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16. Abstract Over 200 publications related to driveway design and operation, access control and safety, and vehicle performance characteristics were reviewed. This report presents annotations of those publications that were relevant to the objectives of the research study on driveway design and operations on urban streets and roadways in Texas.					
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GUIDELINES FOR DRIVEWAY DESIGN AND OPERATION

Vol. 1 - Annotated Bibliography

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Prepared for
Texas State Department of Highways and Public Transportation
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The conclusions and opinions expressed in this document are those of the authors, and do not necessarily represent those of the State of Texas, the Traffic Safety Section, the State Department of Highways and Public Transportation, or any political subdivision of the State or Federal Government.

Billion, C. E. and Scheinbart, I. A Study of Ingress and Egress at Gasoline Stations on Rural State Highways without Access Controls. Proceeding of Highway Research Board, 1956.

In this study the features of driver behavior of motorists entering and leaving gasoline service stations were investigated and related to the best method of controlling the location and design of the access driveways. The driver behavior studies were conducted in three phases considering the following related factors: (1) speed and speed differential of vehicles entering the station; (2) travel path of vehicles entering or leaving a station; (3) highway and station traffic volumes; (4) vehicle placement; (5) interference or conflict at the station; (6) driver preference; and (7) accident patterns at the service stations. Phase 1 consisted of extensive traffic studies at six established channelized service stations. Phase 2 consisted of observing traffic operations at five "open" frontage service stations. Phase 3 consisted of observing traffic operation at the same five service stations studied in Phase 2, but under conditions of various channelization designs experimentally installed.

The primary conclusions drawn from this study concerning service stations, located on New York State rural highways without access control, are

1. The average entrance speed decreased as the angle of driveway entrance increased and varied from a high of 16 mph for a 30 degree angle to a low of 6 mph for a 90 degree driveway.
2. The percentage of left turns made by the entering vehicles increased when the "open" stations were channelized. These increases ran as high as 13 percent for stations along the highway and 25 percent for one station located at an intersection.
3. For all driveways studied, over 87 percent of the vehicles entered within a 20 foot width, and 100 percent entered within a 28 foot width, measured at right angles to the center line of the driveway.
4. Driver interviews showed no preference for "open" or channelized service stations, but drivers tended to favor the driveway design at the station they were patronizing.

5. The traffic accident frequency at service stations on rural highways was 85 percent higher than the overall rural highway accident frequency.
6. Left turn movements at existing service stations on rural highways accounted for more traffic accidents than right turn movements.

Bochner, Brian S. Regulations of Driveway Access to Arterial Streets. Public Works, October 1978, pp. 83-87.

Transportation engineers have long been concerned with control of driveway access. In most jurisdictions, however, every land parcel abutting an arterial street is guaranteed access (usually to the arterial) and control of driveway access is therefore difficult. It is estimated that the capacity of a four-lane arterial street with a 45 mph speed limit is reduced by one percent for every two percent of the traffic that turns between the right lane and the driveways at unsignalized locations. For example, if a street carries 1200 vehicles per hour in a direction and 120 turn into driveways and 120 turn out of driveways per mile (20 percent turns), then the capacity will be reduced by 10 percent. This reduction can cause the level of service on the facility to deteriorate to a congested condition. Therefore, the guidelines presented in this article provide a means, not only to control driveway location and design for each parcel, but also to limit the number of driveways.

The primary goals of these guidelines are to:

1. limit the number of driveways to the minimum required to accommodate safely the traffic generated by each development;
2. provide adequate spacing between driveways so conflicts between vehicles maneuvering at adjacent driveways do not arise; and
3. insure proper design to accommodate driveway traffic and minimize vehicle conflicts without significantly reducing roadway capacity.

