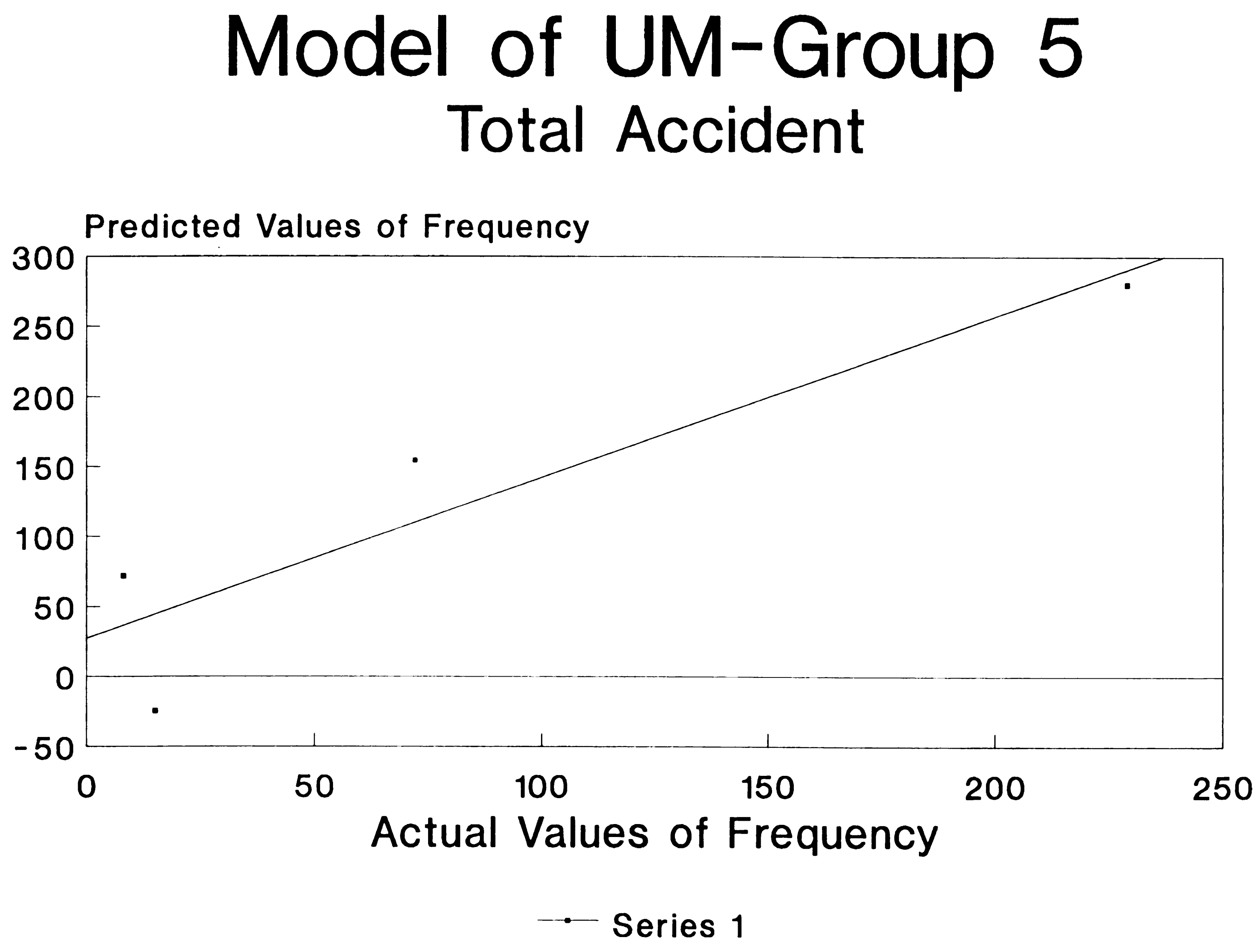
Actual Values	Rank	Predicted Values	Rank
100	3	118.32	3
167	2	215.62	1
173	1	129.36	2
89	4	68.88	4


Model of UM-Group 3
Total Accident
Predicted Values of Frequency
250
200
150
100
50
0
0
50
100
150
200
Actual Values of Frequency
Series 1

Graph 6.1

Table VI.2 Comparison of Actual and Predicted values of total accident frequency in UM-Group 5

Actual Values	Rank	Predicted Values	Rank
72	2	154.60	2
229	1	280.08	1
15	3	-24.34	4
8	4	71.80	3

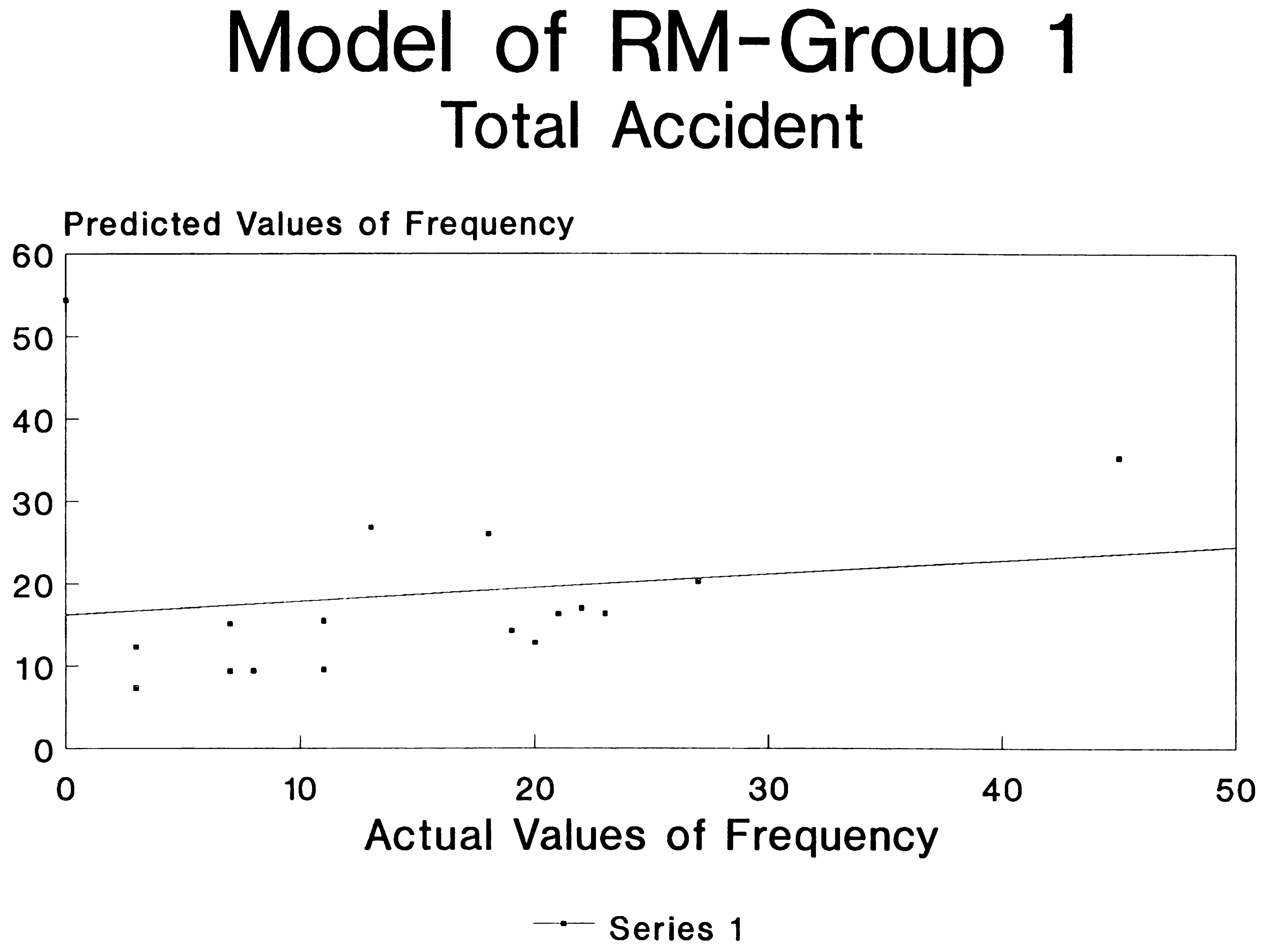


Model of UM-Group 5
Total Accident
Predicted Values of Frequency
300
250
200
150
100
50
0
-50
0
50
100
150
200
250
Actual Values of Frequency
Series 1

Graph 6.2

Table VI.3 Comparison of Actual and Predicted values of Total accident frequency in RM-Group 1

Actual Values	Rank	Predicted Values	Rank
23	3	16.36	7
0	17	54.40	1
21	5	16.32	8
11	10	15.50	9
3	15	7.34	17
45	1	35.28	2
13	9	26.84	3
7	13	15.14	10
18	8	26.06	4
11	10	9.60	14
22	4	17.00	6
27	2	20.32	5
8	12	9.44	15
3	15	12.32	13
7	13	9.38	16
20	6	12.84	12
19	7	14.28	11


Model of RM-Group 1
Total Accident
Predicted Values of Frequency
60
50
40
30
20
10
0
0
10
20
30
40
50
Actual Values of Frequency
Series 1

Graph 6.3

Table VI.4 Comparison of Actual and Predicted values of Total accident frequency in RM-Group 3

Actual Values	Rank	Predicted Values	Rank
52	1	29.68	2
39	2	24.33	3
19	5	10.58	6
26	3	12.94	5
11	6	7.78	7
11	6	6.74	9
10	8	7.02	8
21	4	75.96	1
10	8	21.34	4

