NBSIR 73-175

Estimates of Vehicular Collisions with Multistory Residential Buildings

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Technical Analysis Division
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Washington, D. C. 20234

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Final Report

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U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary
NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

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SUMMARY

This study was designed to investigate the frequency with which motor vehicles collide with buildings in the United States. In particular, the objective was to assess the extent to which motor vehicles collide with multistory* residential buildings, potentially causing substantial damage. It was soon discovered that statistics for "building collision" accidents are not available on a national level; data therefore had to be drawn from state motor vehicle accident records. Two States, Oklahoma and Illinois, provided data on accidents which occurred within their respective jurisdictions in 1970. In general, it was learned that "building collision" accidents are largely the result of single vehicles running off the road in urban areas.

National estimates of "building collision" accidents have been generated, with information extracted from the Oklahoma and Illinois analyses as inputs. It is estimated that the annual number of "building collision" accidents which occur nationally is of the order of twenty to forty thousand. However, when this estimate is modified to account for only those accidents causing substantial damage to multistory residential buildings, the magnitude is then decreased by roughly a thousandfold. Therefore, an estimated value for the number of vehicles colliding with multistory residential

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* Multistory here means buildings with four or more floors.

buildings and causing substantial damage in 1970 is of the order of 40. The annual probability of a given building being affected by such an accident was approximately one in ten thousand. A discussion then follows on existing data collection systems which might be modified to provide better estimates of the number of "building collision" accidents.

1.0 Introduction

Since 1968 there has been growing international concern that buildings, particularly multistory residential buildings, may be subjected to loading conditions not normally considered in design, i.e., abnormal loadings. In that year there occurred the much-publicized collapse of an apartment house at Ronan Point in England. In this 22-story building of precast concrete panel construction, collapse was triggered by an accidental explosion of gas that leaked from the connection of a gas range located in an apartment on the 18th floor. As a result of the explosion, one corner of the building collapsed for the height of the apartment unit.

In November 1971, the Department of Housing and Urban Development requested the National Bureau of Standards to make a study of all aspects of abnormal loading and the problem of progressive collapse. The recognized sources of abnormal loading are discussed elsewhere.* Several of these types of loading were considered to have a frequency of occurrence large enough to warrant particular attention. The collision of motor vehicles with a building is one of these. In an attempt to assess the probability of vehicular collisions with building that might be structurally

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*Somes, N. F., Abnormal Loadings on Buildings and Progressive Collapse, Building Practices for Disaster Mitigation, Building Science Series 46, January, 1973.

significant, this study of related U. S. statistics was initiated. The interpretation of these statistics with regard to design against progressive collapse is beyond the scope of this report.

There are essentially two classes of accidents, namely (a) those involving a vehicle within its normal operating domain (i.e., an automobile in a parking garage) and (b) those accidents that occur as a result of a vehicle leaving its normal operating path or domain (i.e., an automobile leaving a roadway and colliding with a building). This report discusses only the latter type of accident.

In order to ascertain damage done to buildings as a result of vehicular impact, detailed accident records must be examined. Probably the best source of such information would be records maintained by insurance companies. An attempt was made to obtain such records, but this did not meet with any success.

It was then decided that motor vehicle accident records would be the next best available source for the information desired. Ideally, nationwide data should be used since one of the objectives is to obtain a national estimate of the frequency with which motor vehicles collide with buildings. However, neither the National Safety Council nor the National Transportation Safety Board maintain statistics regarding those accidents where motor vehicles have collided with buildings ("building collisions").

Apparently, the reason no national statistics exist is that not all states maintain records of "building collision" accidents. However, two states which do keep records of sufficient accuracy and detail to meet the purposes of this study are Oklahoma and Illinois. Both states graciously consented to provide any available information regarding 1970 motor vehicle accidents involving "building collisions." This information was used as the starting point for the analysis. The details of the Oklahoma and Illinois analyses appear in Appendices A and B, respectively. In Chapter 2, some crude estimates of national building collision accidents are made using information gained from the Oklahoma and Illinois studies.

2.0 National Forecasts of Building Collision Accidents

2.1 Introduction

In this chapter, two methods are described and used to obtain rough estimates of the incidence of vehicular collisions with buildings on a national scale. The first of these is a simple proportionality model which assumes that "building collision" accidents are proportional to either motor vehicle registrations or population. This method estimates only the gross number of "building collisions" and makes no attempt to account for either the type of building struck or the degree of damage caused. The second method uses linear regression to project "building collisions" based on historical accident data. This method is then modified to account for only those accidents which cause substantial damage to multistory residential buildings. Although both methods are first efforts based on scant data, they provide a perspective on the magnitude of "building collision" accidents on a national level.

2.2 Proportionality Method.

The underlying assumption on which this method is based is simply that the number of "building collision" accidents which occur in a given area is directly proportional to the motor vehicle registrations (population) in that area. It then becomes possible to estimate the total number of "building collisions" which take place throughout the United States (US) by means of extrapolation, as shown below:

$$\frac{BC\ (US)}{MV\ (US)} = \frac{BC\ (sample)}{MV\ (sample)} \qquad (1)$$

where BC denotes building collisions and MV denotes motor vehicle registrations.

Assuming that BC (sample), MV (sample), and MV (US) are available, the calculation of BC (US) then becomes obvious.

Using the same proportionality technique, similar estimates can be made separately for urban and rural building collisions:

$$\frac{BC^U\ (US)}{MV^U\ (US)} = \frac{BC^U\ (sample)}{MV^U\ (sample)} \qquad (2)$$

where the superscript denotes urban.

The rural estimate is obtained as follows:

$$\frac{BC^R\ (US)}{MV^R\ (US)} = \frac{BC^R\ (sample)}{MV^R\ (sample)}$$

where the superscript denotes rural.

The sample available for this study consists of the traffic accident records of Oklahoma and Illinois. Details of the accident records are provided in Appendix A and B respectively with the most relevant statistics summarized below.

Total "Building Collision" Accidents in 1970

Oklahoma -	50
Illinois -	1229
Total -	1279

*Urban "Building Collision" Accidents in 1970

Oklahoma - 34

Illinois - 1137

*Rural "Building Collision" Accidents in 1970

Oklahoma - 16

Illinois - 92

Using the Oklahoma data on total motor vehicle registrations** we obtain estimates for the Building Collisions (US) to be 3200. Using Illinois data we obtain the estimate 25,000. Since the collision data for Illinois does not include all of the Chicago data, this last estimate should be revised upward. Note that these estimates are about an order of magnitude apart, so we are in an unfortunate position. If one could assume that the Oklahoma estimate was a representative low one and the Illinois estimate a representative high one, then a pooling of the data (giving equal weight to each) would yield an estimate of about 20,000.

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*The numbers for rural and urban "building collision" accidents in Oklahoma and Illinois do not correspond to the numbers given in the summaries of Appendices A and B because of a difference in the definition of urban. In Appendices A and B municipalities of over 5,000 population were considered urban. However, the Bureau of the Census uses a breakpoint of 2,500 to distinguish between urban and rural. Hence the urban and rural population figures needed in this proportionality analysis are based on this breakpoint. Therefore, the sample "building collision" accident figures were adjusted to correspond to a population breakpoint of 2,500.

**See Table D.1, page 64.

If one were to employ population in place of motor vehicle registrations, one would obtain from the pooled data for Oklahoma and Illinois that BC(US) $\approx$ 19,000, BC^U(US) $\approx$ 16,000 while BC^R(US) $\approx$ 3,000. Both the urban and total US values are smaller than they should be because of the unrecorded Chicago collisions.

The population statistics needed for the analysis are given below.*

Total Population 1970

U.S. - 203.2×10^6
Oklahoma - 2.6×10^6
Illinois - 11.1×10^6

Urban Population 1970 (municipalities $\geq$ 2,500)

U.S. - 149.3×10^6
Oklahoma - 1.8×10^6
Illinois - 9.2×10^6

Rural Population 1970

U.S. - 53.9×10^6
Oklahoma - 0.8×10^6
Illinois - 1.9×10^6

Certainly the BC(US) is greater than 1279, the total of those in Oklahoma and Illinois. If we consider the states with high motor vehicle registrations, like New York, New Jersey, Pennsylvania, Ohio, California, et cetera, a reasonable bound for building collisions in the United States might be on the order of 10,000.

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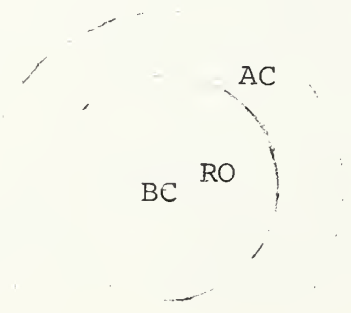
* Taken from Statistical Abstracts of the United States 1971, Table 17.

These admittedly crude estimates are useful in providing insight as to the order of magnitude for the number of buildings struck by vehicles per year. Thus the above estimates suggest that the annual number of vehicular collisions with buildings is on the order of tens of thousands and possibly near 20,000. However, there are other means of obtaining estimates which may prove more reliable.

2.3 Regression Model

2.3.1 Theoretical Development

Before introducing this model it may be instructive to review the necessary antecedent conditions for "building collision" accidents. An obvious major prerequisite is that the vehicle first runs off the road. Therefore, the set of all "building collision" accidents is a subset of the set of all runoff accidents. Similarly, the set of all runoff accidents is a subset of the set of all motor vehicle accidents. This relationship is depicted schematically in figure 2.1.



AC = All Motor Vehicle Accidents
RO = Runoffs
BC = Building Collisions

Figure 2.1

SET THEORY REPRESENTATION OF BUILDING COLLISION ACCIDENTS

Mathematically, this relationship can be represented in terms of frequency ratios as follows:

$$\frac{N(BC)}{N(AC)} = \frac{N(BC)}{N(RO)} \times \frac{N(RO)}{N(AC)} \qquad (4)$$

where N() denotes the number of the expression in ().

If one denotes these numbers simply as BC, AC, ...

then we can write

$$BC = (AC)\ (RO/AC)\ (BC/RO) \qquad (5)$$

that is, the total number of "building collisions" is equal to the total number of vehicle accidents multiplied by the proportion of accidents which are run-off times the proportion of "building collisions" to run-offs.

From the Oklahoma and Illinois studies (Appendices A and B respectively), it was learned that rural "building collision" accidents and urban "building collision" accidents are really two different phenomena. In rural areas, the probability of runoff is relatively high while the probability of colliding with a building, given a runoff, is low. Conversely, in urban areas the probability of vehicular runoff is low, but the probability of vehicular collision with a building given a runoff, is relatively high. This suggests that an estimation model for the number of "building collisions" should have both urban and rural components. Therefore:

Table 2.1. National Motor Vehicle Accident Data

	All Accidents URBAN (10^6)	All Accidents RURAL (10^6)	$\left(\frac{RO}{AC}\right)\%$ URBAN	$\left(\frac{RO}{AC}\right)\%$ RURAL
1967	9.8	3.9	4.9	27.3
1968	10.4	4.2	5.7	27.3
1969	11.1	4.4	4.8	30.2
1970	11.5	4.5	4.9	29.4
1971	11.8	4.6	4.9	29.4

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*Taken from Accident Facts, published by the National Safety Council, Chicago, Illinois, 1968-1972.