The design standards recommended by these guidelines represent some significant changes from common design practice and both minimum and desirable standards are presented. Some of the dimensions representative of the change from common design practice are:

1. Driveway Spacing - Driveways should be spaced a minimum of 200 feet apart to provide safe operation on arterials.
2. Corner Clearance - The minimum tangent curb length between a driveway and an intersection of an arterial with an unsignalized

cross street should be 50 feet. If the intersection is signalized, the clearance should be a minimum of 125 feet for a collector and 250 feet for an arterial street.

3. Number of Driveways - Each parcel should be permitted access through one driveway with additional driveways permitted only under the following conditions:

- The daily volume exceeds 5000 vehicles.
- The traffic using one driveway would exceed the capacity of a stop sign controlled intersection during the peak hour.
- A competent traffic analysis shows that traffic conditions warrant two or more driveways.

Box, Paul C. Access Control and Accident Reduction. Municipal Signal Engineer, May/June, 1965, pp. 27-30.

The analysis of Skokie, Illinois accident records revealed that driveway accidents constituted nearly 12 percent of all major street accidents in the city. A previous study had shown that 75 percent of the injury-producing driveway accidents involved left turns into or out of driveways. Prohibition of these left turn movements should therefore have a significant effect on accident reduction. However, the left turn movements must still take place at nearby intersections; therefore, the application of access controls should also include intersection controls and reconstruction as needed. The control of left turning movements into and out of driveways can best be accomplished by using a barrier median. On the wider streets, the median may be supplemented by individual triangular islands at each driveway, which channelize the inbound and outbound right turn movements. Major problems produced by development of access control include obtaining agreement of abutting property owners and securing required funds for construction. The author illustrates the development, negotiations and agreement, design, and "before" and "after" effects of an access control improvements project in Skokie. Of importance was the 50 percent reduction in accidents during the "after" period. The lessons which were learned from this project are as follows:

1. Development of access control on an existing major traffic route should be undertaken as early as possible in the development stage of adjacent property.
2. Even though the project may not have reached the design stage, the access concepts can be integrated into the design of new roadside developments.
3. It is sometimes possible, by the use of a cooperative technique, to secure cooperation and direct contributions from abutting property owners.
4. Extensive use of accident data may be profitably employed by the public agency in justifying the improvement.
5. Completed improvements should be continually analyzed to develop data on favorable results, as well as to uncover any weaknesses in original design.

Box, Paul C. Driveway Accident & Volume Studies. Public Safety Systems, May/June, 1969, pp. 18-22.

Typically, minimum attention is given to actual driveway operations in the design stage. Although much has been written about the problems associated with driveway operations, a need exists to gather basic data and explore relationships between design and operation. Using data from Skokie, Illinois, the author illustrates general relationships among land uses, volumes, and accidents in which driveways were influencing factors. Findings from a two year study of driveway accidents on major traffic streets include the following:

1. The involvement rate of residential driveways is low (0.02 accidents per driveway per year).
2. 60 percent of the property damage only accidents involved left turning vehicles; 75 percent of the injury type accidents involved left turn maneuvers.
3. The rate per driveway of driveway accidents on routes without median barriers was 9 times greater than the rate on routes with median barriers.

Findings and recommendations from a more extensive five year study of driveway accidents on both major and minor streets include the following:

1. Accidents involving vehicles moving into or out of driveways constitute 11 percent of all reported accidents, 12 percent of the major street accidents and 9 percent of the residential street accidents.
2. Commercial driveway accident rates (accident per driveway per year) were developed for 30 different types of land-use.
3. The rate per driveway of pedestrian accidents involving driveways was extremely low. A higher rate should be expected in a CBD.
4. For spontaneous two-way driveway traffic, a curb return radius of about 15 feet and a minimum driveway width of 30 feet are required to prevent adjacent lane encroachment. High speeds or large numbers of truck movements require increases in turning radii up to 30 feet and widths up to 40 feet.
5. The major contributing factor to pedestrian-driveway accidents was sight obstruction created by adjacent buildings at the driveway exit.