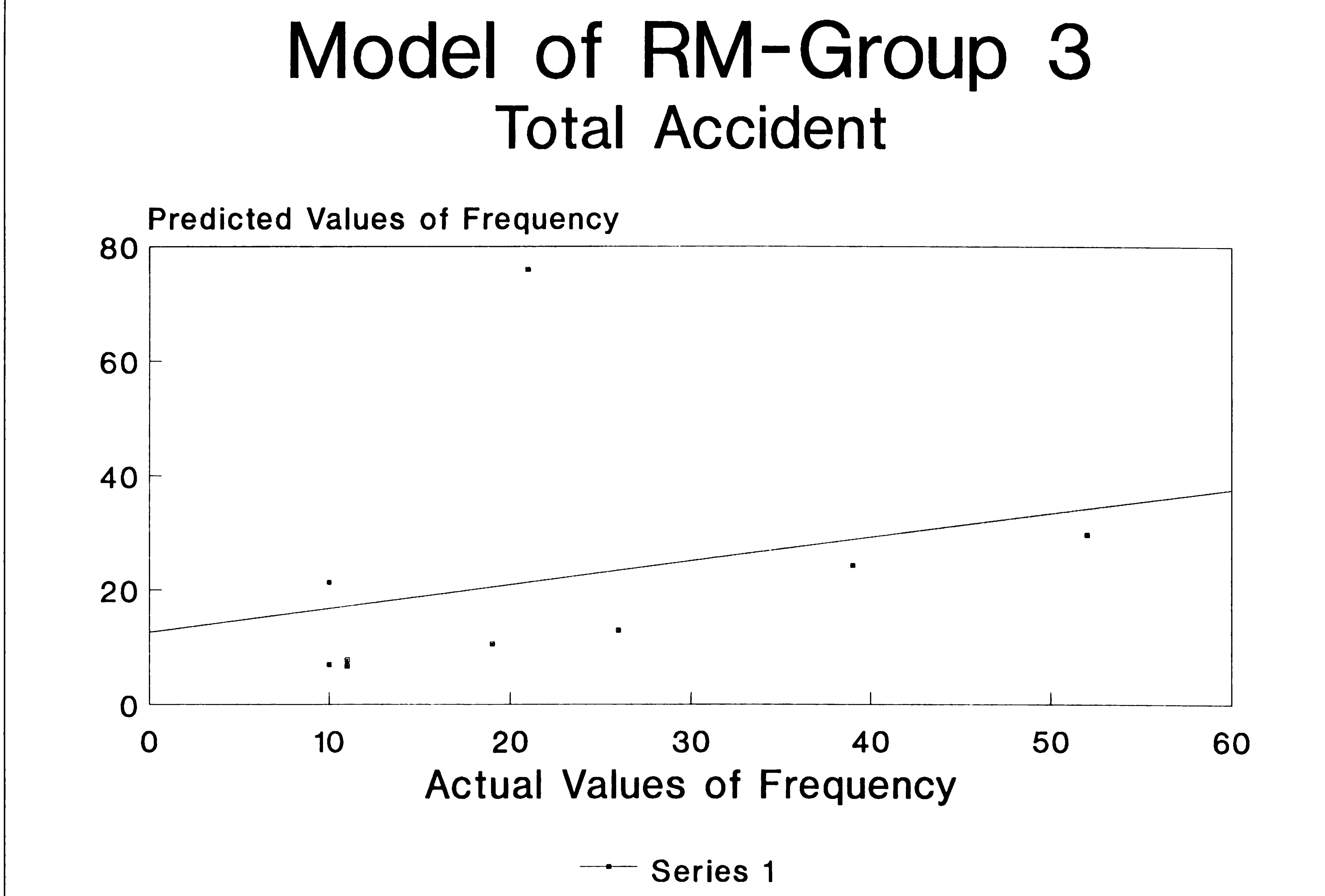
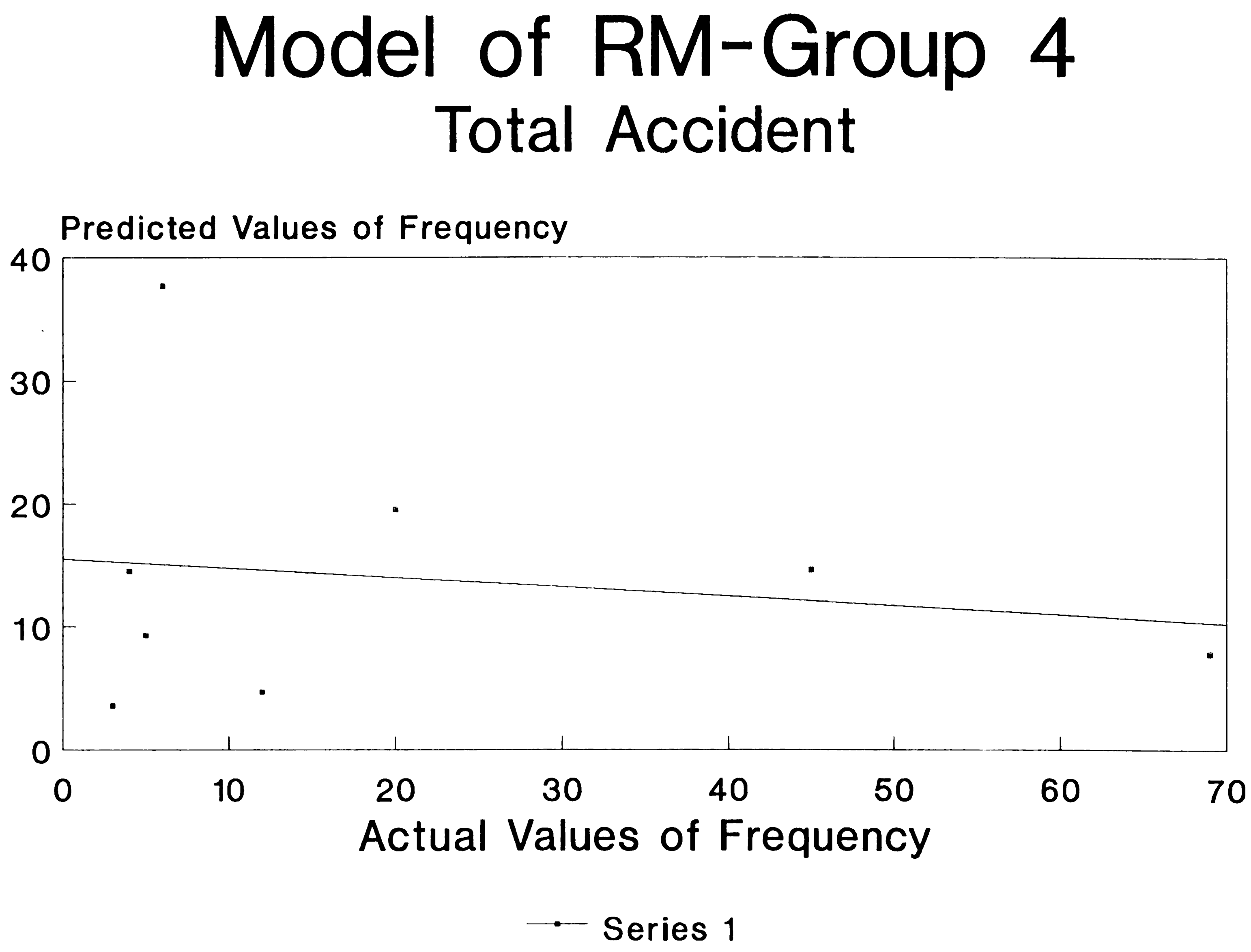

Model of RM-Group 3
Total Accident
Predicted Values of Frequency
80
60
40
20
0
0
10
20
30
40
50
60
Actual Values of Frequency
Series 1
Graph 6.4

Table VI.5 Comparison of Actual and Predicted values of Total accident frequency in RM-Group 4

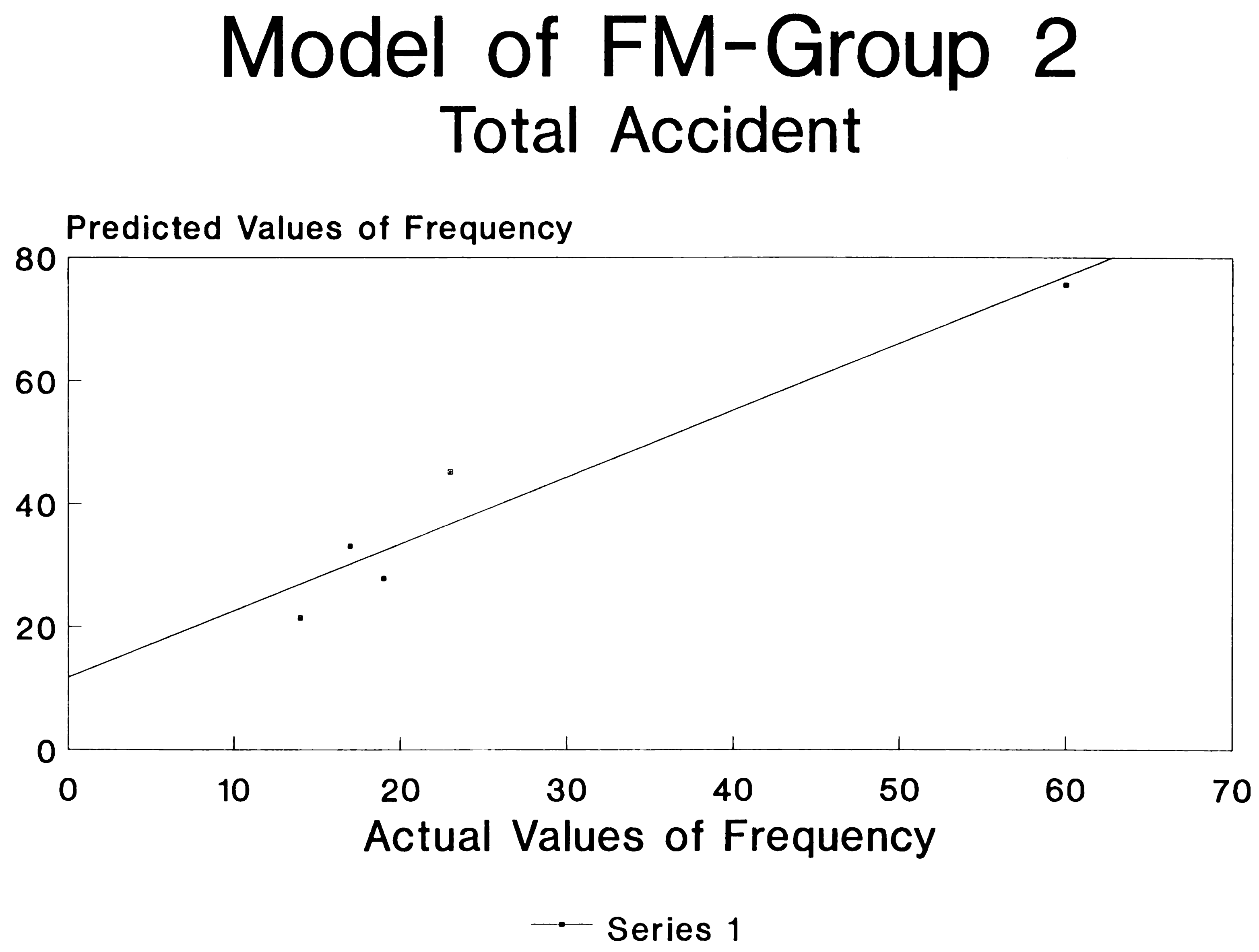
Actual Values	Rank	Predicted Values	Rank
45	2	14.64	3
5	6	9.30	5
4	7	14.52	4
20	3	19.54	2
6	5	37.70	1
3	8	3.60	8
12	4	4.70	7
69	1	7.80	6