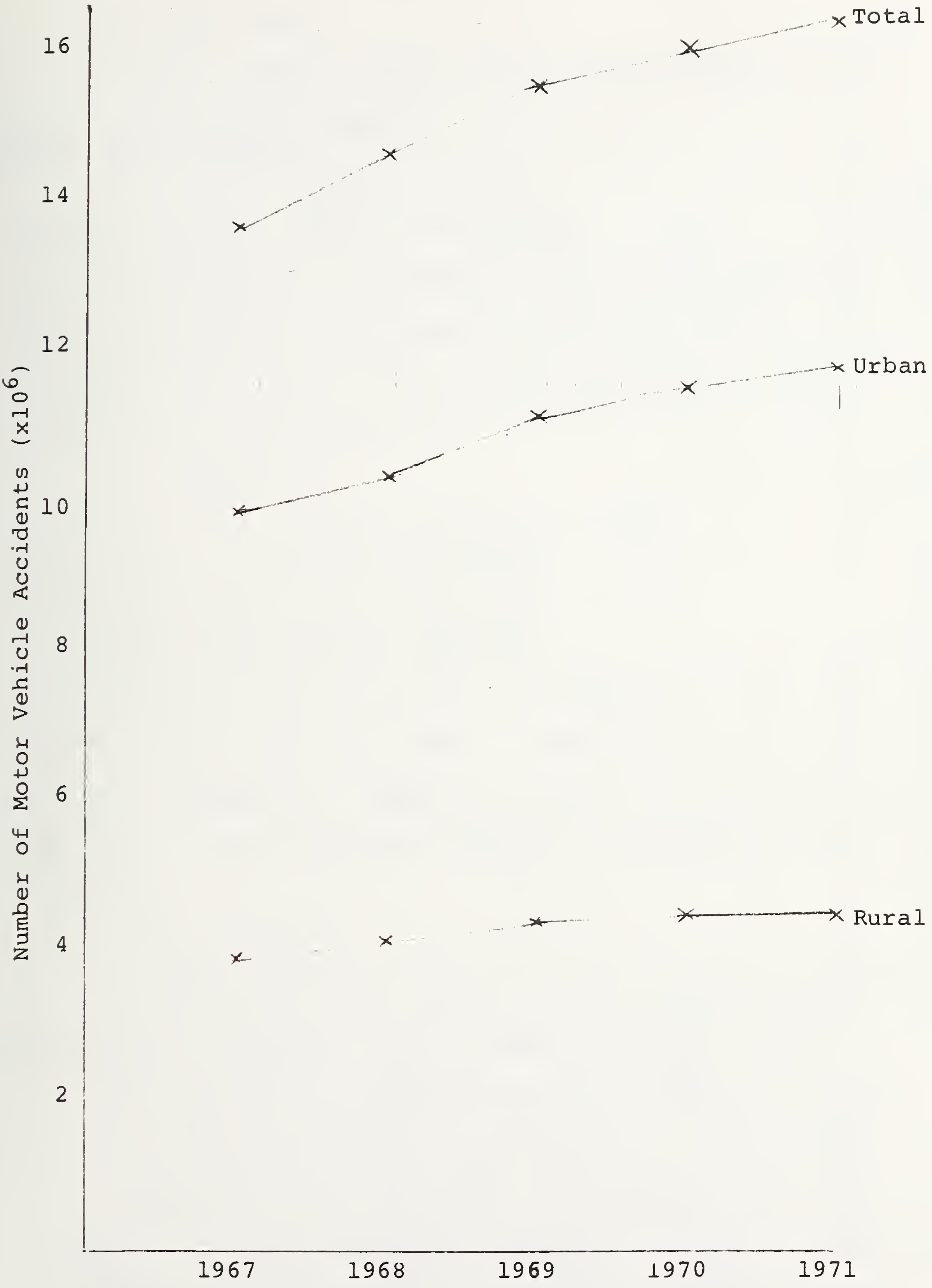

Figure 2.2 Highway Accidents in U. S. 1967-1971.

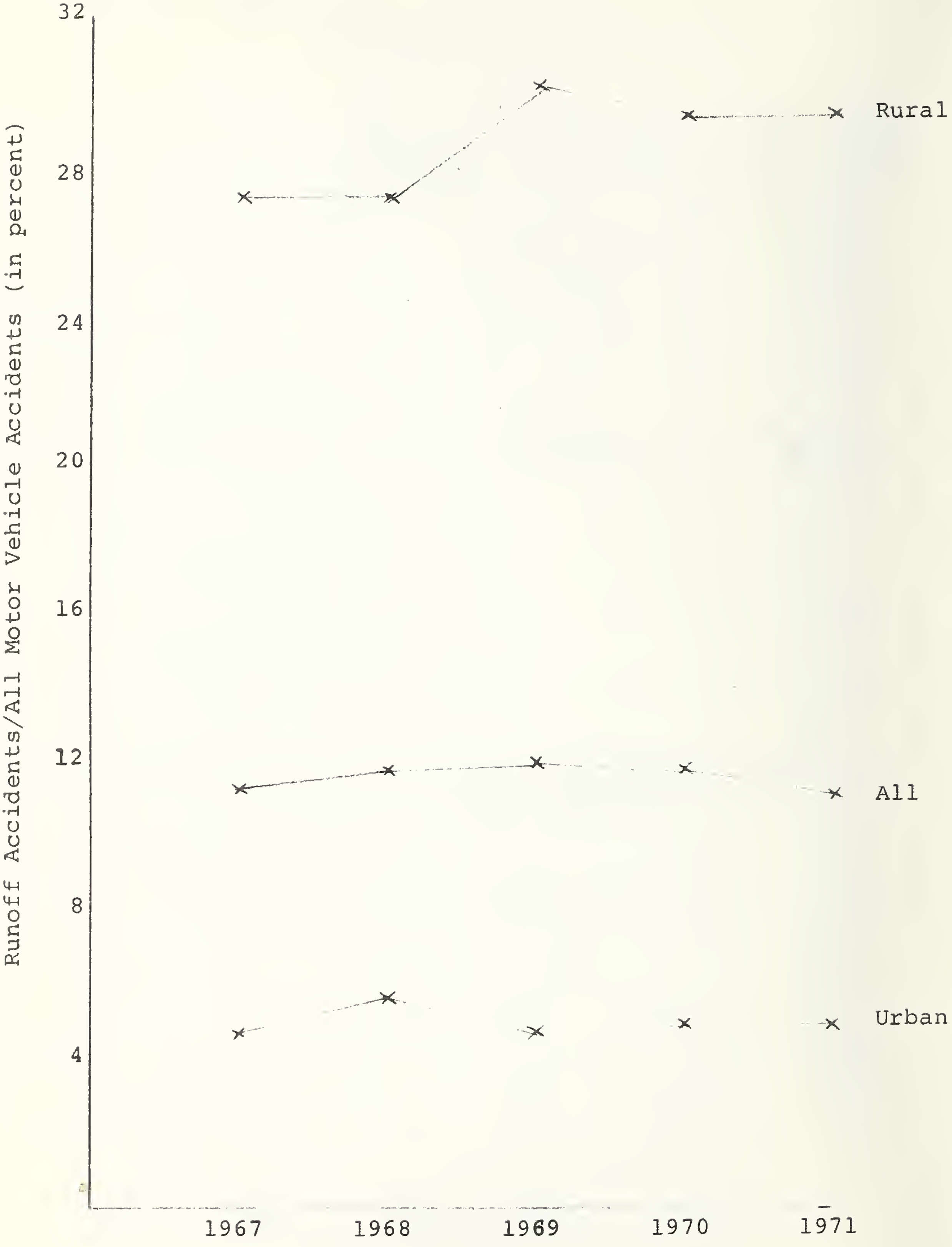

Figure 2.3 Runoff Accidents in U. S. 1967-1971.

$$BC = BC^U + BC^R \tag{6}$$

where the superscripts U and R refer to urban and rural respectively

$$BC^U = (AC)^U \; (RO/AC)^U \; (BC/RO)^U \tag{7}$$

and $$BC^R = (AC)^R \; (RO/AC)^R \; (BC/RO)^R \tag{8}$$

If this model is intended for use in the prediction of future occurrences of "building collision" accidents, it is necessary to include a time factor in the model. This requirement is indicated by:

$$BC_t = BC_t^U + BC_t^R \tag{9}$$

where the subscript t denotes the year

and $$BC_t^U = (AC)_t^U \; (RO/AC)_t^U \; (BC/RO)_t^U \tag{10}$$

$$BC_t^R = (AC)_t^R \; (RO/AC)_t^R \; (BC/RO)_t^R \tag{11}$$

Equations 9-11 constitute the prediction model. The terms on the right hand sides of equations (10) and (11) must now be estimated for future years. The following section deals with the methodology employed in generating such estimates.

2.3.2 Model Input

The National Safety Council maintains annual national statistics regarding both the number of motor vehicle accidents and the percentage of those accidents which were runoffs. This information is available for 1967 through 1971, and is shown in table 2.1. Figures 2.2 and 2.3 provide general representations of the data in table 2.1. In general, it appears that the number of motor vehicle accidents has increased over time (figure 2.2), while the percentage of accidents which are runoffs has remained relatively constant (figure 2.3). Simple linear regression was applied to the 4 columns in table 2.1, using time as the independent variable to test the hypotheses stated above. The values of time (t) used in the analysis were the last two digits of the year in question (67, 68, ...71). Also, the number of accidents is predicted in millions, while the proportion of runoffs is predicted in percent. The results of the analysis appear in table 2.2.

Table 2.2. REGRESSION RESULTS

		Intercept	Slope	R^2*	P(t)**
(1)	All Urban	-24.27	.51	.975	>.995
(2)	All Rural	- 7.41	.17	.938	>.995
(3)	%RO Urban	10.56	-.08	.116	<.95
(4)	%RO Rural	-14.75	.63	.555	<.95

---

*R^2, the square of the correlation coefficients, is a simple measure of the degree of goodness of fit between the input data and the calculated regression line. An R^2 equal to 1 indicates perfect fit and any R^2 greater than 0.9 is considered to be a good fit. The use of R^2 does not imply in any way that time itself is a determinant of accident behavior, however.

**P(t) refers to the percentage point of a Student's-t distribution with 3 degrees of freedom corresponding to the ratio of the slope of calculated regression line to its estimated standard deviation.

The high levels of R^2, for rows 1 and 2 of table 2.2 indicate that the regression lines are good estimators of both $(AC)_t^R$ and $(AC)_t^U$, at least over a short period of time. Student's-t tests were applied to the estimates of the slopes of the lines in rows 1 and 2 in order to test the hypotheses that the slopes could be zero. The results of the t-tests indicate that the hypotheses that the slopes are zero must be rejected at the 99.5% confidence level. Therefore, the best estimates for $(AC)_t^U$ and $(AC)_t^R$ are the following:

$$(AC)_t^U = (-24.27 + .51t)\ 10^6 \qquad t = 70,\ 71\ \ldots. \qquad (12)$$

$$(AC)_t^R = (-7.41 + .17t)\ 10^6 \qquad t = 70,\ 71\ \ldots. \qquad (13)$$

Unfortunately, the regression results for $(RO/AC)_t^U$ and $(RO/AC)_t^R$ were not as significant. The relatively low levels of R^2 in rows 3 and 4 of table 2.2 indicate a poor correlation. In addition, applying t-tests to the estimates of the slopes in rows 3 and 4 reveals that the hypotheses that the slopes are zero cannot be rejected at the 95% level. Therefore, it is not unreasonable to assume that $(RO/AC)_t^U$ and $(RO/AC)_t^R$ remain constant over time. For modeling purposes, then, $(RO/AC)_t^U$ and $(RO/AC)_t^R$ will be set equal to the means of $(RO/AC)_t^U$ and $(RO/AC)_t^R$ from 1967 through 1971:

$$(RO/AC)_t^U = .05 \text{ for all } t \qquad (14)$$

$$(RO/AC)_t^R = .29 \text{ for all } t \qquad (15)$$

Unfortunately, the National Safety Council does not maintain statistics regarding building collision accidents. Estimates for $(BC/RO)_t^U$ and $(BC/RO)_t^R$ have therefore been obtained from the information gathered from Oklahoma and Illinois. Since only 1970 data was gathered, the estimates of $(BC/RO)_t^U$ and $(BC/RO)_t^R$ were, of necessity, point estimates.

At this point we can digress and check the estimates for the year 1970. Here the national AC and (RO/AC) figures are known while the (BC/RO) values are known only for Oklahoma and Illinois. Using these data one generates the estimates for 1970 in Table 2.3.

Table 2.3 ESTIMATES FOR BC(US) FOR 1970 AND VALUES OF (BC/RO) FOR 1970.

BC Based on:				BC/RO Based on:			
	Okla. Data	Ill. Data	Pooled Data		Okla. Data	Ill. Data	Pooled Data
Urban	11800	27600	26500	Urban	.021	.049	.047
Rural	7300	14500	13200	Rural	.0055	.011	.010
U. S.	19100	42136			-	-	-

It is interesting to note that using Illinois or pooled data from Oklahoma and Illinois, one again has an estimate of about 40,000 building collision accidents for the U. S., and that the Oklahoma data alone would yield an estimate of 19,100. The agreement with the estimates based on proportionality assumptions may well be fortuitous, but it is certainly not discouraging to have this agreement.

At this point we return to the estimation of BC_t^U and BC_t^R over time. Using the least squares linear regression for AC_t^U and AC_t^R, and assuming that the ratios of $(RO/AC)_t^U$ = .05 and $(RO/AC)_t^R$ = .29 for all times and that the ratios $(BC/RO)_t^U$ = .047 and $(BC/RO)_t^R$ = .010 are constant with time and equal to the pooled values for Oklahoma and Illinois for 1970, the estimation equations reduce to:

$$BC_t^U = -57035 + 1199t \qquad \text{(Urban Component)} \qquad (16)$$

$$BC_t^R = -21490 + 493t \qquad \text{(Rural Component)} \qquad (17)$$

Because of the data limitations we rounded off these equations to

$$(BC)_t^U = -57000 + 1200t \qquad (18)$$

$$(BC)_t^R = -21500 + 500t \qquad (19)$$

Combining equations 18 and 19 yields a total estimate for the number of building collision accidents in a given year:

$$BC_t = BC_t^U + BC_t^R \qquad (20)$$

$$BC_t = -78500 + 1700t \qquad t = 70,\ 71 \ldots. \quad (21)$$

Equations 9, and 18 through 21 constitute the prediction model. In the next section the output from this model will be presented and interpreted.