6. Commercial driveway accident rates (accidents per driveway per year) for routes with no median barrier increased with increasing ADT on the major route. In developing driveway accident rates along routes with median barriers, it would be appropriate to use one-half the route ADT.
7. For the seven different types of land use that were checked, uncontrolled driveway (driveway widths from 100 to 120 feet) accident frequency was greater than controlled driveway accident frequency in every case.

Box, Paul C. Driveway Accident & Volume Studies -- Part II -- Service Stations. Public Safety Systems, July/August 1969, pp. 15-18.

This study of service station accidents is confined to urban and suburban sites. Accident data were largely taken from 56 months of Skokie, Illinois accident records while volume counts were from stations in several cities and towns across Illinois. The study revealed that the greater the number of driveways per station, the greater the number of annual accidents per station. This trend occurred because the accident frequency per driveway for driveways opening onto major streets was relatively constant. Service station driveways that opened onto local or minor streets were relatively accident free. Further analysis showed that service station accidents are most directly related to the number of driveways connecting to a major street. Another finding was that, even though an average of 36 percent of service station driveway traffic enters or exits the station by a left turn maneuver, 63 percent of the total driveway accidents are associated with left turns.

Results of the service station driveway volume studies showed an average of about 6 vehicles per hour per driveway (two-way) during the peak traffic hours. Also, the estimated traffic generation of a service station driveway is not more than 50 percent of the driveway volume.

Accident frequencies for service station driveways at stations in the same block with public uses are no greater than the frequencies for service station driveways at other locations. For stations having obtuse, right, and acute angle street corners, driveway accidents per station per year were lower than average, about average, and higher than average, respectively.

Box, Paul C. Driveway Accident & Volume Studies -- Part III -- Design Considerations. Public Safety System, September/October 1969, pp. 16-19.

Although many driveways must be designed for two-way operation, there is a sufficient number of one-way driveways in most cities to justify separate design standards. Also, driveways on one-way streets have different design requirements.

Driveways should be designed to take traffic into and out of a facility with maximum convenience and minimum hazard to all road users. In areas of heavy pedestrian activity, the sidewalk user must also be considered. The planner needs to know something of expected site volumes in order to make intelligent decisions about which streets should have driveway access.

Total driveway traffic volumes (per PM hour of peak street traffic) for 27 specific land uses were gathered at sites in Skokie, Illinois. A few driveways serving a two-way volume exceeding 100 vph were found. The high volume driveways require adequate width at the central limit, plus an adequate turning radius. The two elements are directly related, since a greater width at the control line can compensate for a small radius, and vice versa. Traffic should be able to enter the driveway from the curb lane without encroachment into the other lane. This can be accomplished with a radius or flare of 12 to 15 feet along with a throat control width of 30 to 35 feet. The distance from the street curb face to the right-of-way line should not be an artificial limit for the turning radius of a driveway. Two philosophies, "step-down" and "baby carriage," for design of driveway curbing as it crosses sidewalks are also discussed.

In conclusion, policies, standards, regulations or ordinances should really represent "guidelines." When there is good and reasonable cause for variation, there should be a simple and intelligent way of engineering for site conditions.

Box, Paul C. Major Intersection Improvement -- An Urban Example. Public Safety Systems, July/August 1968, pp. 13-16.

A major intersection improvement project in Skokie, Illinois is presented. A four-year accident study (1962/1963 "before" and 1964/1965 "after") showed an overall accident reduction of 30 percent. The theoretical reduction was even better, as accidents rose 26 percent in other parts of the city during the "after" period. Driveway related accidents, in areas where barrier median was installed, dropped from 17 to 4.

Box, Paul C. and Associates. Traffic Control and Roadway Elements -- Their Relationship to Highway Safety: Chapter 5 - Driveways. Highway Users Federation for Safety and Mobility, 1970, pp. 1-8.