Model of RM-Group 4
Total Accident
Predicted Values of Frequency
40
30
20
10
0
0
10
20
30
40
50
60
70
Actual Values of Frequency
Series 1

Graph 6.5

Table VI.6 Comparison of Actual and Predicted values of Total accident frequency in FM-Group 2

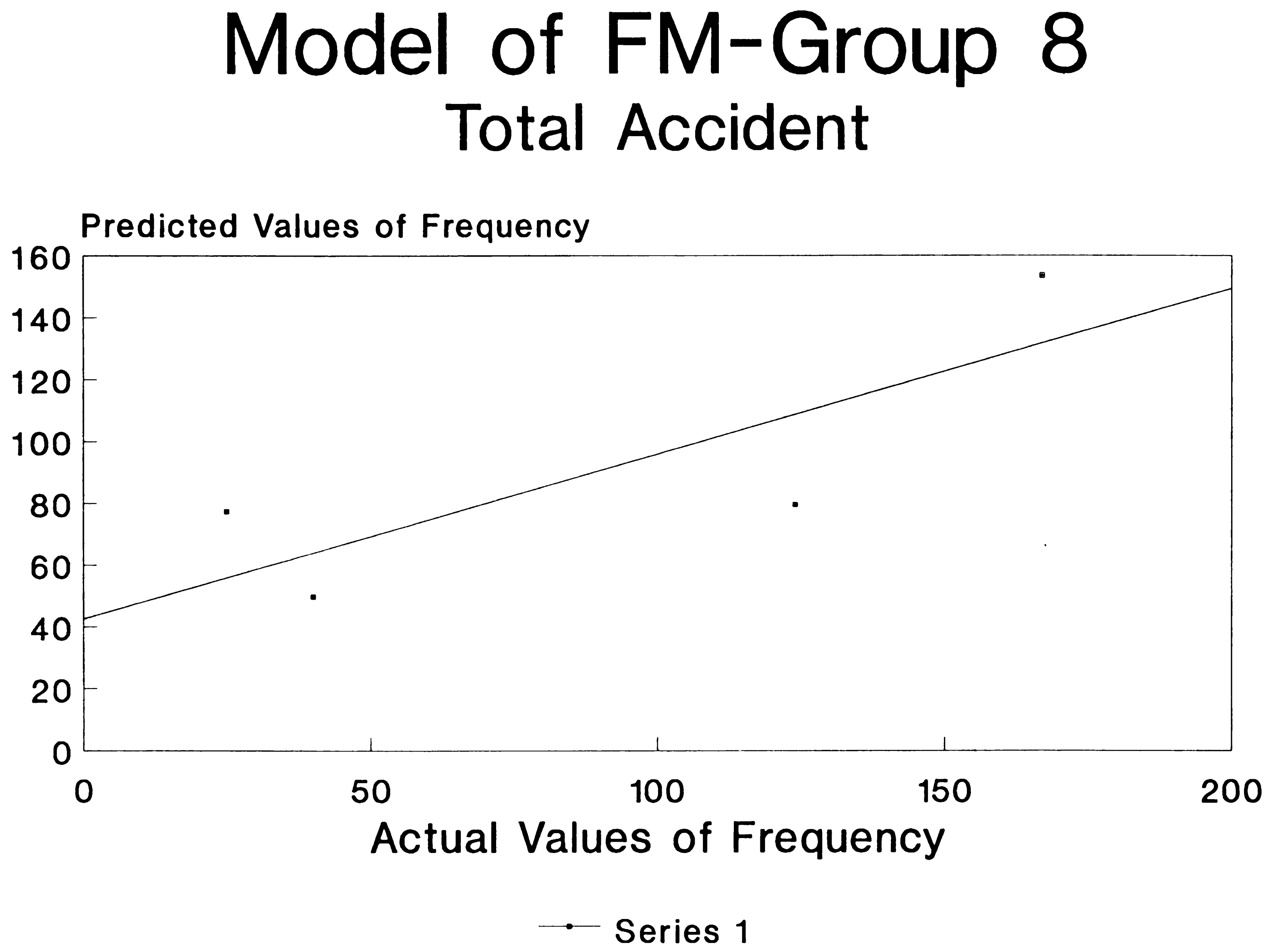
Actual Values	Rank	Predicted Values	Rank
23	2	45.23	2
17	4	33.17	3
19	3	27.92	4
14	5	21.45	5
60	1	75.59	1


Model of FM-Group 2
Total Accident
Predicted Values of Frequency
80
60
40
20
0
0
10
20
30
40
50
60
70
Actual Values of Frequency
Series 1

Graph 6.6

Table VI.7 Comparison of Actual and Predicted values of Total accident frequency in FM-Group 8

Actual Values	Rank	Predicted Values	Rank
167	1	153.56	1
25	4	77.38	3
124	2	79.67	2
40	3	49.86	4


Model of FM-Group 8
Total Accident
Predicted Values of Frequency
160
140
120
100
80
60
40
20
0
0
50
100
150
200
Actual Values of Frequency
Series 1

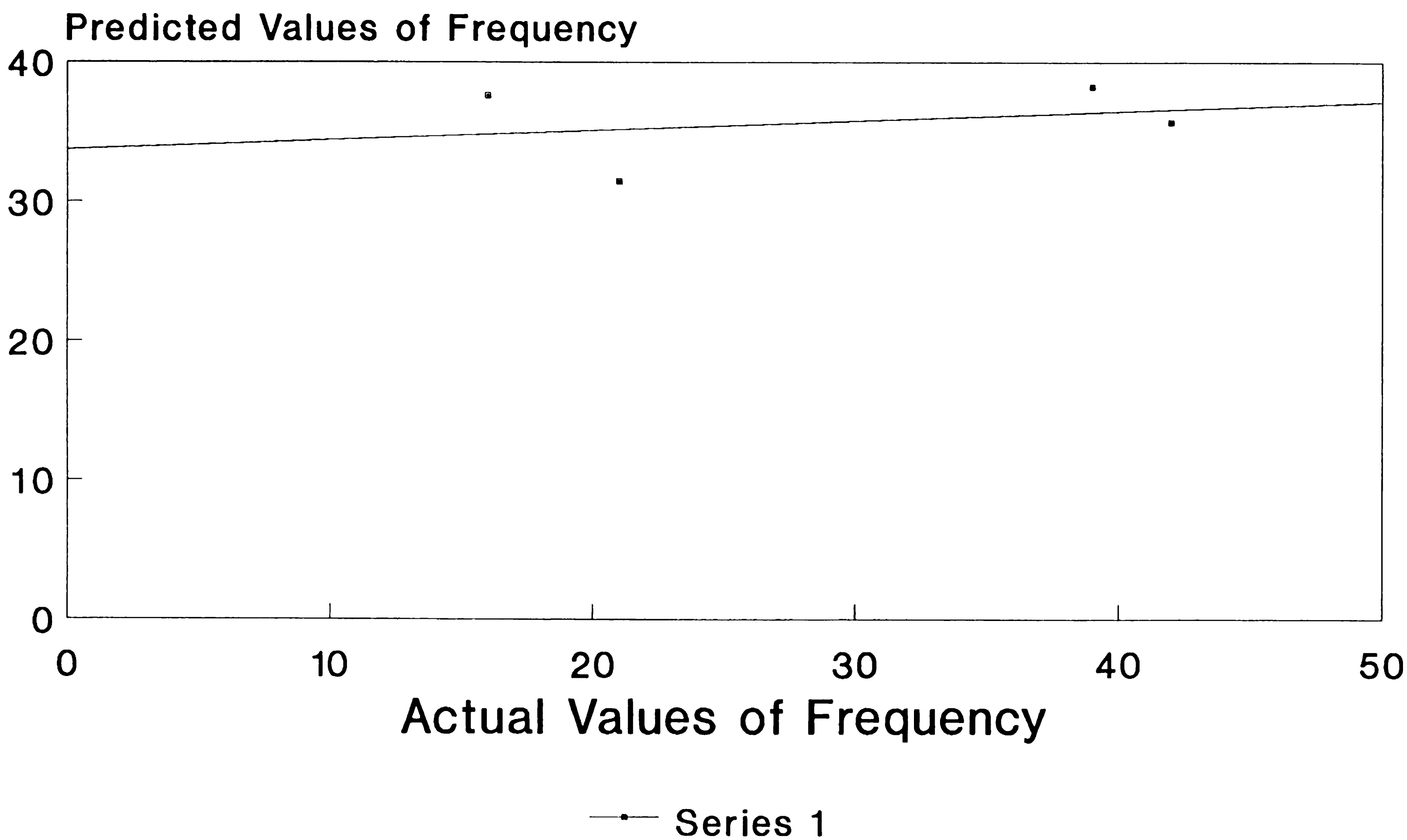
Graph 6.7

Table VI.8 Comparison of Actual and Predicted values of Total accident frequency in FM-Group 9

Actual Values	Rank	Predicted Values	Rank
39	2	38.24	1
42	1	35.69	3
21	3	31.46	4
16	4	37.61	2