2.3.3 Model Output

Table 2.4 presents the output generated by the model.

Table 2.4 ESTIMATED BUILDING COLLISION ACCIDENTS

Year	Urban Building Collisions	Rural Building Collisions	Total
1967	23400	12000	35400
1968	24600	12500	37100
1969	25800	13000	38800
1970	27000	13500	40500
1971	28200	14000	42200
1972	29400	14500	43900
1973	30600	15000	45600
1974	31800	15500	47300
1975	33000	16000	49000

No attempt has been made to extrapolate past 1975. Because of the linear nature of the estimation method, the number of building collision accidents may be expected to continue to increase at a constant rate. However, long-term extrapolation is hardly warranted considering the limitations inherent in the development of the method. The constant growth projection is essentially due to the fact that the total number of motor vehicle accidents increased at an approximately constant annual rate from 1967 to 1971.

The magnitude of the estimates generated by the model requires further examination. Mathematically, the method is structured so that the number of building collision accidents is directly proportional to BC/RO. This implies that if, for example, the estimate of $(BC/RO)_t^U$ were halved, then the resultant predictions for BC_t^U would be halved for all times. The estimate for $(BC/RO)_t^U$ was calculated by combining both Oklahoma and Illinois data. However, if only the Oklahoma data had been used, the estimate would have been 32/1489 = .0215. The estimate of $(BC/RO)_t^U$ used for modeling purposes may well be biased on the high side.

2.3.4 Model Extensions

One conclusion which can be drawn from these estimates is that, regardless of the exact proportion of runoffs which result in building collisions, the number of vehicles which annually collide with buildings is on the order of tens of thousands. However, the number of accidents provides no information about either the type of building hit or the kind and amount of damage caused. One goal of this study is to assess the extent to which vehicular impact might be responsible for substantial damage to multistory residential buildings, and perhaps leading to progressive collapse. Two questions therefore, remain at issue:

(1) What proportion of "building collisions" cause substantial damage?

(2) What proportion of the substantially damaged buildings in (1) are multistory residential buildings?

With regard to the first question, $1,000 in building property damage was chosen as a convenient breakpoint which certainly eliminates non-substantial damage, although larger damage amounts may not be necessarily significant. Examining the Illinois and Oklahoma data, it was found that of the 1279 reported "building collision" accidents, 119 or 9.3% had building property damage estimates of at least $1,000. For purposes of crude estimation, it is assumed that approximately 10% of the "building collision" accidents result in substantial damage to the building.

With regard to the number of buildings which are multistory residential, rough estimates were derived from the 1970 Census of Housing. Details of the approximation appear in Appendix C. A summary follows.

In summary, there are approximately 50 million residential buildings in the United States, of which less than 1% (that is, 400,000) are multistory in the sense of having four or more floors above ground. It must be emphasized that the figures cited above are based entirely on housing data, with no account taken of commercial structures, for which no information was available, since earlier calculations have been based on building collisions, it can readily be seen that the multistory residential buildings must be significantly less than 1% of the total number of buildings.

Assuming that the combined Oklahoma and Illinois damage distribution is somewhat representative of the nation as a whole, and that the percentage of building collision accidents which affect multistory residential buildings is similar to the proportion of residential structures which are multistory, then one can derive a national estimate for the number of multistory residential buildings which are likely to be affected by vehicular collision annually. This estimate is generated by using the model output described in section 2.3.3 and adjusting it for (a) damages exceeding $1000 and (b) multistory residential buildings. Since damages exceeding $1000 account for 10 percent of all "building collisions," and multistory residential structures constitute approximately 1 percent of all residential buildings, estimates of the total number of motor vehicles which collide with multistory residential structures and which cause significant damage can be determined by dividing the data in table 2.4 by 1000. Table 2.5 presents the adjusted estimates.

These admittedly crude estimates indicate that the number of vehicles colliding with multistory residential buildings and causing substantial damage is small compared to the total number of estimated "building collisions, and that the rate of increase is also relatively low. When one considers the manner in which the damage, multistory residential, and "building collision" components of the method were calculated, the entries in tabel 2.4 are felt to be on the high side. The actual number of significant accidents for any given year probably lies somewhere

Table 2.5 ESTIMATED BUILDING COLLISION ACCIDENTS RESULTING IN DAMAGE TO MULTISTORY RESIDENTIAL STRUCTURES WHICH EXCEEDS $1000.

YEAR	ACCIDENTS
1967	35
1968	37
1969	39
1970	40
1971	42
1972	44
1973	46
1974	47
1975	49

between zero and this estimated high value, implying that the collision of a motor vehicle with a multistory residential building and causing substantial damage to it is a relatively rare phenomenon in the United States. In fact, the annual probability of a given multistory residential building being struck by a vehicle with substantial damage resulting can be crudely estimated as 40/400,000 = 0.0001 and possibly smaller. This estimate was obtained by dividing the number of significant accidents by the number of multistory residential buildings. Unfortunately, there appears to be no readily available information to validate the prediction results developed and discussed above.

2.4 Discussion

In this chapter, estimates were made of the number of vehicles which collide with multistory residential buildings and cause substantial damage. These estimates were based on accident statistics maintained by the National Safety Council, statistics regarding "building collision" accidents maintained by the states of Oklahoma and Illinois, and housing statistics maintained by the U. S. Census Bureau. However, this entire estimation procedure would not have been necessary had statistics regarding "building collision" accidents been aggregated on a national level.

Such an aggregation would naturally require that each state maintain "building collision" statistics. These statistics should include such information as already maintained by the states of Oklahoma and Illinois and detailed in Appendices A and B, respectively. This includes information as vehicle type, road type, and locality of accident. However, in addition, such information as the type of building struck, as well as a more detailed explanation of the damage caused would be extremely useful.

If statistics concerning the number of vehicles impacting multistory residential buildings are to be gathered, the need for maintaining the type of building struck is clear. Detailed damage explanations are needed as a supplement to dollar estimates because the dollar estimates by themselves do not convey very much information with regard to the type of damage done. In this chapter, substantial damage was considered to be any reported damage of at least $1000. However, there is no way of determining whether this damage is structurally significant. For example, it may be possible that in some cases, a plate glass window was shattered and the resultant damage was in excess of $1000.

If someone is considering changes to the existing data systems, we suggest that changes along the line of the above discussion be considered. The data then could be employed in more meaningful analyses.

2.5 Chapter Summary

In this chapter, attempts were made to forecast the number of building structures impacted annually by motor vehicles. A crude proportionality model was established and results obtained from Oklahoma and Illinois were extrapolated for the nation as a whole. The model indicates approximately 20,000 building collision accidents for 1970, with the greater number occurring in urban areas.

An alternative model, based on regression analysis, was then developed to predict future occurrences of building collision accidents as a function of historical accident data. This model estimates roughly 40,000 instances of building collision accidents for 1970, of which 27,000 were urban. It is felt that these estimates may be high because of the seemingly high estimated value used for the proportion of urban run-offs which resulted in building collisions (as used in the second model).

The results of the second model were adjusted to consider only those cases where vehicles collided with multistory residential buildings and caused damage in excess of $1000. It is estimated that about 40 such accidents occurred in 1970, and it is felt that this is more likely a high value than the true value. On the basis of the magnitude of the modified estimates, it is tentatively concluded that the annual probability of vehicular collision with multistory building is of the order of one in ten thousand.

Appendix A

Oklahoma Vehicular Impact Analysis

A.1 Introduction

A study of 1970 Oklahoma motor vehicle accident reports was undertaken in an attempt to determine the frequency with which motor vehicle accidents involved collision with a building, and to discover the most prevalent circumstances attendant on such a collision. Oklahoma was chosen because individual traffic accidents reports include a specific code for vehicular collision with a building and because a data tape was available.

A.2 Analysis

The data for Oklahoma show a total of 65,183 motor vehicle accidents in 1970. Of these accidents, 50 were collisions with a building. The category in the Oklahoma Investigators Collision Report Coding Guide under which collision with a building occurs, is specified as "Object Struck - First Contact." Discussion with personnel of the Oklahoma Department of Public Safety indicated that a vehicle deflecting from one object (e.g., grazing a sign post or curb) and then hitting a building is not coded as hitting a building. It would probably be coded under Type of Collision as "running off road." A total or 4791 such accidents occurred. Many of the following computations were made using "run off road" data, and are noted as such.

The data indicate that roughly 2/3 of all run-off accidents occurred in non-built-up areas, where there is less chance of a building being struck. This is shown in figure A.1, which exhibits the frequency of both run-off accidents and building collision accidents by location.

Most collisions with buildings caused minor dollar damage to the building, as is shown in figure A.2, a chart displaying the frequency of collision vs. property damage. By Oklahoma standards for coding, property damage refers to all property damage excluding damage to the vehicle. Figure A.3 shows the frequency of collision with buildings at various speeds of impact. Further evaluation of the data shown in these three figures yields the following:

(1) The fraction of the run-off accidents that were reported to hit a building was 50/4791 = .0104 ≈ .010. The average property damage when a vehicle strikes a building was $622, and the average speed at impact was 14 mph.

(2)* For non-built up areas the fraction of the run-off accidents that were reported to hit a building was 5/3219 = .00155 ≈ .002. Here average property damage was $800, and the average speed at impact was 38 mph.*

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[*] The sum of accidents in built-up areas and non-built-up areas is less than the totals shown in (1) because 128 run-offs and 3 building collisions did not specify location. (See Figure A.1)