Recent studies of driveway accident rates have shown that driveway accidents represent 11 to 13 percent of all traffic accidents. This article addresses three elements which affect the probability of driveway accident occurrence:

1. Route characteristics
2. Driveway characteristics
3. Control and design factors

Studies that have evaluated the use of access controls have found that full access control (driveways and intersections) along a road section significantly reduces the accident rate when compared to an uncontrolled section. Other route characteristics such as frequency and types of driveways, traffic volumes, intersection spacing, and speed have been studied and attempts made to determine their relative importance to driveway accident rates. Schoppert found that rural driveway accident rate predictors involve the following factors, listed in order of importance:

1. Volumes
2. Frequency of driveways
3. Design features

Another study, performed by J. A. Head, determined that urban accident rate predictors were similar to those derived by Schoppert; however, Head's ranking of the predictors was different. He ranked the factors as follows:

1. Number of commercial units
2. Number of traffic signals
3. Number of intersections
4. Speed
5. Volumes
6. Pavement width

Driveway characteristics that influence the accident rate are: restriction of turning movements; lane width; sight restrictions; and driveway volume. Several studies have concluded that the most critical traffic operational element of the driveway accident problem is traffic entering driveways. Left turn accidents are the most critical in relationship to safety.

Recognition that left turn movements are the largest single factor in driveway accidents indicates that barrier medians and median storage areas can greatly reduce the accident rate.

Box, Paul C. Signal Control of High-Volume Driveways. Municipal Signal Engineer, November/December 1965, pp. 21-24.

For many years, traffic signals have been used successfully to handle private driveway volumes at industrial plants and shopping centers. Although some driveway signals are designed to facilitate entry to a private driveway, the left turning traffic exiting from the driveway is the movement most in need of signal control from the standpoints of both delay and safety. By widening a high volume "tee" type driveway and channelizing the major route, greater efficiency and safety can be achieved. Advantages of this type of design include a continuous through movement on the arterial, exclusive lanes for the driveway exit traffic, and shadowed storage bays for left turn entry and exit traffic. The primary limitation of the design concerns commercial vehicle operation; therefore, it is recommended that commercial vehicle access and egress be handled at other entry points. This route channelization concept has been in use for a number of years at a shopping center in Skokie, Illinois. A four year accident analysis at three of the driveways around the shopping center is presented. Also, the principle of throat length extending onto private property is discussed. If this concept is not initially incorporated into a project, problems involving internal circulation, and parking layout can be expected to develop. Throat length design factors should include inbound and outbound storage capacity requirements, relative volume of outbound turns, and weaving volume within the throat. As the developer/property owner benefits economically by high quality design, the author suggests that he should pay for on-site and adjacent highway improvements made as a direct result of the development.

Cribbins, P. D., Horn, J. W., Besson, F. V., and Taylor, R. D. Investigation of Medians and Median Openings on Divided Highways in North Carolina. Highway Research Program Final Report ERD-110-Y, North Carolina State University, Raleigh, June 1966.

This report presents the results of an investigation of the effect of certain roadway characteristics on the accident rate and level of service for selected sections of highway. The roadway characteristics studied were: median width; speed limit; ADT; the number of signalized intersections per mile with and without left turn storage; the number of unsignalized intersections per mile with and without storage; and the extent of roadside access. The objective of the research was to determine the optimum median opening spacing with regard to safety, roadside access and level of service. Accident information and roadway characteristics for every section of multi-lane divided highway without access control and having barrier medians in North Carolina were collected. Data were stratified by location type and analyzed using multiple regression techniques.

The following statements constitute the principal findings of this investigation:

1. The ADT and roadside access, combined with the number and type of median openings, are the most important predictors of accident rates.
2. Unsignalized and signalized intersections are the most hazardous accident locations, respectively.
3. Accident rates and level of service can be accurately predicted for a section of existing highway using regression models.
4. A precise "ideal" spacing of median openings cannot be derived due to the interaction of many traffic and roadway variables.
5. Accident data on existing facilities do not serve as a reliable predictor for future facilities; however, future predictions on existing facilities can be made through the use of regression equations.