Model of FM-Group 9

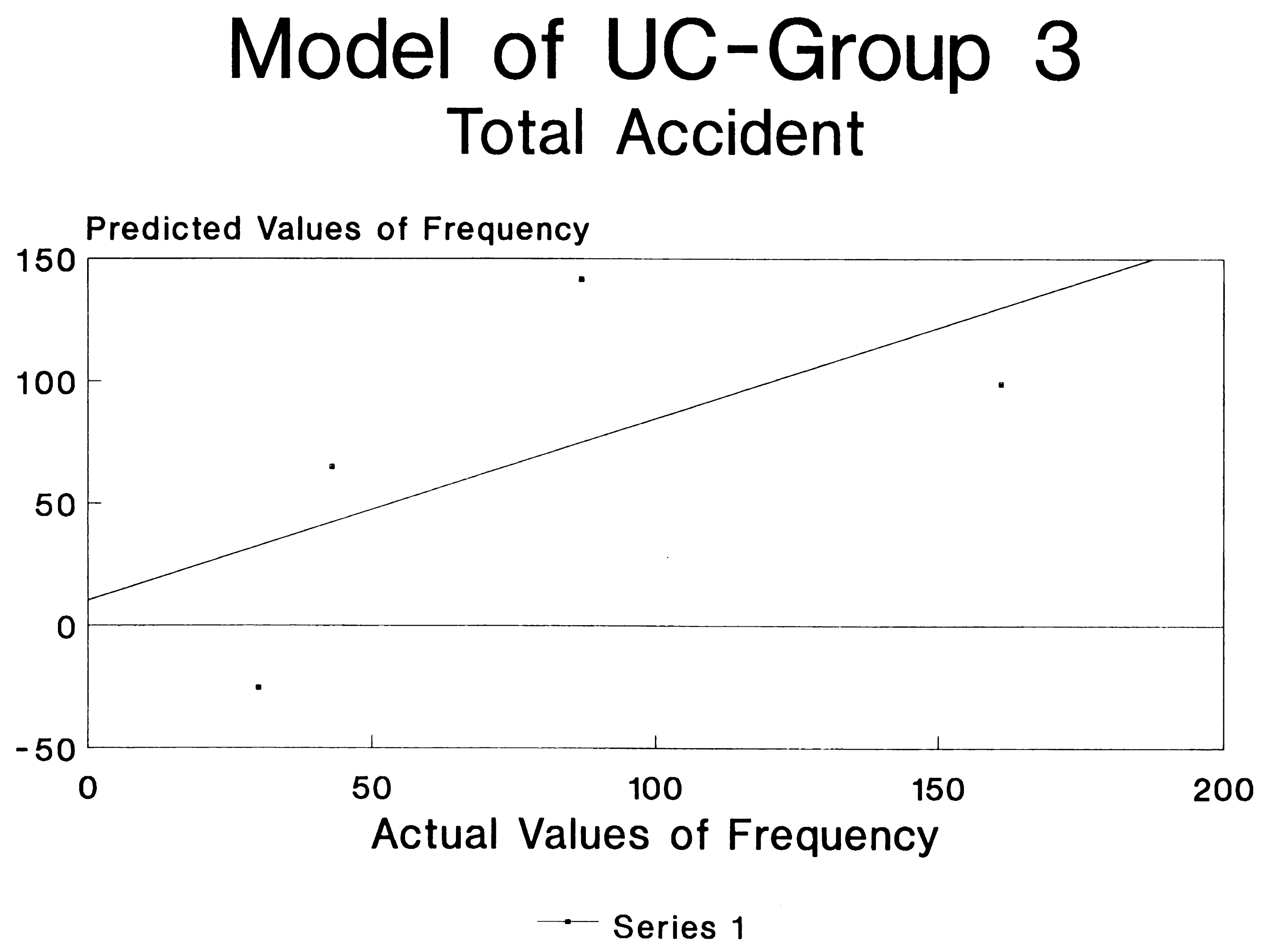
Total Accident



Graph 6.8

Table VI.9 Comparison of Actual and Predicted values of Total accident frequency in UC-Group 3

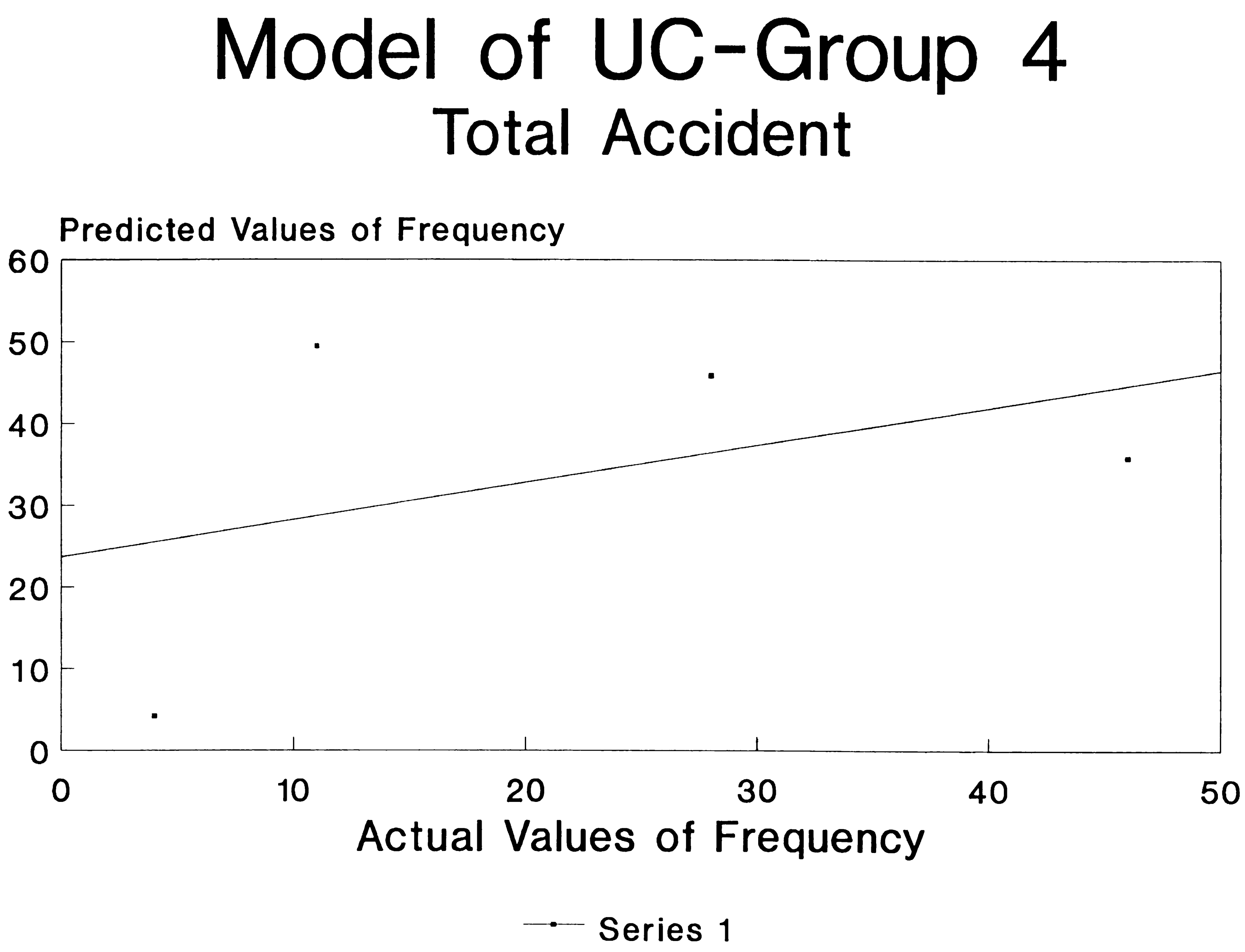
Actual Values	Rank	Predicted Values	Rank
87	2	141.48	1
43	3	65.04	3
30	4	-25.20	4
161	1	98.96	2


Model of UC-Group 3
Total Accident
Predicted Values of Frequency
150
100
50
0
-50
0
50
100
150
200
Actual Values of Frequency
Series 1

Graph 6.9

Table VI.10 Comparison of Actual and Predicted values of Total accident frequency in UC-Group 4

Actual Values	Rank	Predicted Values	Rank
46	1	35.85	3
11	3	49.46	1
28	2	45.87	2
4	4	4.22	4



Model of UC-Group 4
Total Accident
Predicted Values of Frequency
60
50
40
30
20
10
0
0
10
20
30
40
50
Actual Values of Frequency
Series 1

Graph 6.10

Table VI.11 Comparison of Actual and Predicted values of Total accident frequency in RC-Group 1

Actual Values	Rank	Predicted Values	Rank
3	10	2.26	16
10	4	16.08	6
4	8	17.23	5
2	12	10.61	7
1	13	2.61	14
12	3	2.37	15
14	2	9.99	8
0	17	5.05	12
37	1	49.94	1
3	10	5.74	11
1	13	6.79	10
4	8	18.62	4
1	13	0.87	17
8	5	22.45	2
1	13	9.57	9
7	6	3.65	13
6	7	22.45	2