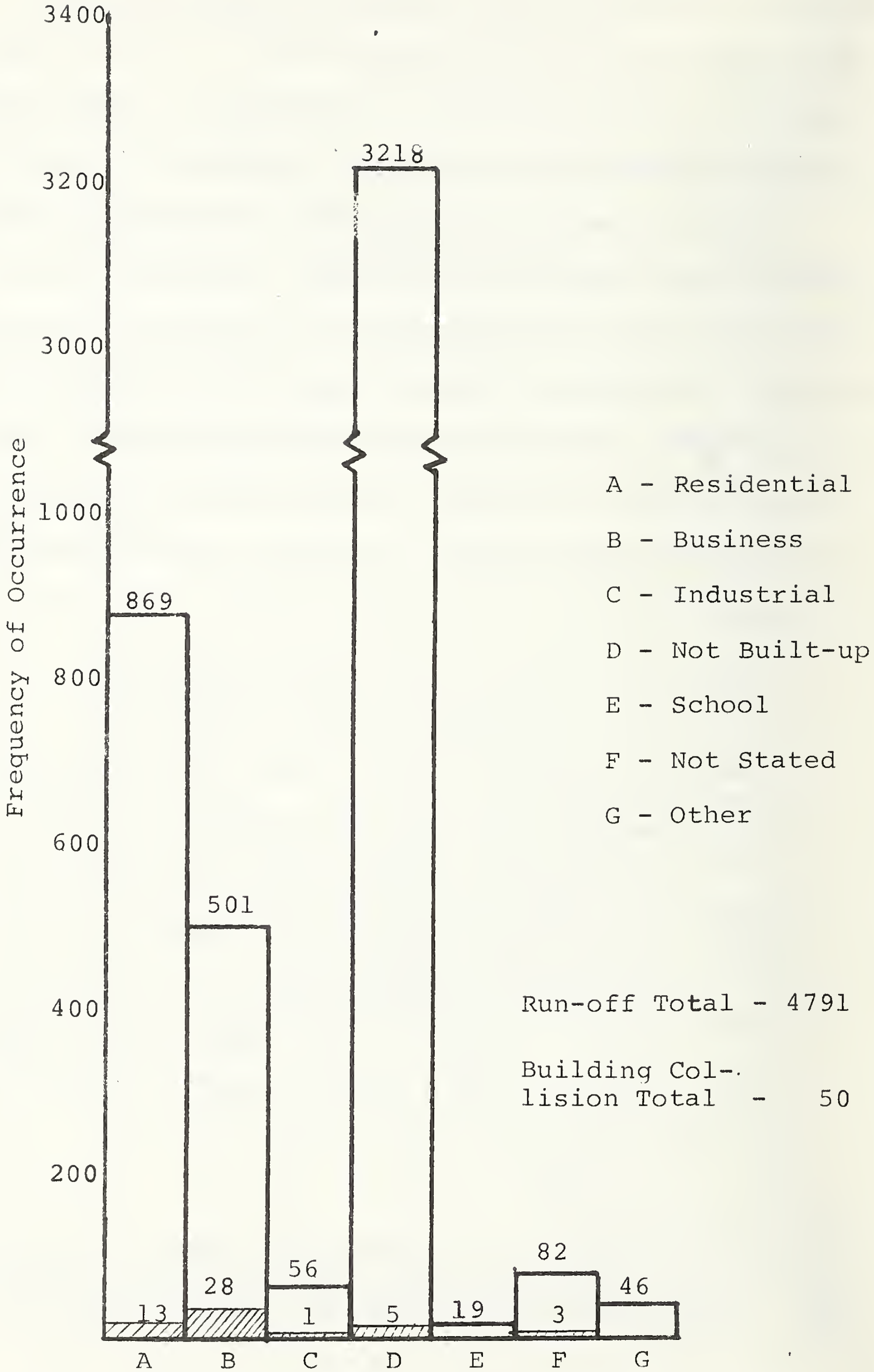


Figure A.1 Run-off Accidents and Building Collision by Location

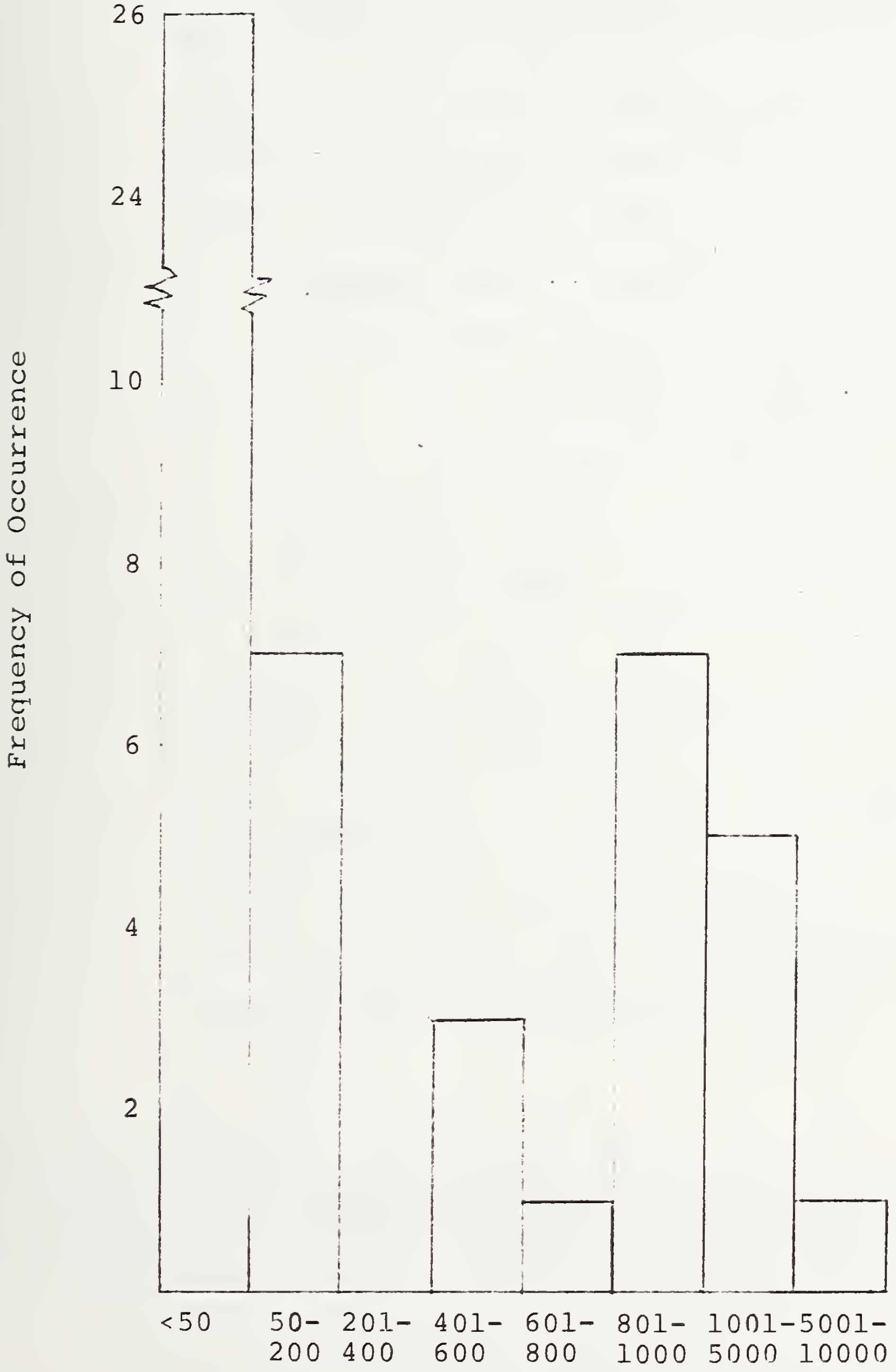
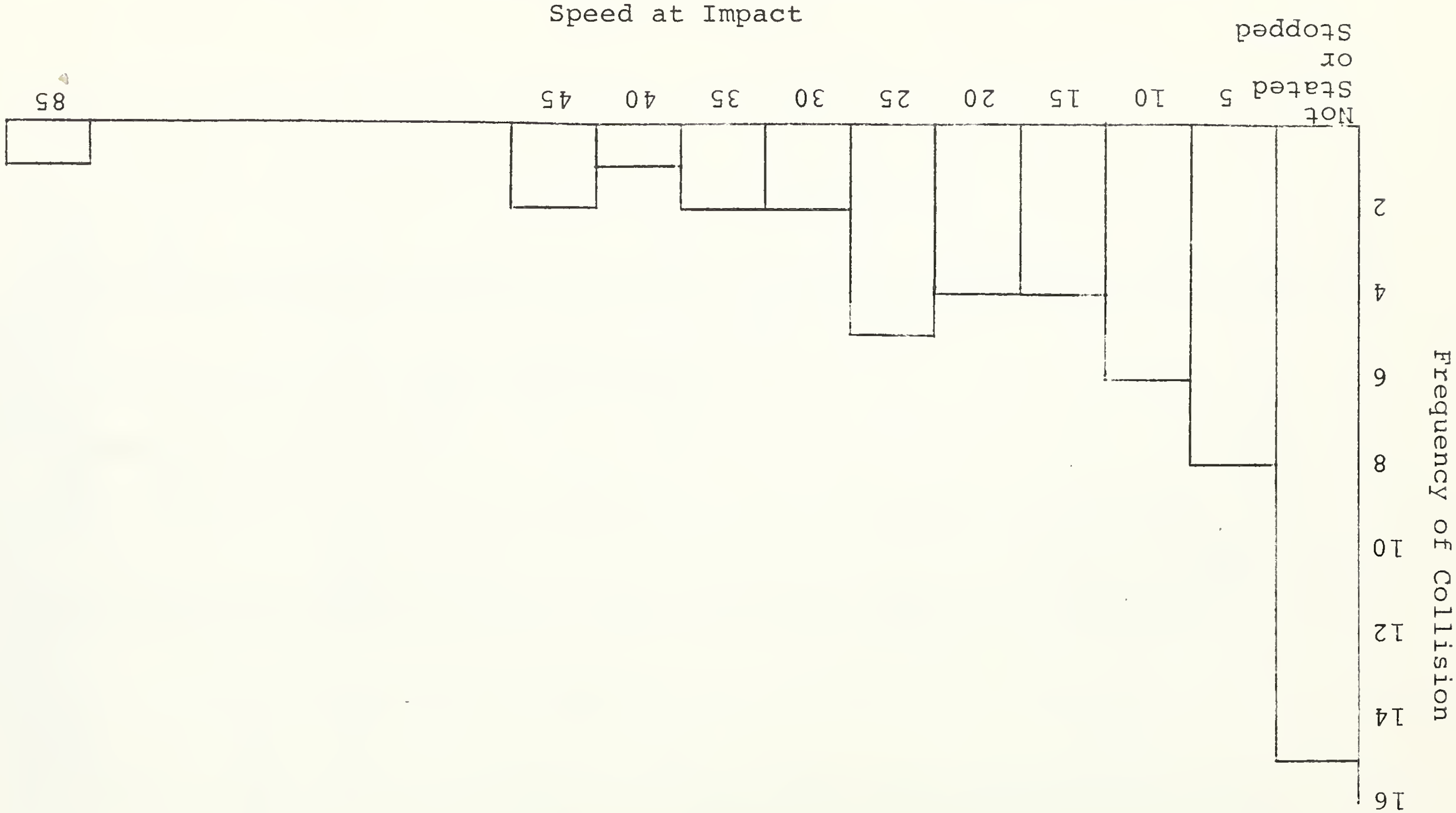


Figure A.2 Frequency of Collision Versus Dollar Damage to Building

Figure A.3 Frequency of Collision Versus Speed at Impact



(3)* For built-up areas (defined in the Oklahoma Coding Guide to be business, industrial, residential or school areas) the fraction of the run-off accidents that were reported to hit a building was 42/1445 = .029. Average property damage in such areas was $585, and the average speed at impact was 11.5 mph.

(4) For a business area the fraction of the run-off accidents that were reported to hit a building was 28/501 = .056, with average property damage of $698 and average speed at impact of 10.1 mph.

(5) For a residential section, the fraction of the run-off accidents that were reported to hit a building was 13/869 = .015. In this instance, average property damage was $194, and the average speed at impact was 12.7 mph.

(6) For an industrial section, the fraction of the run-off accidents that were reported to hit a building was 1/56 = .018. Average property damage was $2500 and the average speed at impact was 35 mph.

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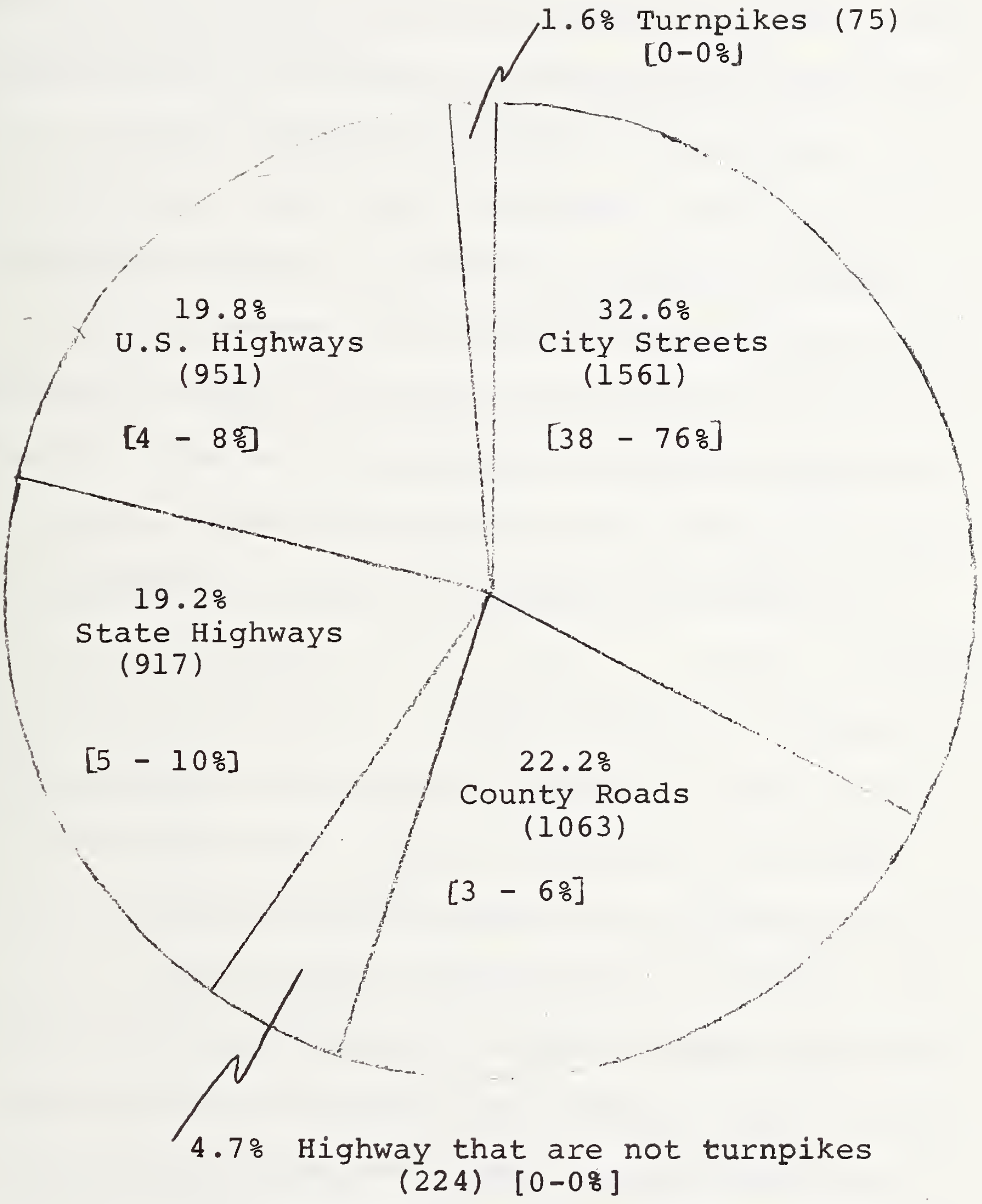
[*] The sum of accidents in built-up areas and non-built-up areas is less than the totals shown in (1) because 128 run-offs and 3 building collisions did not specify location. (See Figure A.1).