The following conclusions were drawn from the findings of this investigation:

1. As the volume increases, usage of median openings becomes hazardous.

2. The signalization of median openings does not necessarily reduce the hazards associated with high volume conditions, but offers orderly traffic flow and better time distribution.
3. As roadside development increases and crossovers of any type are permitted, the number of accidents increases.

This report recommends that each State formulate a policy regarding median placement on future facilities and also the closing or addition of median openings on existing facilities. It also recommends that the States encourage businesses to locate and develop in accord with the most efficient and safe use of the public highway.

The intersection of urban streets is one of the principal locations of accidents and a primary source of congestion. Through analysis of vehicular behavior adjacent to and within these intersections and the rational application of the derived information, the undesirable condition may be reduced or eliminated. This study is concerned with only right turn vehicular movements at urban intersections.

The data were collected using time-motion pictures of an intersection located in Hartford, Connecticut. The major street (one-way) was intersected by a minor two-way street. This type of intersection allows the driver maximum freedom of movement to choose the path taken through the turn, with no opposing traffic and plenty of separation between vehicles. Therefore, the movement through the intersection should represent a normal driver movement.

The major results of this study are:

1. The speed distribution mode and median were both between 12-13 mph, while the mean was 11.7 mph.
2. The maximum speed was 16 mph.
3. The minimum radius used by any driver was 40 feet.

Besides these factors, there were other conclusions drawn which touch on the psychological, as well as physical, nature of normal turning traffic movement through an intersection.

1. The patterns of speed behavior and placements show that motorists try to negotiate each turn with the minimum of time at their respective speed, but are limited by centrifugal force.
2. Curb returns are regarded as less hazardous than parked vehicles; therefore, drivers turn on shorter radii when there are no parked vehicles.
3. Faster drivers accept less clearance from both parked cars and the curb return radius than their slower counterparts.

4. Minimum radius used during the turn negotiation does not vary with the speed range studied, but that radius is maintained for less time and distance and accomplishes less turning for faster vehicles.

Emmerson, J. Speed of Cars on Sharp Horizontal Curves. Traffic Engineering and Control, July 1969, pp. 135-137.

The distribution of the speeds of cars on horizontal curves is of interest to highway engineers because the information can be compared to the theoretical speeds for which the curves have been designed. This article describes the results of speed tests on cars at six sites on horizontal curves along two-lane roads in rural areas of Cheshire and Lancashire. The test sites were chosen so that curvature was the only parameter effecting the variation of speed along the road section. The radii of the sites ranged from over 1100 feet to less than 100 feet.

From the observations taken along these road sections, it was determined that no "comfortable" speed exists for all drivers and the variation of speeds between drivers was quite large. Curves with a minimum radius of 1100-600 feet can be comfortably negotiated with a side friction factor of 0.15 for most drivers. This corresponds to the findings which were used in establishing the AASHTO Geometric Design Standards. Short radius turns, with design speeds less than 40 mph, should adopt a much higher factor, perhaps, greater than the AASHTO standards.

A follow-up to the original article was published in November 1970, Traffic Engineering and Control. This brief article introduces an equation which can be used to determine the mean speed (velocity) from the curve radius. This equation was derived from the original experimental data and new data collected in the same manner. The data revealed a sharp drop in the mean speed for curves with less than a 200-foot radius and no significant change in mean speed for curves with a radius greater than 200 feet.

Faulkner, Robert Allen. Evaluation of Current Standards and Policies Concerning Access Driveways. Masters Thesis, Civil Engineering Department, Texas A&M University. January 1969, pp. 1-93.

This thesis was researched and written in conjunction with the study conducted by the Texas Transportation Institution which produced NCHRP 93, "Guidelines for Medial and Marginal Access Control on Major Roadways." This study gives particular attention to existing practices used in various States in the design of access driveways. Current standards for access driveway design are summarized as well as the policies used to regulate the various features of the driveways.