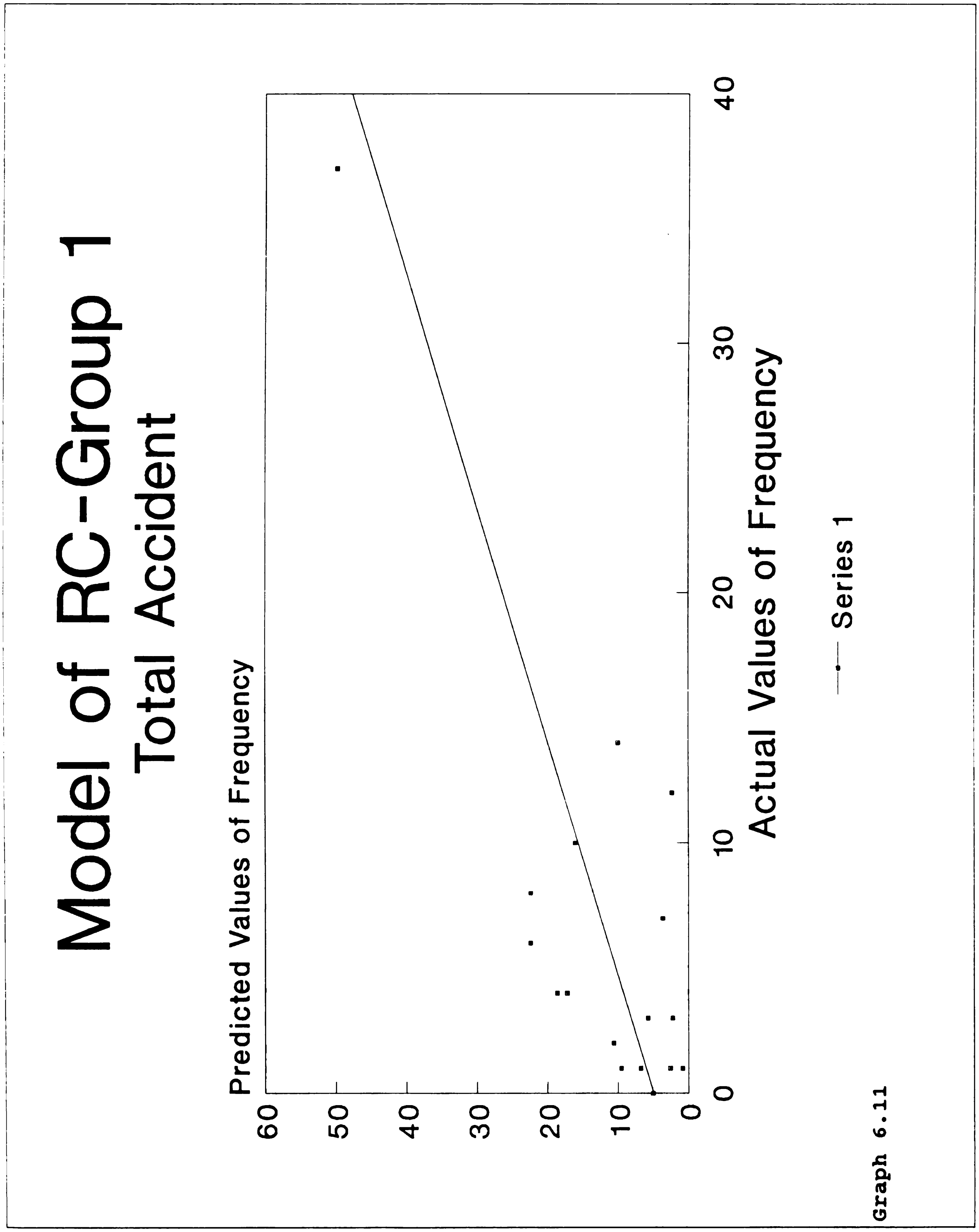
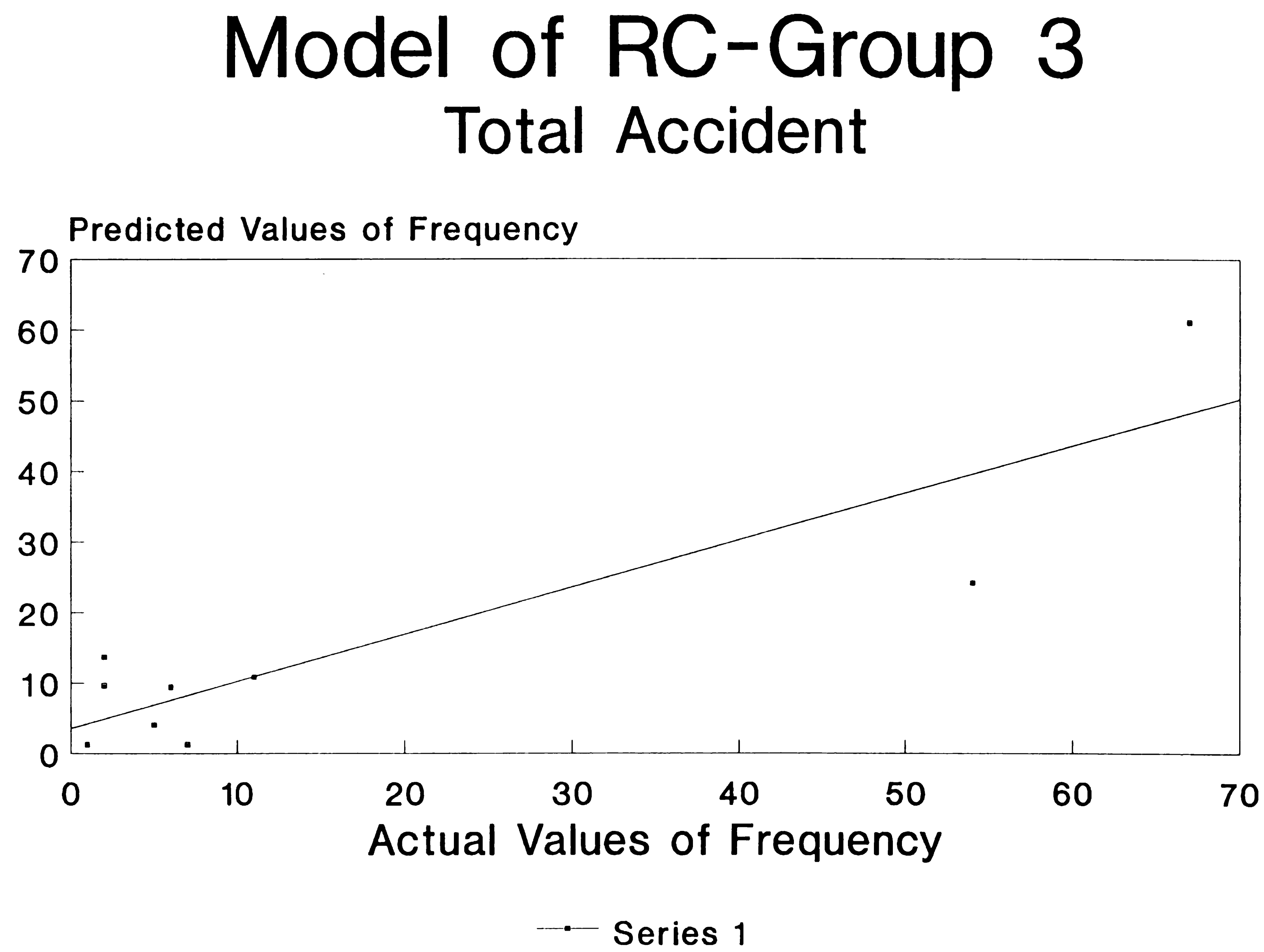

Model of RC-Group 1
Total Accident
Predicted Values of Frequency
60
50
40
30
20
10
0
0
10
20
30
40
Actual Values of Frequency
Series 1
Graph 6.11

Table VI.12 Comparison of Actual and Predicted values of Total accident frequency in RC-Group 3

Actual Values	Rank	Predicted Values	Rank
54	2	24.20	2
6	5	9.42	6
11	3	10.83	4
1	9	1.27	9
7	4	1.29	8
2	7	9.66	5
5	6	4.09	7
67	1	61.12	1
2	7	13.68	3


Model of RC-Group 3
Total Accident
Predicted Values of Frequency
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
Actual Values of Frequency
Series 1

Graph 6.12

Table VI.13 Comparison of Actual and Predicted values of Total accident frequency in RC-Group 6

Actual Values	Rank	Predicted Values	Rank
44	1	29.59	2
1	3	-66.03	4
1	3	-60.81	3
29	2	82.68	1