It should be noted that each of the categories described above contains a very small number of accidents in which buildings were struck. The cited statistics must therefore be used with great care, especially since coding errors are considered to be not at all unlikely. In addition, speed and extent of damage were frequently left unreported, contributing further to possible unreliability of the average values shown. No meaningful correlation was found between speed, dollar damage, and location of accident, but a far larger data sample would be required to verify the validity of this apparent lack of relationship.

Run-off and hit-building accidents were then separated by highway classification, as is shown in figure A.4. It should be noted that city streets were the scene of run-off accidents more frequently than any other type of road, while limited access highways (interstates and turnpikes) had significantly fewer reported. In addition, although only 32.6% of run-off accidents occurred on city streets, 76% of the total hit-building accidents took place on this type of road (where, of course, more buildings are to be found). Thus the probability that a building will be hit, given that a run-off accident has occurred on a city street, is estimated as 38/1561 = .024. The average property damage reported in such cases was $531, and the average speed at impact was 14 mph. Not surprisingly, there were no accidents on interstate highways or turnpikes that involved hitting a building.



(4791)* (OKLAHOMA, 1970) [50-100%]**

*The number in parentheses is the total number of run-off accidents for that class.

**The numbers in brackets are the number of buildings hit for a highway class and the % of the total buildings hit.

Figure A.4 Highway Classification for Run-Off Accidents

Truck accidents were examined separately from automobile accidents. An accident involving a heavy truck, such as a semi-trailer, might do more structural damage to a building than would a car (given otherwise identical circumstances) due to the increased size and weight of the vehicle. A total of 423 accidents involving trucks were reported, including eight specifically listed as hitting buildings, The number of accidents involving the various types of trucks is shown in figure A.5. The high number of pick-up truck and single unit truck accidents is probably due to the large number of such vehicles compared to other truck types. The accidents considered in this histogram are coded as follows:

Code 1 - run-off road

Code 10 - collision on road with fixed object

Code 11 - collision on road with other object (excluding such objects as guard rails, other cars, utility poles, etc., which are specified in other codes).

These three types include all accidents where a building was struck. Truck accidents occurring in built-up areas were further broken down by speed at impact and type of truck. The results are shown in figure A.6. The percentages on the graph are an indication of the proportion of accidents occurring at higher speeds. The frequency of accidents where the truck was traveling at greater than or equal to 30 mph, or greater than or equal to 40 mph, should be noted, because a higher speed at impact combined with the heavier weight of a truck could cause considerable structural damage. In 1/3 of the accidents within a given category the speed at contact was not reported, hence those cases were omitted from the percentage calculations.

In addition to the 50 vehicular accidents which were listed as having hit buildings, an additional 17 run-off accidents were considered as possible "building collisions." These all had listed a first-struck object of little value, but had reported total property damage greater than $800. In all of these cases (65%), the object struck was specified as "other". Further inquiry of the Oklahoma Department of Public Safety (which supplied the data) yielded no clue as to what this might indicate. A total of 94% of these possible "hit-building" accidents were on undivided highways and 61% were on roads with legal speed limits greater than or equal to 40 mph. The vehicle was traveling at speeds greater than or equal to 40 mph in all specified cases, and greater than or equal to 30 mph <u>at contact</u> in 83% of the specified cases.

Twenty-six individual accident reports were requested from the Oklahoma Department of Public Safety. The individual reports have a short summary and description of the collision, as well as a diagram of the scene of the accident. These reports provided information which had not been coded and hence was not on the computer tape. The

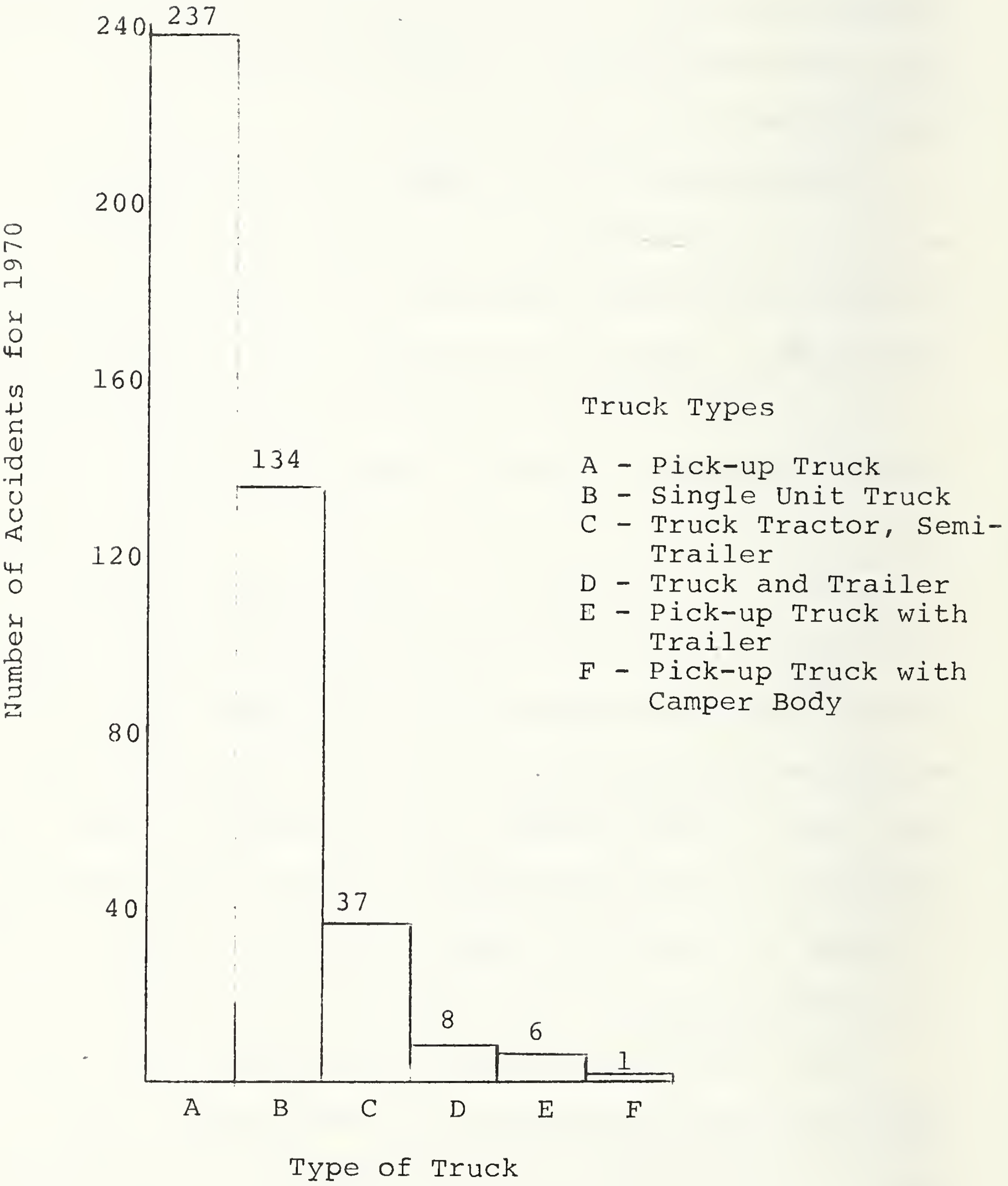


Figure A.5 Truck Accidents (Code 1, 10, 11)
VS.
Type of Truck

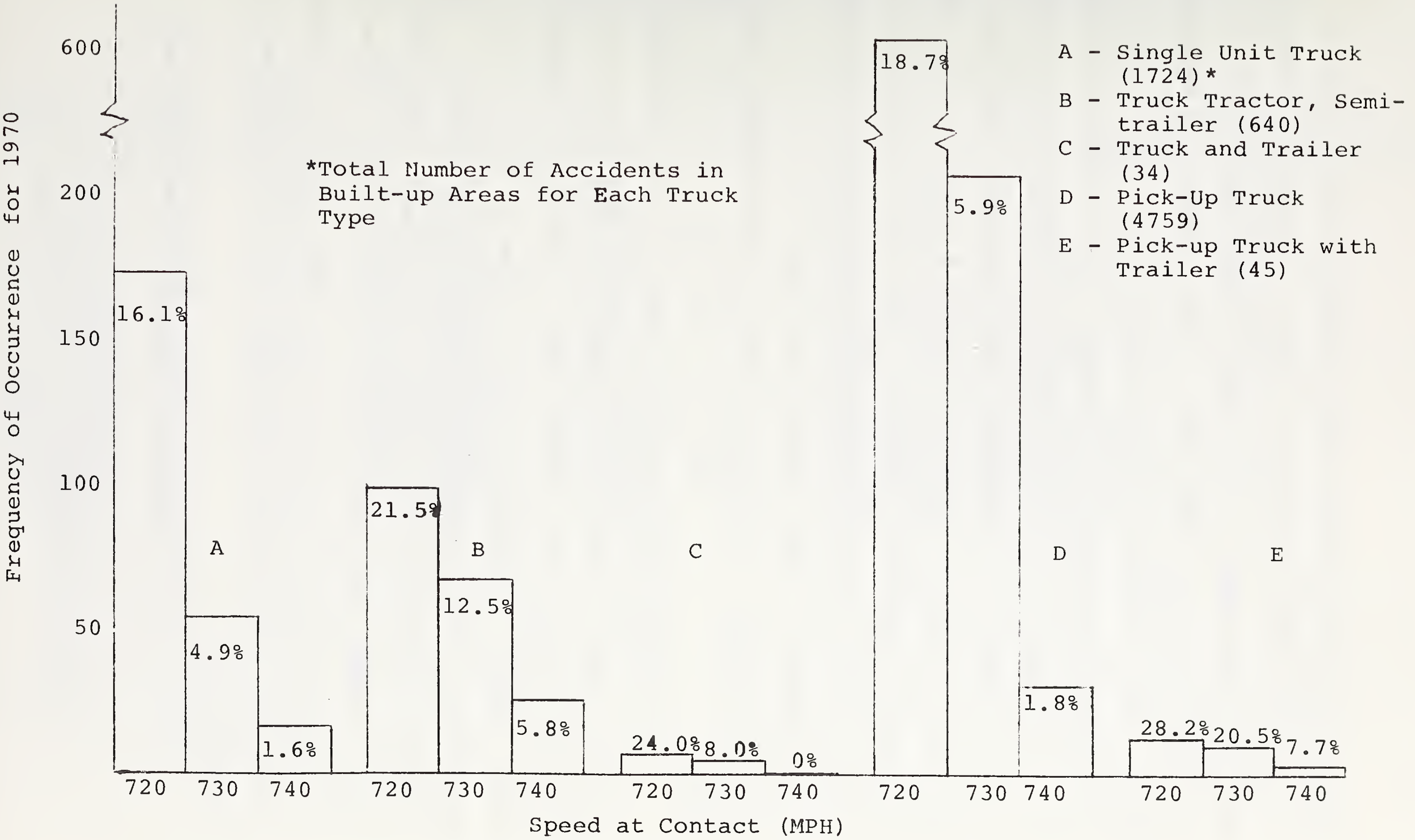


Figure A.6 Frequency of Truck Accidents in Built-up Areas Vs. Speed reports could be divided into 2 categories, the first of which (identified hereafter as Group A) includes 14 accidents which had been coded as collisions with buildings and which had involved damage (other than to the vehicle) in excess of $800. Also in Group A is one accident which involved four vehicles and a building, but damage to the building of only $50. A summary of the information obtained from Group A is shown in Table 1. A second set of 12 accidents (known as Group B) was chosen from those accidents referred to in the immediately preceding paragraph. These were accidents not coded as having involved collisions with buildings but which were suspected to have involved buildings due to high property damages. A summary of these reports appears in table 2.

The diagram and descriptive summary of the individual accident reports permitted the derivation and analysis of data pertaining to the distance that the vehicle traveled before impact, the distance from the edge of the road to the object, and the physical location of the accident. The reported information was in many cases based on estimates only; in other cases no data was provided at all. Based on information gathered from the 14 accident reports in Group A (coded as having struck buildings), the following results are obtained.

(1) 13 of the accidents occurred on two lane roads, one on a four lane road; none of these was on a divided highway.