These standards were evaluated on the basis of desirable roadway and driveway operation. Particular aspects of driveway operation were related to well known quantitative traffic flow theories. After an evaluation of existing policies, flexible as well as comprehensive policy guidelines were formulated so that the recommended driveway standards may be effectively implemented.

The geometric standards recommended by this study include these driveway design elements: driveway width; entrance angle; curb return radius; profile grade; edge clearance; and corner clearance. These elements are presented in such a way that it is possible to understand the relationship between the dimension of a particular design element and the parameters established by the other design elements. Therefore, driveway width is dependent on the angle of the driveway, the curb return radius, and vehicle speed.

The recommended policy guidelines are compiled in tabular form as an appendix to the report. The table is divided into several different categories such as general regulations, construction regulations, vehicle service features, and other topics. This table makes it possible to quickly locate specific policy statements.

Franklin, William D. and Evans, Lynn A. The Effects of Access on Highway Right-of-Way Costs and the Determination of Special Benefits. Texas Transportation Institute, Research Report 82-1F, October 1968.

Acquisition of right-of-way for a major highway system presents a number of unique problems in property evaluation. It is agreed that, if all the land owned by an individual is to be taken for right-of-way, the individual should be paid the market price for that particular piece of property. However, problems arise whenever an individual has land remaining after the necessary amount is taken for right-of-way purposes. The remaining land may incur damages because of the right-of-way purchase and it might also incur benefits due to the purchase.

From an analyses of land values, right-of-way costs, type of access and amount of development, it is evident that the granting of access has the effect of reducing the amount paid for damages connected with property acquisition, for highway right-of-way purposes. The primary results of the statistical analyses can be summarized as follows:

1. An examination of approximately 3600 acres of acquisitions for highway right-of-way indicated that the amount paid for damages to those properties granted access was approximately 53 percent less than damages paid to those properties not granted access.
2. An analysis of the remaining real estate transactions indicated a net percentage differential increase of approximately 153 percent for unimproved property with access as opposed to such property without access.
3. Agricultural property with access had a 12 percent differential increase.
4. Residential properties with access had an 89 percent differential decrease.
5. Commercial properties with access had a 97 percent increase.
6. Properties abutting an interchange showed an increase of 273 percent, whereas the percent increase became smaller as the distance from the interchange increased.

7. The "peak" increase was in the value of properties located at the end of an egress ramp; a 205 percent increase was observed for these properties.
8. A comparison of abutting properties along highways constructed with and without frontage roads indicated that properties abutting highways with frontage roads sell for a higher price than those along highways without frontage roads. Unimproved property sold for 42 percent higher, agricultural property sold for 69 percent higher, and residential property sold for 53 percent higher.

Good, M. C. and Joubert, P. N. Driver-Vehicle Behaviour in Restricted-Path Turns. Ergonomics, Vol. 20, 1977, pp. 217-248.

This study examines the driver and vehicle response to the geometric design of curves. Building on an earlier study of driver/vehicle characteristics of "free-path" turns, this study constrained the driver to stay within a specific geometric design. A secondary effect examined in the study was the relationship between time savings and acceptable levels of comfort in cornering. Sixteen drivers with an age range of 21 to 53 and varying levels of driving skills made 134 "restricted" turns. As was the case in the "free-path" study, it was determined that drivers would accept larger lateral acceleration than is outlined in the AASHTO geometric standards.

From the analysis of the data collected in these tests it was concluded that:

1. There was no evidence that in restricted-path turns drivers tried to maintain maximum yaw rates.
2. Where possible, drivers attempted to "cut corners" so as to reduce the maximum curvature of the vehicle path.
3. The maximum lateral accelerations developed decreased with increasing curve radius; therefore, there was no "preferred lateral acceleration" for all curves.
4. The mean levels of lateral acceleration were close to those given in the AASHTO geometric standards; however, many drivers accepted significantly higher lateral accelerations.