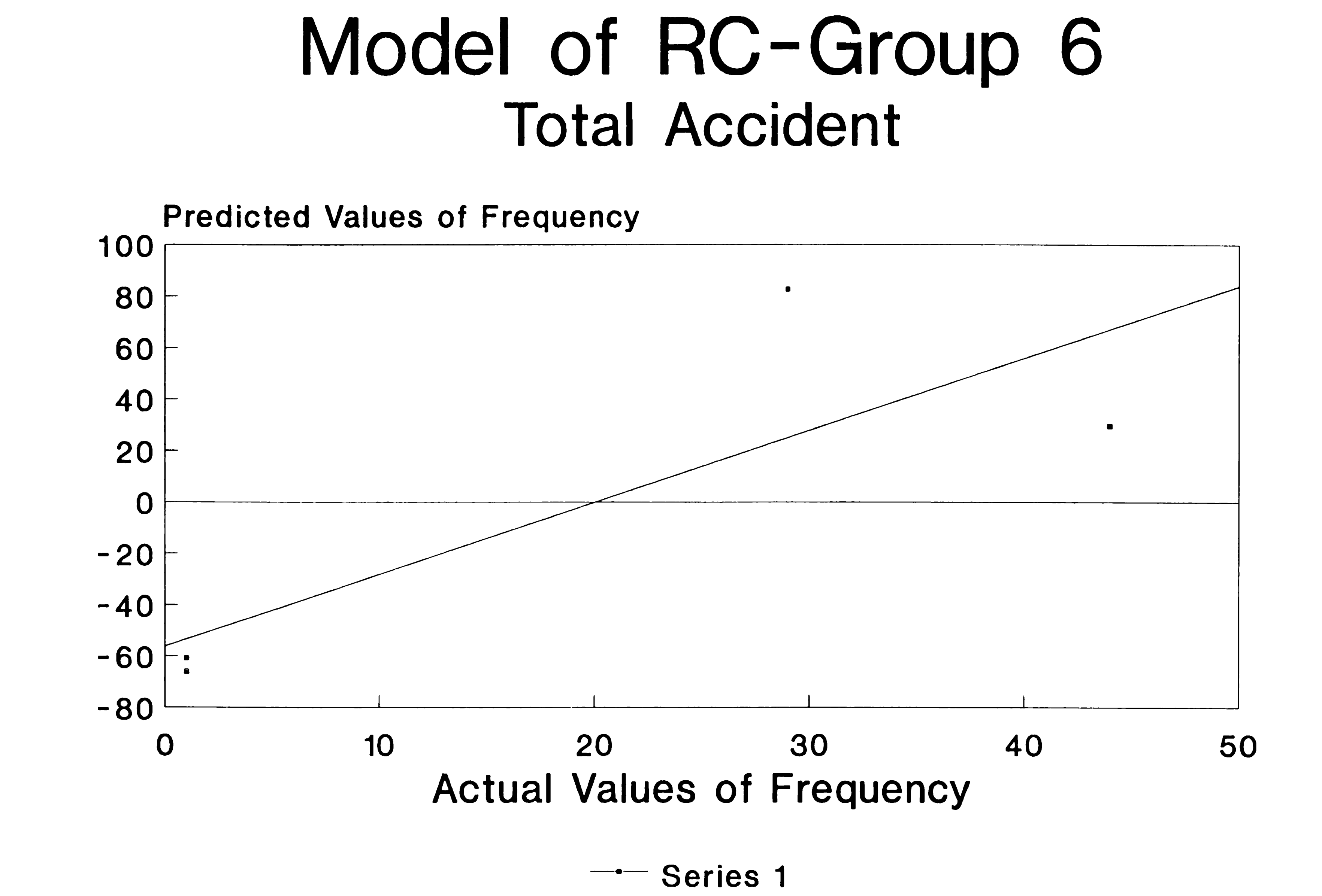
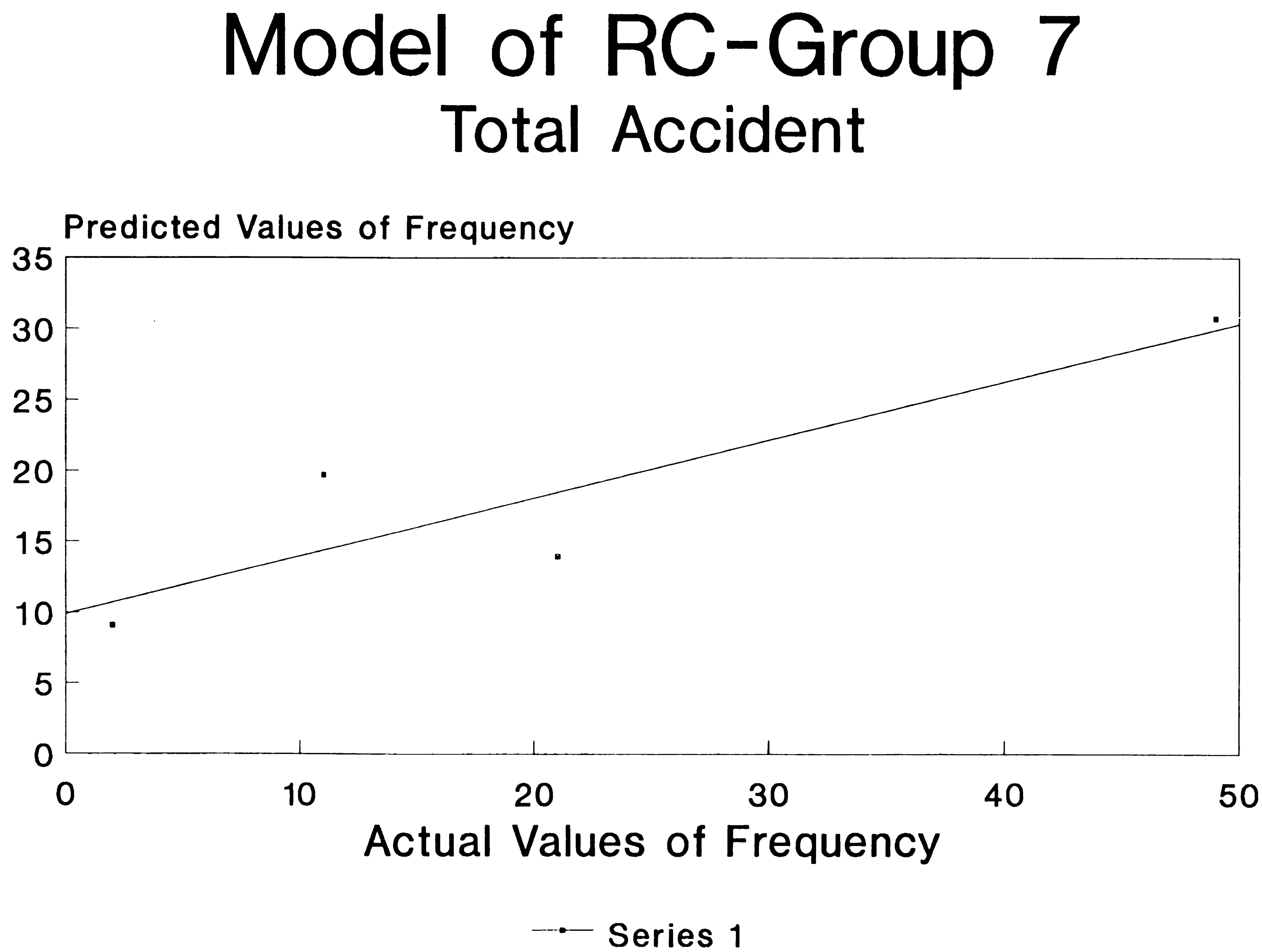

Model of RC-Group 6
Total Accident
Predicted Values of Frequency
100
80
60
40
20
0
-20
-40
-60
-80
0
10
20
30
40
50
Actual Values of Frequency
Series 1
Graph 6.13

Table VI.14 Comparison of Actual and Predicted values of Total accident frequency in RC-Group 7

Actual Values	Rank	Predicted Values	Rank
2	4	9.08	4
11	3	19.72	2
21	2	13.96	3
49	1	30.76	1

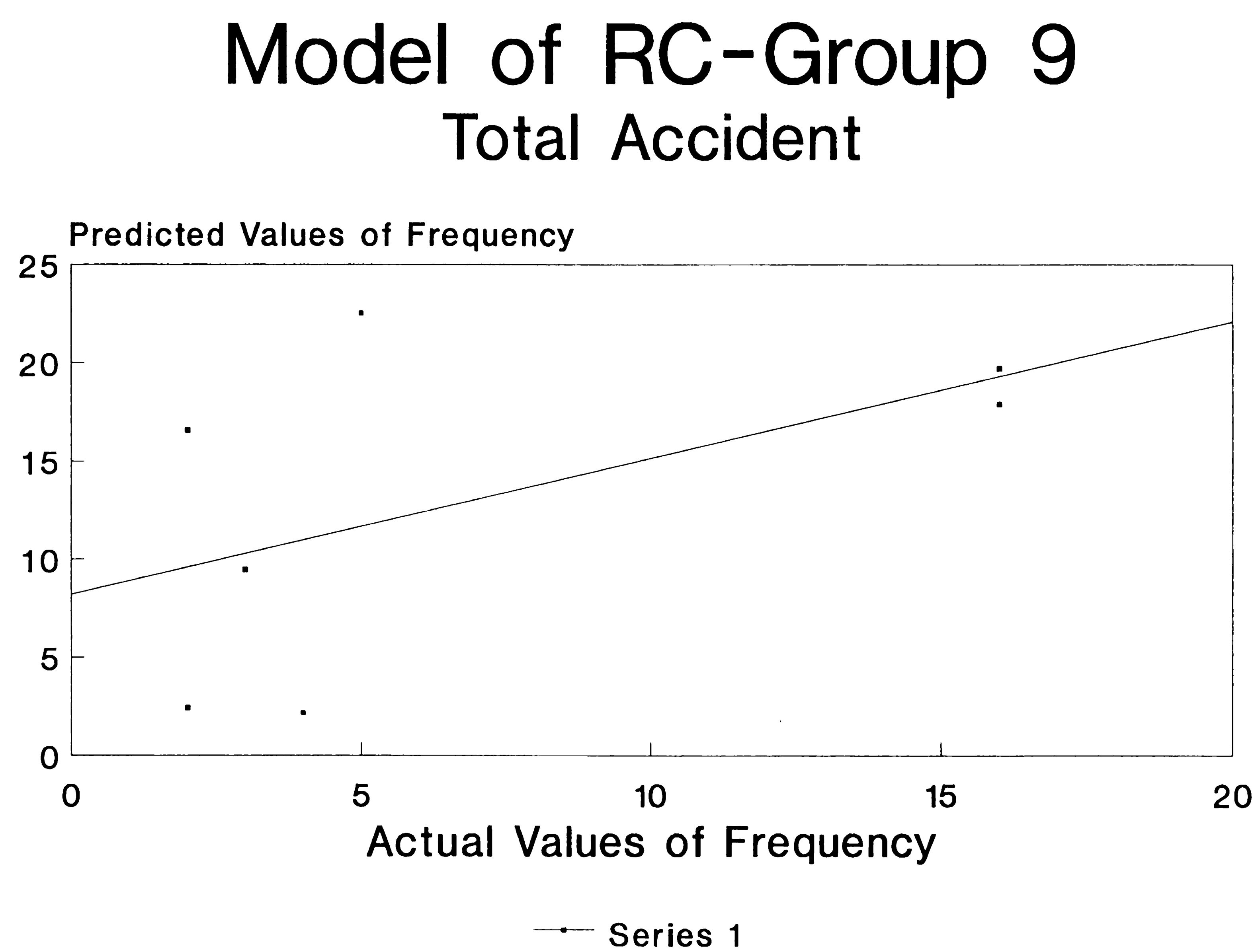


Model of RC-Group 7
Total Accident
Predicted Values of Frequency
35
30
25
20
15
10
5
0
0
10
20
30
40
50
Actual Values of Frequency
Series 1

Graph 6.14

Table VI.15 Comparison of Actual and Predicted values of Total accident frequency in RC-Group 9

Actual Values	Rank	Predicted Values	Rank
16	1	19.72	2
16	1	17.92	3
2	6	16.57	4
2	6	2.44	6
3	5	9.47	5
5	3	22.53	1
4	4	2.17	7