Table A.1. GROUP A SUMMARY

Accident Number	Legal Speed	Speed Before Contact	Hit Object Considered	Damage	Object Distance From Road	Object Location Relative to Vehicle Before Accident	Distance Traveled by Vehicle
30151	65	60*	1st Bldg.	$1,000		Same side of road	150'
225613	35	30	1st Bldg.	900		Same side of road	109'
600109	45	70	1st Bldg.	8,000	68'	Same side of road	316'
610037	65	45*	1st Bldg.	1,500	68'	Opposite side of road	80'
723882	25		3rd Bldg.	50		Same side of road	50'
773365	25		1st Bldg.	900	30'	Straight ahead	
835424	40	25	1st Bldg.	3,000	38'	Opposite side of road	
1130729	55	55*	1st Bldg.	1,800		Same side of road	105'
1344698	22		1st Bldg.	1,000		Same side of road	158'
1912879	25	15	1st Bldg.	900	48'	Opposite side of road	
2724872			1st Bldg.	2,500	8'	Opposite side of road	
3031245	25	5	1st Bldg.	1,500	11'	Same side of road	93'
3035433	35	15	1st Bldg.	1,000	45'	Opposite side of road	
3092677	20	5	1st Bldg.	900		Same side of road	

*unsafe speed

Table A. 2. GROUP B SUMMARY

Accident Number	Legal Speed	Speed Before Contact	Hit Object Considered	Damage	Object Distance From Road	Object Location Relative to Vehicle	Distance Traveled by Vehicle
175521	40	60*	1st-gas pumps	$1,000		Straight ahead	
362544	40	40	1st-gas meter	1,200	18'	Opposite side of road	141'
210865	25	55*	1st-rr sign	3,000	4'	Same side of road	108'
1423798	40		1st-gas pumps	1,000		Same side of road	
1501102	55	55*	1st-gas pumps	5,500	42'	Straight ahead	
1530185	45	60*	1st-gas main	2,000	13'	Same side of road	175'
1572367	40	40*	1st-gas pumps	2,000	32'	Same side of road	56'
2293015		*	2nd-house	1,000		Opposite side of road	
2365582	25		2nd-house	2,000	38'	Opposite side of road	196'
3052831	30	70*	2nd-lumber rack	1,200	54'	Straight ahead	70'
3213946	30		2nd-house	1,500	46'	Straight ahead	210'
3444047	25	60*	2nd-rock wall	2,000	60'	Straight ahead	351'

* unsafe speed

(2) 10 were on city streets, two on state roads, one on a county road, one on a U. S. highway.

(3) Nine occurred in business districts, two in not-built-up areas, one in industrial, one in residential, one not stated.

(4) Four took place in areas with less than 500 population, four in areas with greater than or equal to 100,000 population.

(5) 12 involved cars, one involved a tractor trailer, one a single unit truck.

(6) Five occurred on roads with legal speeds greater than or equal to 40 mph.

(7) Three involved unsafe speeds (marked with "*" on Figure 7) and four more did not specify "speed before contact."

(8) Seven accidents involved a building on the same side of the road as the vehicle, four on the opposite side, one straight ahead (across an intersection), one not stated.

(9) The average distance traveled by the vehicle before impact in eight specified cases was 132.6 ft.

(10) The average distance of the building from the road was 39.5 ft. in eight specified cases.

(11) There seems to be no correlation between distance the vehicle traveled before impact, or distance from the road to the building, and property damage.

(12) Only one collision involved swerving to avoid another vehicle. Most were due to mechanical failure of the vehicle, or unsafe or negligent driving.

(13) One accident took place at a curve, seven occurred at or approaching intersections.

Although Group A constitutes a small sample, the information above does not vary significantly from the statewide statistics. Items (7) through (13) provide information not on the computer tape.

The 12 accidents reports in Group B (coded as having hit something other than a building) yielded the following:

(1) Three of the accidents involved collisions with buildings where the building was <u>not</u> the first object struck. An additional accident involved a vehicle striking a large lumber rack.

(2) In four of the accidents, gas pumps were the first object struck; all four occurred in business districts and three accidents were on city streets.

(3) 10 of the 12 accidents occurred on city streets, one was on a U. S. highway, one on a state highway.

(4) Eight accidents occurred on two-lane roads, four on four-lane roads; none of these were divided highways.

(5) Seven accidents took place in business districts, four occurred in residential areas, and one occurred in a not-built-up area.

(6) Five accidents were in areas with population greater than or equal to 100,000, one in an area with population less than 500.

(7) 10 involved cars. Two accidents involved pick-up trucks.

(8) Six took place on roads with legal speeds greater than or equal to 40 mph.

(9) Seven involved unsafe speeds.

(10) Three had the object struck on the same side of the road as the vehicle, three on the opposite side, four straight ahead (across an intersection or at a curve).

(11) The average distance the vehicle traveled before hitting the major object (building, gas pumps, etc.) was 163.5 ft.

(12) The average distance of the object from the edge of the road in eight specified cases was 34 ft.

(13) There seems to be no correlation between distances traveled, or object distance from the road, and property damage.

(14) Only one collision involved swerving to avoid other vehicles. Most resulted from mechanical failure of the vehicle, or unsafe or negligent driving.

(15) Three took place at a curve, six occurred at or approaching an intersection.

Again, the information in this small sample seems to follow the trend for the state as a whole. In addition to the four cases involving gas pumps, two others involved a natural gas meter and a natural gas main. This seems to account for many of the high damage value accidents with "other" coded as the first object struck. Many of the accidents in Group B involved vehicles deflecting from traffic signs and making further contacts, or running through fences into other obstacles. It is significant that three of the 12 collisions examined involved buildings, suggesting that the estimated number of buildings hit in accidents, as derived from the coded tape, is low. The only way to determine how many additional buildings were struck would be to examine all of the reports, a task which is not feasible from the point of view of the time, effort, and cost which would be necessary.

A.3 Summary

Of a total of 65,183 accidents which occurred in Oklahoma in 1970, 4,791 or 7.3% were run-off accidents. Of the total run-off accidents, 50 or 1.1% are known to have involved collisions with buildings. 67.2% of the run-off accidents occurred in rural areas, but 76% of the known collisions with buildgins occurred in cities. The highest chance of hitting a building, given that a run-off accident has occurred, is in the business district; it is approximately .056. The highest average speed of impact (38 mph) and the highest average property damage ($800) occurs in non-built-up areas. The number of buildings coded as being hit (50) is low, due in part, to the fact that an additional number of buildings were undoubtedly hit, but not reported because they were not the first object struck.

Using municipalities with a population of 5,000 as a breakpoint between urban and rural, 1,489 of the 4,791 run-offs can be classified as urban. Similarly, 32 of the 50 "building collision" accidents occurred in urban areas. The respective rural figures are 3,302 run-offs and 18 "building collisions." Of the 50 "building collision" accidents, six resulted in estimated damage in excess of $1,000. Of these six, one resulted in damage in excess of $5,000.

It should be noted that a very small number of hit-building accidents occurred in each of the various sub-divisions used above. Information on speed and damage was omitted frequently enough that the data were considered insignificant. Mistakes in coding are also a possible source of error. A correlation between speed, dollar damage, and location of the accident was sought, but not found to exist at a meaningful level. However, a larger data sample would be required to verify this apparent lack of correlation.

Run-off and hit-building accidents were then separated by highway classification, as is shown in figure A.4. It should be noted that city streets were the scene of run-off accidents more frequently than any other type of road, while limited access highways (interstates and turnpikes) had significantly fewer reported. In addition, although only 32.6% of run-off accidents occurred on city streets, 76% of the total hit-building accidents took place on this type of road (where, of course, more buildings are to be found). Thus the probability that a building will be hit, given that a run-off accident has occurred on a city street, is estimated as 38/1561 = .024. The average property damage reported in such cases was $531, and the average speed at impact was 14 mph. Not surprisingly, there were no accidents on interstate highways or turnpikes that involved hitting a building.

Most non-passenger-car accidents involved pick-up trucks. Individual accident reports indicate that the average distance traveled by a vehicle after run-off and before impact is 146.4 ft., while the average distance from the road of the struck object is 37 ft. In addition, slightly more collisions occur with objects on the same side of the road as the vehicle, and the fewest occur with an object straight ahead. Many collisions occur near intersections, and most are due either to mechanical failure of the vehicle or unsafe driving. Eleven of the 26 cases studied individually were based on collisions on roads where the legal speed was at least as high as 40 mph, and all 26 took place on undivided highways.

Appendix B

Illinois Vehicular Impact Analysis

B.1 Introduction

This chapter provides a statistical summary of building collision accidents which occurred in the State of Illinois during 1970. In conjunction with the Oklahoma data discussed in the previous chapter, it attempts to provide additional insight as to the nature of such accidents. Illinois motor vehicle accident records are very comprehensive, reporting up to three involvements for any vehicle in an accident. Thus, a vehicle which collides with a stop sign, for example, and then deflects into a building, will be coded as having done exactly that.

B.2 Analysis

According to state records, 409,174 motor vehicle accidents occurred in Illinois during 1970. Of these, 37,462 or 9.2% were recorded as run-off accidents. In turn, 1229 of these run-off accidents resulted in collisions with buildings. Building collision accidents accounted for 3.2% of the run-off accidents, or 0.3% of all motor vehicle accidents recorded. However, motor vehicle accident records maintained by the state include only a fraction of the accidents which occurred in Chicago, namely those which occurred on state or U.S. numbered routes and/or those which resulted in fatalities. Of the 164,889 accidents which occurred within Chicago in 1970, only 37,043 or 22% are maintained on state accident files. Therefore, the state accident statistics are biased downward as a result of this ommission.

B.2.1 Building Collision Accidents by Road Type

In figure B.1, the 1229 building collision accidents are categorized according to the type of roadway on which they occurred. As can be seen, 717 (or 58.3% of all building collision accidents reported) took place on urban city streets (category A). When the other urban categories (B, C, and D) are combined with this figure, the resultant proportion of building collision accidents which occurred in urban areas is 85%, even with Chicago largely disregarded. This is reasonable since building collision accidents are likely to happen more frequently in built-up areas than in non-built-up areas.

In addition, figure B.1 indicates the low frequency with which building collision accidents happen on controlled-access highways. In all, only four reported building collisions resulted from motor vehicle accidents on controlled-access highways (categories D,E, and H). This low incidence is probably due to a general paucity of buildings in immediate proximity to such highways, as well as safety features commonly found on many urban expressways.

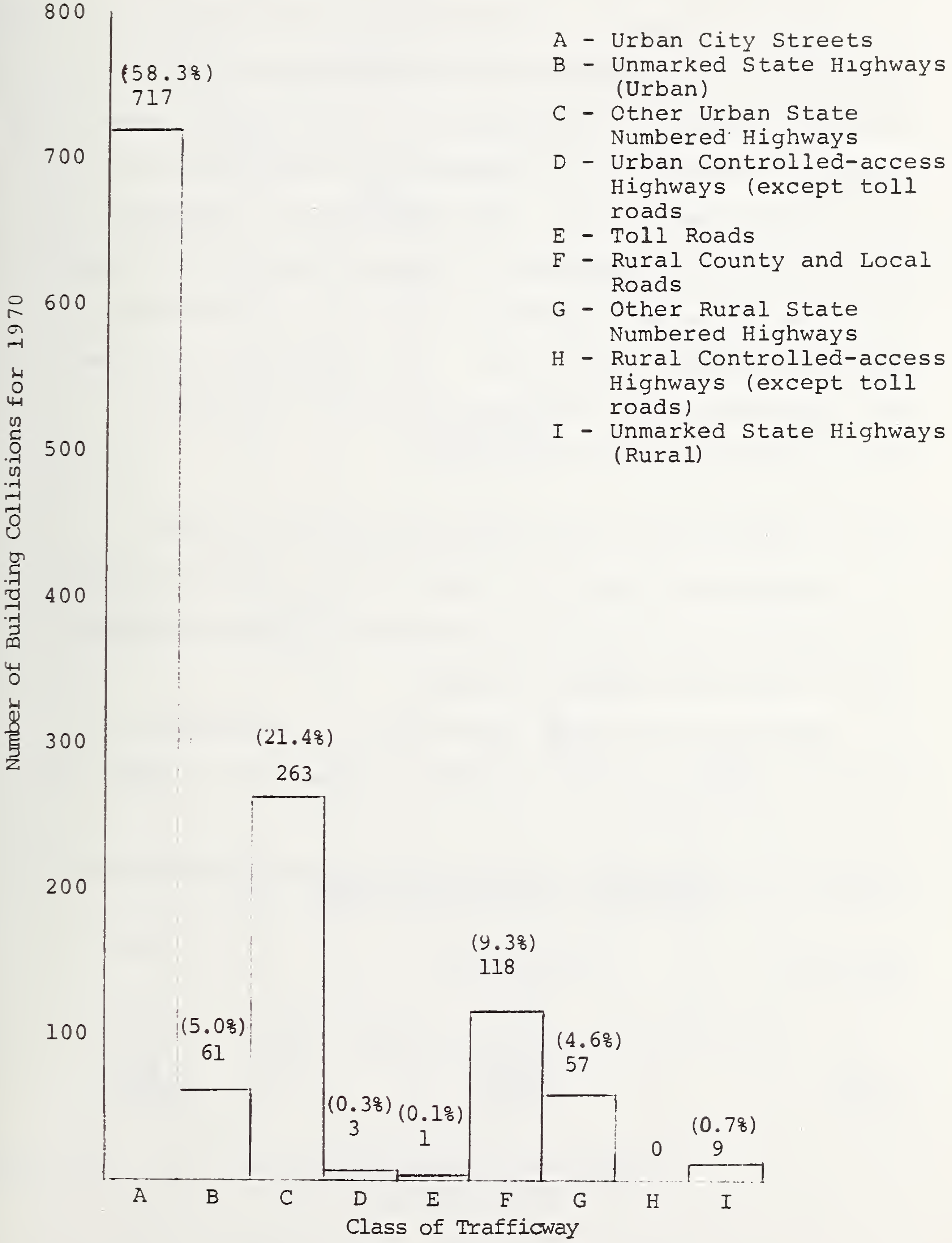


Figure B.2 Building Collision Accidents by Road Type

B.2.2 Building Collision Accidents by Population

Figure B.2 depicts the distribution of "building collision" accidents by the population of the location in which the accidents occurred. The State of Illinois defines urban areas as "locations in or adjacent to a municipality or other urban areas of over 5,000 population." Therefore, using 5,000 as a breakpoint, it appears that 86.1% of the "building collision" accidents took place in areas with a population greater than 5,000. This agrees well with the 85% figure for urban "building collision" accidents calculated from the Oklahoma data.