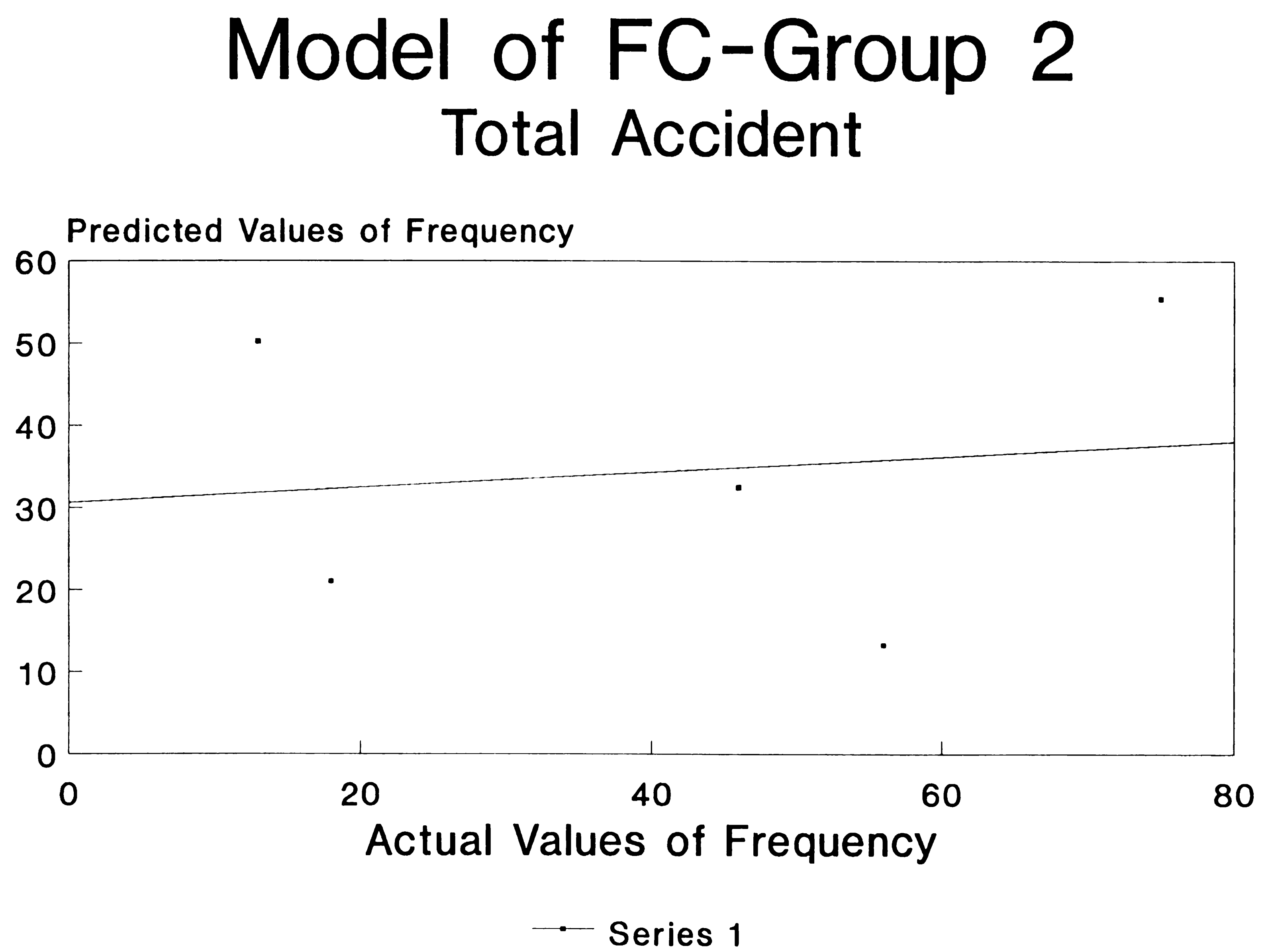


Model of RC-Group 9
Total Accident
Predicted Values of Frequency
25
20
15
10
5
0
0
5
10
15
20
Actual Values of Frequency
Series 1

Graph 6.15

Table VI.16 Comparison of Actual and Predicted values of Total accident frequency in FC-Group 2

Actual Values	Rank	Predicted Values	Rank
46	3	32.52	3
56	2	13.30	5
18	4	21.06	4
13	5	50.21	2
75	1	55.44	1

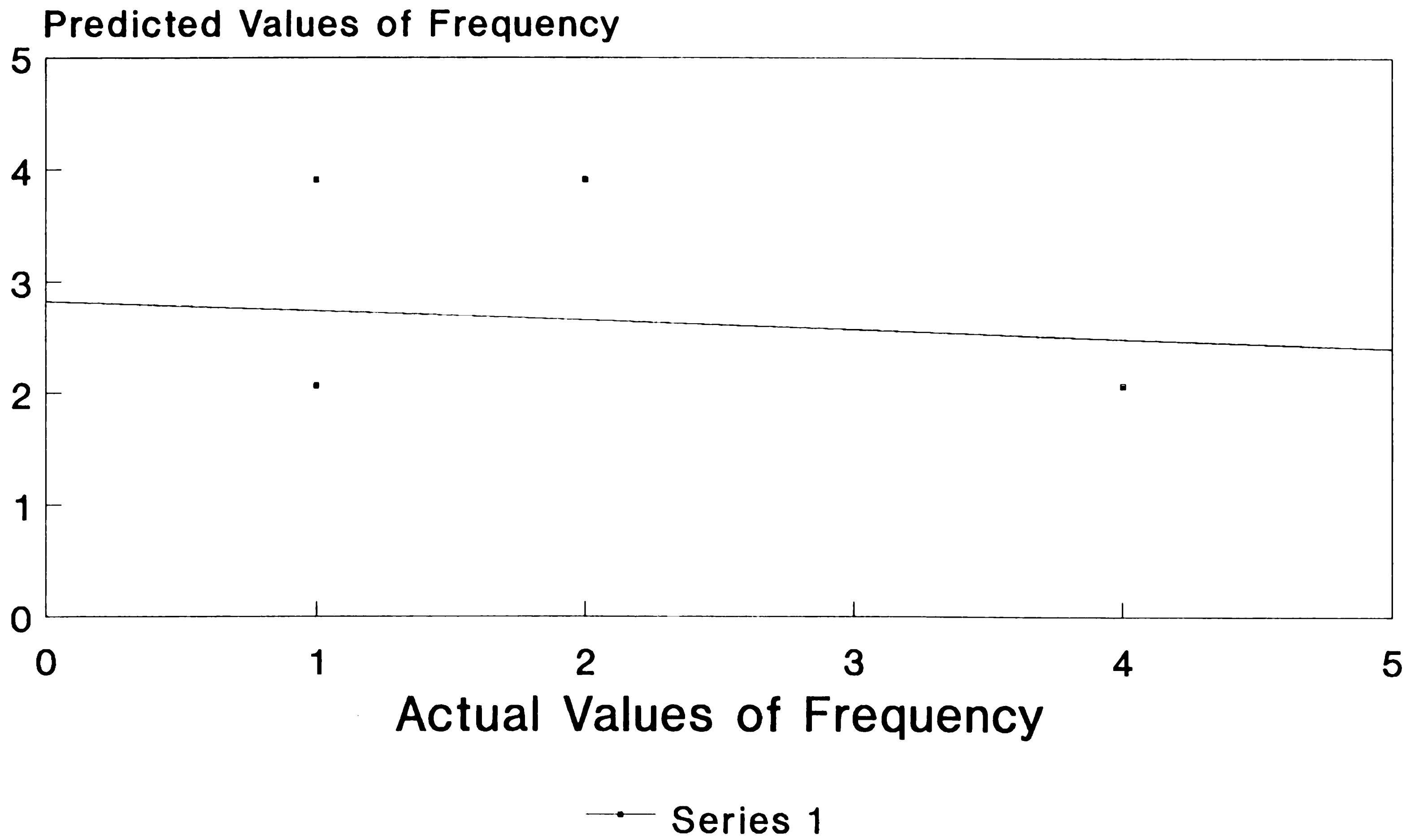

Model of FC-Group 2
Total Accident
Predicted Values of Frequency
60
50
40
30
20
10
0
0
20
40
60
80
Actual Values of Frequency
Series 1

Graph 6.16

Table VI.17 Comparison of Actual and Predicted values of Total accident frequency in UON-Group 2

Actual Values	Rank	Predicted Values	Rank
4	1	2.07	3
1	3	2.07	3
2	2	3.91	1
1	3	2.07	3
1	3	2.07	3
1	3	3.91	1