B.2.3 Building Collision Accidents by Vehicle Type

As shown in figure B.3, 1090 (88.7%) of the "building collisions" were caused by automobiles; of the remaining 11.3%, 8.9% were caused by trucks.

Information was also available as to the number of vehicles involved in each accident, summarized in table B.1.

TABLE B.1 DISTRIBUTION OF BUILDING COLLISION ACCIDENTS BY NUMBER OF VEHICLES INVOLVED

No. of Vehicles	No. of Bldg. Collisions	Percent
1	884	71.9
2	316	25.7
>2	29	2.4
TOTALS	1229	100.0

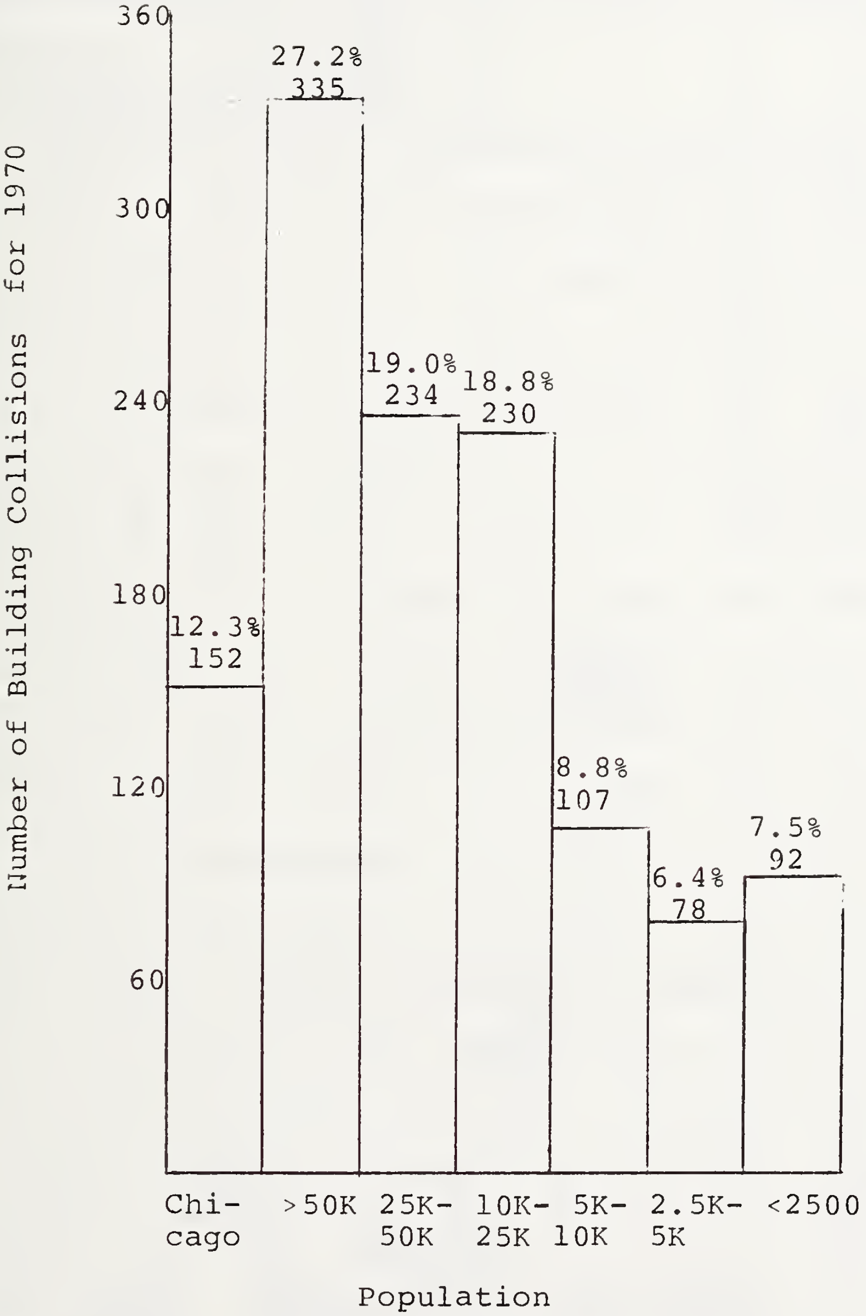


Figure B.2 Building Collision Accidents By Population

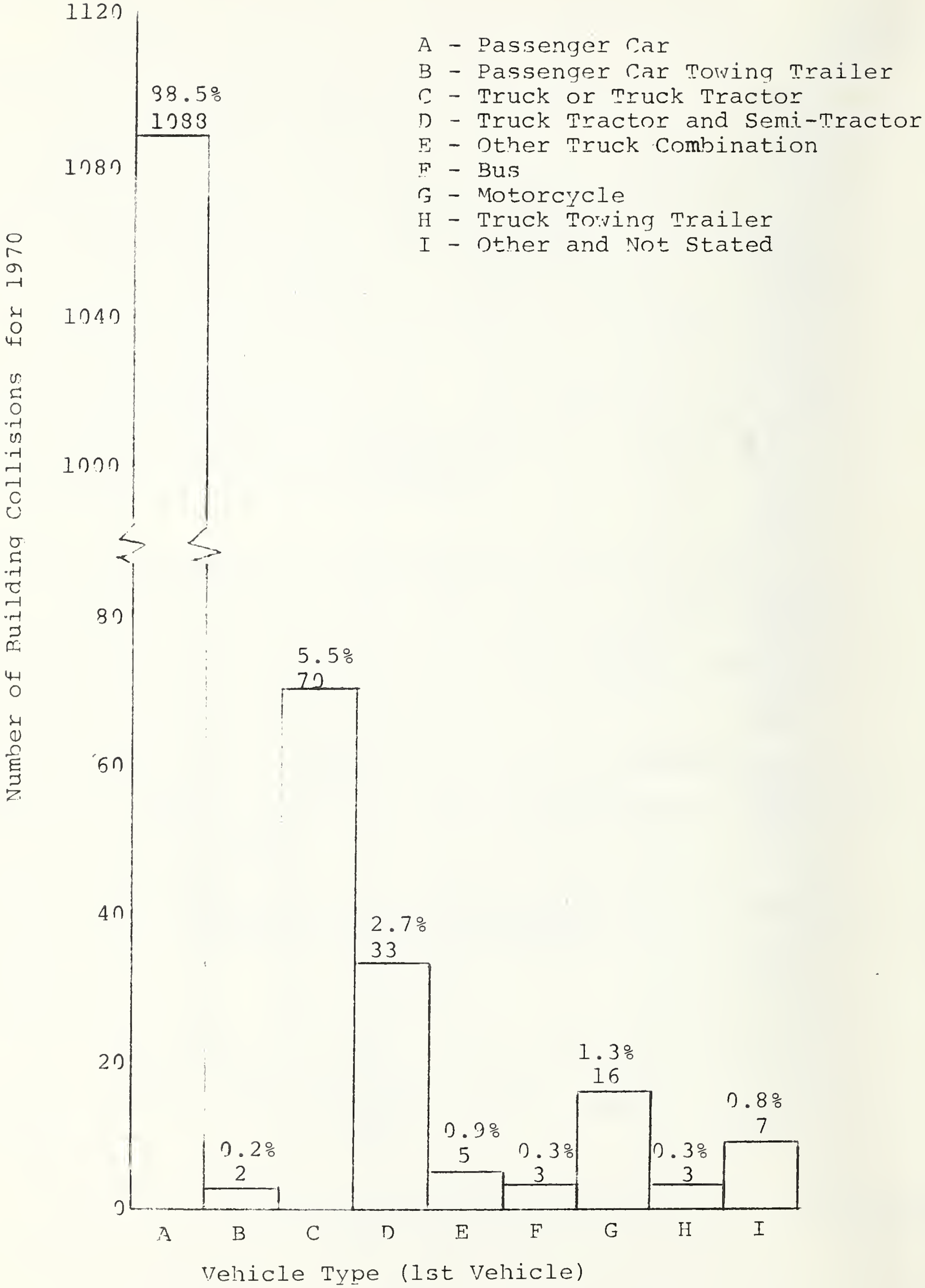
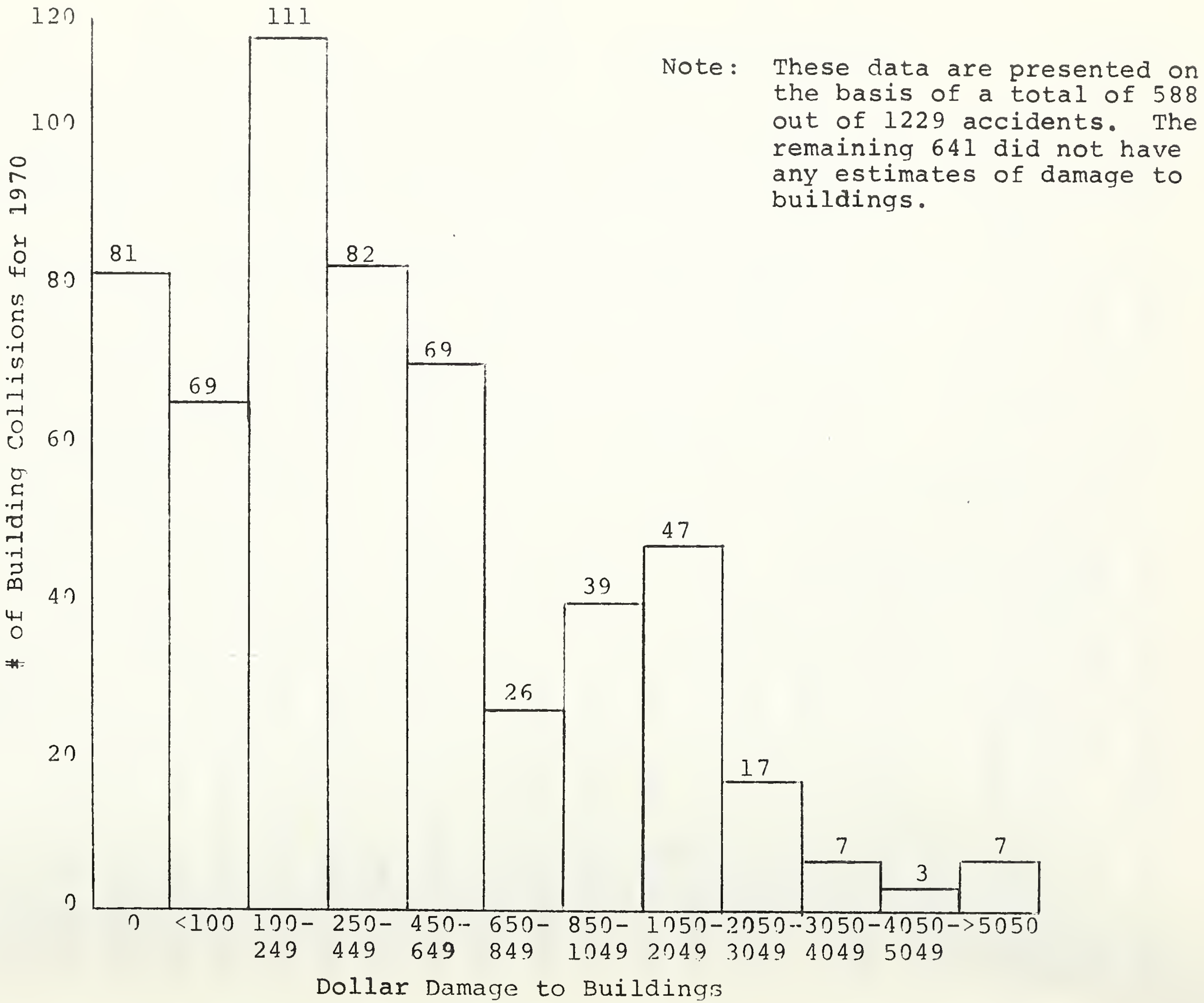


Figure B.3 Building Collision Accidents by Vehicle Type

The table indicates that 884 of 1,229 accidents involved only one vehicle. Of these single vehicle accidents, 776 involved only passenger cars. Therefore, of the 1229 "building collision" accidents, 776, or 63%, involved a single automobile.

B.2.4 Building Collision Accidents By Dollar Damage to Property

Figure B.4 displays the distribution of building collision accidents by dollar damage. This distribution is unfortunately incomplete, for of the 1229 accidents used as the base, only 558 (45%), had damage estimates associated with them. There is no readily available information as to the methodology employed to estimate damage, in general or in specific incidents, nor as to whether the estimates are restricted to the damage done to the buildings. However, since all accidents in the data base are building collision accidents, an assumption that damage estimates refer only to damage done to buildings is not totally unreasonable. For the 558 accidents for which damage was reported, 343 were estimated to have caused less than $550 damage. Of the remaining 215 accidents, 132 reported damage in multiples of $500, leading one to believe that these estimates are little more than "ballpark" guesses as to the amount of damage incurred. Nevertheless, because the information is the best available, it is still useful to perform a cursory analysis in an attempt to gain additional insight as to the nature of building collision accidents. Furthermore, to the extent that damages may have been



Note: These data are presented on the basis of a total of 588 out of 1229 accidents. The remaining 641 did not have any estimates of damage to buildings.

Figure B.4 Building Collision Accidents by Dollar Damage sustained by objects other than the buildings affected by collision, true damages are likely to be less than those reported and analyzed below.

The average damage for the 558 accidents was calculated to be $667. However, 412 (74%) had damage estimates less than $650, and the median for the damage distribution is approximately $300. (The substantial difference between the mean and median can be explained by the occurrence of 6 accidents with damage estimated to be greater than $900, tending to drive the mean upwards. In contrast, the occurrence of 261 accidents with estimated damage of less than $250 tends to lower the median.)

A comparison of damage caused by trucks and that due to automobiles reveals some notable differences. The average damage caused by trucks colliding with buildings was calculated to be $1,191, although the median was approximately $300. Mean damage for automobile accidents was calculated as $614, or approximately half of the truck mean damage. However, the median for automobile accidents was also estimated at $300. Certainly one would expect trucks to cause more damage to buildings than automobiles, because trucks have greater mass and therefore greater potential to cause extensive damage.

The average damage was also calculated separately for urban and rural accidents. The mean damage for rural building collisions was computed as $833, while the average damage for urban accidents was $618. These figures were based on a sample of 125 rural accidents and 443 urban accidents, because there were only 558 accidents for which damage was reported. The rural accidents probably entail higher average damage because vehicles travelling on rural roads tend to be driven at greater speeds than vehicles on urban streets.

It was decided to extract from the data base those accidents which had damage estimates of at least $3000 and to submit these to further analysis. There were 24 such accidents. In table B.2, a few summary statistics derived from the sample are displayed in comparison to statistics gathered from the entire data base.

TABLE B.2 SUMMARY COMPARISON: MAXIMUM DAMAGE (>$3000) BLDG. COLLISION ACCIDENTS VS. ALL BLDG. COLLISION ACCIDENTS

	Sample		All	
	Frequency	Percent	Frequency	Percent
No. in Sample	24	100%	1229	100%
Urban	16	67%	1044	85%
Automobile	17	71%	1090	89%
Single-Vehicle	16	67%	884	72%

These results appear to be consistent with the mean damages discussed above: because urban accidents cause lower average damage than do rural accidents and because passenger vehicles do less damage than trucks, one would expect lower incidences of both automobile and urban accidents in a sample consisting of those accidents causing the most damage.

The frequency of single vehicle accidents in the sample does not appear to be significantly different from the frequency of single vehicle accidents for all building collision accidents. The occurrence patterns of the single-vehicle accidents were closely scrutinized in an attempt to observe general trends. Of the total of 16 single vehicle accidents, 13 ran off the road and collided with buildings directly; the remaining three were deflected into buildings after first colliding with a highway sign, a utility pole, and a fence, respectively. Of these 16 accidents, 11 involved automobiles and five involved trucks. Only one of the truck accidents was a deflection. Based on this scanty evidence, it is difficult to draw any conclusions concerning the nature of major single-vehicle building collision accidents, although the data does seem to indicate that direct collisions occur more frequently than do deflections.

B.3 Summary

1) The analysis was based on a total of 1229 building collision accidents. These accidents constituted 3.2% of all run-off accidents and 0.3% of all motor vehicle accidents. However, the omission of 78% of the Chicago accidents introduces a downward bias to many of the results presented here.

2) 1058 of the 1229 building collision accidents (86%) occurred in urban areas and, 58% took place on city streets. Similarly, 21,537 of the 37,462 run offs are classified as urban.

3) Automobiles were the first vehicle involved in 89% of the building collision accidents, while trucks accounted for only 9%.

4) A single vehicle was involved in 72% of the building collisions. 63% of the building collisions were caused by a single automobile.

5) Only 45% of the building collision accidents had damage estimates associated with them, with an average damage calculated at $667. The average damage in truck-related accidents was $1191, but automobile accident mean damage was calculated at $614. The average building damage in rural accidents was $833, whereas the average damage in urban accidents was $618. Damage was estimated in excess of $1000 in 113 accidents. Of those 113, 10 carried damage estimates in excess of $5,000.

APPENDIX C

Multistory Residential Buildings

In Table 1, housing units for 1970 are partitioned according to the number of units per building. For example, the third row of the table can be interpreted as follows:

> There are (1.706) x 10^6 owner occupied housing units located in buildings which contain 2 units per building. Therefore, these units account for $((1.706 \times 10^6) \div 2 = (0.853) \times 10^6$ residential buildings.

Those buildings which we assumed to be <u>multistory</u> residential are designated by a triple star. This information was taken from 1970 Census of Housing, Detailed Housing Characteristics, United States Summary, Table 22, and is shown on the following page.

Table C.1 1970 Housing Data

Units per Building	Housing Units (x10^6)*	Buildings (x10^6)**
Owner Occupied		
1 detached	34.396	34.396
1 attached	1.112	1.112
2	1.706	0.853
3 and 4	.454	0.454
5 or more	.463	<0.463***
Mobile homes	1.751	1.751
	39.882	38.335
Renter Occupied		
1 detached	7.736	7.736
1 attached	0.794	0.794
2	3.402	1.701
3 and 4	2.816	0.804
5 to 9	2.284	0.326
10 to 19	2.219	0.153***
20 to 49	1.873	0.054***
50 or more	2.115	<0.042***
Mobile home	0.321	0.321
	23.560	11.931
Vacant for Rent		
1	0.571	0.571
2 to 4	0.407	0.135
5 to 9	0.194	0.028
10 or more	0.494	<0.049***
		0.783
	65.108	51.049 (total)

---

* taken from 1970 Census of Housing, Detailed Housing Characteristics, United States Summary, Table 22

** calculated; all values are approximations due to varying size of class intervals.

*** assumed to be multistory buildings (4 or more stories)

From the above information, the number of multistory residential structures (N) in 1970 is calculated as follows:

10^{-3} N $\leq$ 93,000 + 153,000 + 54,000 + 42,000 + 49,000 = 391,000

The proportion of residential structures which are multistory (P) is then calculated as follows:

$$P \geq 391/51{,}049 \geq .008 \approx 1\%$$

However, the estimated number of multistory residential buildings is somewhat questionable. In order to lend credibility to the estimate, an alternative procedure was performed using the number of residential units in structures with four or more floors. According to the 1970 Census figures, there are 3,295,304 residential units located in structures with four or more floors.* By making the extreme assumption that there are only four units per structure, the number of multistory residential structures is estimated as 824,000. On the other hand, if the previous estimate of 391,000 is used, this would yield 8.4 as an average number of residential units per structure. This still appears to be low. Thus, the previous estimates of 391,000 appears to be a high estimate for the number of multistory residential structures in the United States in 1970.

Housing data for 1960 is given in table 2.

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* 1970 Census of Housing, Detailed Housing Characteristics, United States Summary, Table 24.

Table C2. 1960 Housing Data

Units per Building*	Housing Units (x 10^6)*	Buildings (x 10^6)**
Owner Occupied		
1 detached	28.436	28.436
1 attached	1.526	1.526
2	1.443	0.722
3 and 4	0.456	0.130
5 or more	0.258	<0.052***
Mobile home	0.677	0.677
	32.797	31.543
Renter Occupied		
1 detached	7.891	7.891
1 attached	1.860	1.860
2	2.683	1.342
3 and 4	2.343	0.669
5 to 9	1.770	0.253
10 to 19	1.141	0.079***
20 to 49	1.283	0.037***
50 or more	1.165	<0.023***
Mobile home	0.090	0.090
	20.227	12.244
Vacant for Rent		
1	0.603	0.603
2 to 4	0.378	0.126
5 to 9	0.154	0.022
10 or more	0.291	<0.029***
	1.426	0.780
	54.450	<44.567

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* Taken from 1960 Census of Housing, Detailed Housing Characteristics, United States Summary, Table 5.

** calculated; all values are approximations due to varying size of class intervals.

*** assumed to be multistory buildings (4 or more stories)

Table C. 3 provides a summary comparison between the 1960 and 1970 figures.

Table C. 3. Summary Comparison of Housing Data 1960-1970

	1960	1970	Change	% Change
Multistory Buildings (x 10^6)	0.220	0.339	0.171	78%
Residential Buildings (x 10^6)	<44.567	<51.049	≈6.482	≃15%
$\frac{\text{Multistory Buildings}}{\text{Residential Buildings}}$	>0.005	>0.008		
Multistory Units (x 10^6)	4.133	7.164	3.026	73%
Housing Units (x 10^6)	54.450	65.108	10.658	20%
$\frac{\text{Multistory Units}}{\text{Housing Units}}$	0.076	0.110		

Basically, the figures indicate that in the 1960's, multistory housing had grown at a rate considerably faster than housing in general. Even so, in 1970, multistory buildings accounted for less than 1% of the residential buildings. However, these multistory buildings contained 59% of the 1970 housing units.

APPENDIX D

Motor Vehicle Registrations 1960-1970

Table D. 1. displays the number of motor vehicles registered in the United States, as well as in the sample states of Oklahoma and Illinois from 1960 to 1970. Data are available at five year intervals for individual states and the U. S., and on a yearly basis from 1965 to 1970 only for the U. S.

Table D. 1. Motor Vehicle Registrations ($x10^3$)*

	U.S.	Okla.	Ill.
1960	73,869	1,184	3,776
1965	90,358	1,438	4,437
1970	108,436	1,713	5,238

In Table D.2, information regarding the growth of motor vehicle registrations from 1960 to 1970 is provided.

Table D. 2. Growth of Motor Vehicle Registrations 1960-1970

	Difference ($x10^3$)	% Change	Annual % Change
1960-1965			
U.S.	16,489	22.3	4.5
Okla.	254	21.5	4.3
Ill.	661	17.5	3.5
1965-1970			
U.S.	18,078	20.0	4.0
Okla.	275	19.1	3.8
Ill.	801	18.1	3.6
1960-1970			
U.S.	34,567	46.8	4.7
Okla.	529	44.7	4.5
Ill.	1,462	38.7	3.9

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* Taken from Statistical Abstract of the United States 1971, Table 849.

These figures indicate that motor vehicle registrations have grown at the rate of roughly 4% annually throughout the 1960's. In order to obtain more precise annual growth estimates, the number of motor vehicle registrations should be presented for every year, rather than for every five years. Detail is available* for the United States as a whole but not for individual states. Table 3 presents the yearly registration data for the entire U. S. from 1965 to 1970.

Table D. 3. Motor Vehicle Registrations in U.S. 1965-1970*

	Registration ($x10^3$)	Difference ($x10^3$)	% Change
1965	90,358	3,835	4.2
1966	94,193	2,738	2.9
1967	96,931	4,108	4.2
1968	101,039	4,058	4.0
1969	105,097	3,339	3.2
1970	198,436	-	-

According to the data in Table D.3, the average of the annual rates of growth of motor vehicle registrations in the United States between 1965 and 1970 is 3.7%.

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* From Statistical Abstract of the United States 1971, Table 847.

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16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

Through analysis of data from Oklahoma and Illinois along with national statistics, estimates are made of the number of vehicular collisions with buildings on an annual, nation wide basis. The best estimate is on the order of tens of thousands. However, since the impetus for the study was on multistory buildings and the likelihood of their being subject to progressive collapse the calculations have been refined to apply to substantial damage to multistory residential buildings. In 1970, such accidents were only on the order of 40, hence the probability of a given building being so affected in a single year is approximately one in ten thousand. Some discussion is provided on improvement for data collection for the future.

17. KEY WORDS (Alphabetical order, separated by semicolons) Collisions of vehicles with buildings; multistory buildings; progressive collapse of buildings; residential buildings; vehicular impact.

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