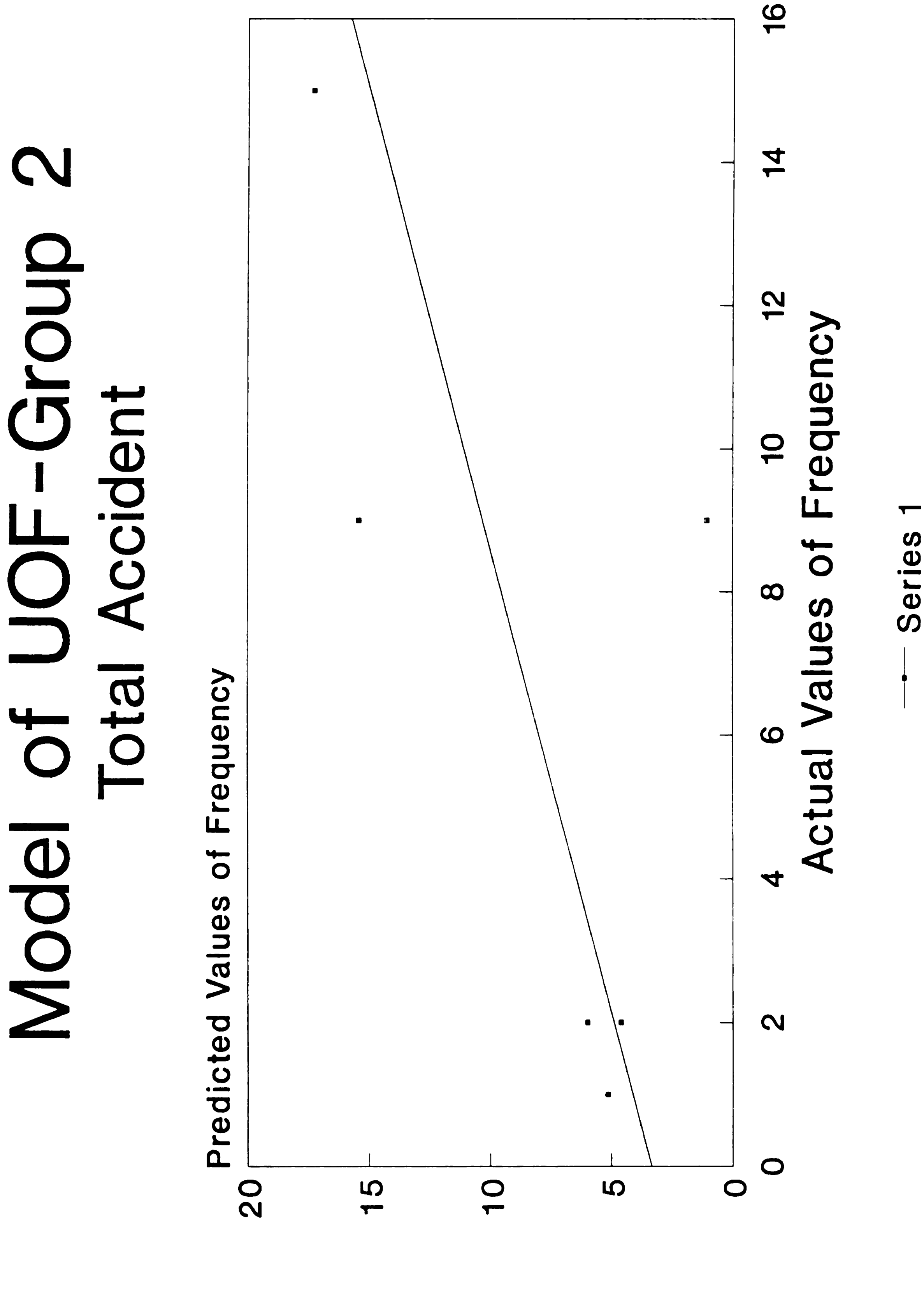
Model of UON-Group 2
Total Accident



Graph 6.17

Table VI.18 Comparison of Actual and Predicted values of Total accident frequency in UOF-Group 2

Actual Values	Rank	Predicted Values	Rank
2	4	5.99	3
2	4	4.61	5
15	1	17.30	1
9	2	1.07	6
1	6	5.15	4
9	2	15.43	2


Model of UOF-Group 2
Total Accident
Predicted Values of Frequency
20
15
10
5
0
0
2
4
6
8
10
12
14
16
Actual Values of Frequency
Series 1
Graph 6.18

CHAPTER VII

SUMMARY and CONCLUSIONS

Summary

Freeway interchanges play a very important role in reducing the probability of vehicular conflicts during transfer from one road to another. However, the number of accidents on freeway interchanges is increasing with increased traffic on the freeway.

The purpose of this study was to identify the type of accidents that occurred on the elements of the interchanges, compare the accident rates with the results from J. A. Cirillo's study, and finally construct freeway interchange accident predictive models based on the elements which comprise an interchange.

The first step in constructing these models was to obtain geometric data, accident data and traffic data for interchanges located in the State of Michigan. The data obtained were:

- o Geometric data describing the elements of the freeway interchange geometry were obtained from the Michigan Department of Transportation's Highway Accident Master Data file.
- o Accident data from 1982 to 1984 were obtained from the

Michigan Department of Transportation's Highway Accident Master Data file.

- o Traffic Data describing the level of use of the freeway interchange elements were available from the Michigan Department of Transportation's TVM (Trunkline Vehicle Miles) Master Data file and Traffic Flow map.

These data files were merged to produce a master data file composed of geometric data, accident data and traffic data. This file was then stratified into 3 analysis units for constructing freeway interchange accident predictive models for each element of an interchange. These analysis units were:

- o mainline unit
- o crossroad unit
- o ramp unit

During the study period 4464 out of 9534 accidents occurred on the mainline unit, 2536 accidents occurred on the crossroad unit and 2534 accidents occurred on the ramp unit, respectively.

Based upon the total number of accidents for each analysis unit, the first attempt was made to construct a linear regression model using all interchanges in one model. The multiple regression **R** coefficient for the mainline unit was 0.5624, indicating that less than 30 % of the variance in

accident frequency was explained by the independent variables used.

The master data file was then stratified into 3 area types of activity density (urban, rural and fringe). The master data file was further classified into groups of interchange configurations with similar accident rates. The interchange type with the lowest average accident rate (accidents per interchange per 3 years) was 0.91 for the Partial Diamond type interchanges and the highest value of the average accident rate was 14.29 for the Full Directional type interchanges. Interchange types that were similar to each other in the average accident rate and variance were grouped for further analysis. The interchanges were classified into 12 groups for each analysis unit:

- Group 1 - Diamond
- Group 2 - Tight Diamond, Urban Diamond
- Group 3 - Modified Diamond, Modified Tight Diamond, Parclo A 4 Quad
- Group 4 - Partial Diamond, Partial Tight Diamond, Trumpet A, Partial Directional Y
- Group 5 - Split Diamond, General Directional, Other
- Group 6 - Diamond plus 1 loop, Parclo B 4 Quad, Trumpet B, Directional Y
- Group 7 - Parclo AB, Partial Directional
- Group 8 - Cloverleaf, Cloverleaf with CD Roads, Cloverleaf

minus 1 loop, Directional with loops

- Group 9 - Parclo A, Parclo B, Parclo AB 4 Quad
- Group 10 - Full Directional, General
- Group 11 - SRI-A
- Group 12 - SRI-B

For the classified groups, group 4 had the lowest value of 1.25 acc./int./3 yrs. and group 10 had the highest value of 10.27 acc./int./3 yrs.

The most common accident types occurring on the urban interchanges were fixed object, rear-end and angle straight accidents. Group 2 had the highest percentage of fixed object, rear-end and angle straight accidents. The accident types on the rural interchanges were fixed object, rear-end and animal accidents. Group 1 had the highest percentage of fixed object and animal accidents, and group 3 had the highest percentage of rear-end accidents. The predominant accident types on the fringe interchanges were fixed object, rear-end and animal accidents. Group 3 had the highest percentage of fixed object and rear-end accidents, and group 1 had the highest percentage of animal accidents.

Based on the total number of accidents per interchange for each analysis unit (considering only groups with more than 10 interchanges), rural group 4 and urban group 10 had the lowest value of 4.84 acc./int. and highest value of 13.75 acc./int., respectively on the mainline unit. On the crossroad

unit rural group 4 had the lowest value of 1.03 acc./int., and urban groups 7 and 10 had the highest value of 6.5 acc./int. On the on-ramp unit rural group 2 had the lowest value of 0.60 acc./int., and urban group 6 had the highest value of 3.50 acc./int. On the off-ramp unit rural group 4 had the lowest value of 0.54 acc./int., and urban group 3 had the highest value of 4.82 acc./int.

From the classified groups, only groups with more than 10 interchanges were selected for constructing linear regression models. Three fourth of the stratified data in each cell were used to construct the model and the remaining 25 % of the data were used for calibrating the model. Variables used to construct the models were population (in 1000's) of the county, lane mileage (0.01 mile units) of the analysis unit, number of on-ramps, number of off-ramps, average daily traffic (ADT) for the independent variables and the total number of accidents for the dependent variable. Models with greater than 0.7 in multiple **R** coefficient were tested against the remainder of the stratified data.

The last step in constructing linear regression models for predicting accidents on freeway interchanges was to compare predicted and actual accident frequencies for the acceptable models.

Conclusions

The following conclusions concerning modeling accidents on freeway interchanges were drawn:

1. The data support the literature which found that the accident rate on ramp units is higher than on mainline and crossroad units.
2. Models with all interchanges in one model are not reliable, because there is too much variance to be explained by the variables used in the study. The type of interchange (configuration) is the most important variable, with accident rates ranging between 0.91 acc./int. and 14.29 acc./int.
3. Out of the variables used for constructing accident predictive models, the average daily traffic (ADT) was found to be the most significant in modeling freeway interchange accidents. The number of accidents on the mainline and crossroad units increased with increased traffic. However, the number of accidents on the ramp units tended to decrease with increased traffic.
4. It is possible to obtain reasonable predictions of the accident frequency on the elements of some interchange classes (see **R** values in Table V.3).
5. Some of the other variables tested (over or under, lighting, and ramp control) might improve the model

prediction power, but the data base was not large enough to make these additional stratifications.

BIBLIOGRAPHY

BIBLIOGRAPHY

1. Cirillo, J. A., "Interstate System Accident Research Study II, Interim Report II." Public Roads, Vol. 35, No. 3, 1968, pp. 71-75.

2. Oppenlander, J. C. and Dawson, R. F., "Traffic Control & Roadway Elements - Their Relationship to Highway Safety/ Revised. Chapter 9: Interchanges." Highway Users Federation for Safety na Mobility, 1970, 11 pp.

3. Fisher, R. L., "Accident and Operating Experience at Interchanges." Highway Research Board Bulletin, 1961, No. 291, pp. 124-138.

4. Vostrez, J and Lundy, R. A., "Comparative Freeway Study." Highway Research Record, Highway Research Board, 1965, No. 99, pp. 157-199.

5. Janoff, M. S., Freedman, M. and Decina, L. E., "Partial Lighting of Interchanges." Transportation Research Board, NCHRP Report No. 256, Dec. 1982, 81 pp.

6. Tipton, W. E. and Pinnel, C., "An investigation of factors affecting the design location of freeway ramps." Highway Research Record, Highway Research Board, 1967, No. 152, pp. 1-35.

7. N. J. Rowan, D. L. Woods, V. G. Stover, D. A. Anderson and J. H. Dozier, "Safety Design and Operational Practices for Streets and Highways." US Department of Transportation, Technology Sharing Report: 80-228, Topic

3, Session 8, May 1980, pp. 1-13.

8. Michael D. Meyer and Eric J. Miller, "Urban Transportation Planning: A Decision-Oriented Approach." McGraw-Hill Book Company, 1984. pp. 115-122.

9. Irwin Guttman, "Linear Models: An Introduction." John Wiley & Sons, Inc., 1982, pp. 1-5.

10. John Neter, William Wasserman and Michael H. Kutner, "Applied Linear Regression Models." Richard D. Irwin, Inc., 1983, pp. 23-40.

11. N. R. Draper and H. Smith, "Applied Regression Analysis." John Wiley & Sons, Inc. 1966, pp. 163-177.

12. T. L. Maleck and W. J. Sproule, "Freeway Interchange Geometric Inventory: Users Manual." Michigan State Univ. Dept. of Civil and Environmental Engg., May 1985.