Good, M. C., Rolls, K. J., and Joubert, P. N. Driver-Vehicle Behaviour in Free-Path Turns. Transportation Research, Vol. 3, 1969, pp. 43-68.

The aim of this research program was to establish driver preference and driver/vehicle performance on various curves and to correlate these with objectively measurable characteristics of the curve and vehicle. Drivers were allowed to make "free-path" turns, constrained only by the final heading and forward velocity, in a vehicle with known characteristics. During these turning maneuvers data were recorded for lateral acceleration, longitudinal acceleration, yaw rate, steering wheel force and angle, distance traveled, and vehicle speed. Besides these data, information was collected from the driver (subject) and passenger (experiment observer) on their perception of the comfort of each turn, with a scale which ran from "complete comfort" to "very uncomfortable." Six drivers, ages 30-50 with varying levels of driving skills, performed turns from 30° to 240° at speeds ranging from 10 to 50 miles per hour.

The results of these tests showed a significant difference in the acceptable discomfort in making a turn than was determined by the studies conducted for AASHTO. These tests revealed a significantly higher lateral acceleration, even though the subjects were told to make a "comfortable" turn. Even though the drivers were instructed to make comfortable turns and were not confined in how they could negotiate the turn, many rated their "free-path" turn as uncomfortable.

The major conclusions which came out of this study were:

1. There was no significant difference between driver behaviour on left and right turns.
2. The levels of lateral acceleration utilized by drivers were generally higher than those found in restricted-path driving or allowed for in road design.
3. The level of lateral acceleration seemed to be minor in determining how the turns were made.
4. The vehicles trajectories for each condition of longitudinal acceleration were characterized by a constant maximum yaw rate, which was independent of forward speed for any given deviation angle.

Gwynn, David W. Accident Rates and Control of Access. Traffic Engineering. November 1966, pp. 15-21.

Using 1964 accident statistics two sections of an Interstate Highway (controlled access) in New Jersey are compared with two parallel sections of State Highway (no access control). Length and ADT-characteristics on each section of State Highway were similar to those on the section of Interstate Highway it paralleled. However, accident and injury rates on the sections of State Highway were at least 470 percent greater than the corresponding rates on the parallel sections of Interstate Highway. This leaves little doubt as to which sections were safest; however, by using accident data on the State Highway sections prior to the opening of the Interstate Highway sections, the author demonstrates that construction of the Interstate Highway routes did not improve the accident experience on the parallel State Highway routes. Therefore, he concludes that in addition to constructing new roadways, something should be done to improve existing routes. The same principles that make new highways safer should be applied to existing highways. For example, by controlling access to reduce to a bare minimum the marginal friction, the number of injuries and accidents and their corresponding rates can be reduced. In some areas, marginal development is at a stage where conversion (no access control to full or partial control) is practical from an economic standpoint. These areas should be the target of early action, and the line where such conversion is practical and where it is not should be drawn without delay.

Head, J. A. Predicting Traffic Accidents from Roadway Elements on Urban Extensions of State Highways. Highway Research Board - Bulletin 208, 1958.

The investigation described in this report represents research by the Oregon State Highway Department to develop equations which can be used to predict accidents on the urban extensions of the State Highway System from roadway elements such as ADT, commercial and residential units and driveways, intersections, signalized intersections, indicated speed, pavement width, effective lane width and the number of lanes.

The study utilized a sample of 426 sections with a total length of 186.4 miles. Data were analyzed by grouping the sections by the number of lanes and ADT. Within these groups additional subgroups of urban extensions were studied. The multiple correlation analysis resulted in a series of equations indicating the relationship of the various roadway elements to accident rates on the subgroups of urban highways in Oregon.

The most important conclusions which can be drawn from this study in regard to driveways, access and land use are:

1. The number of commercial driveways, residential units and residential driveways, and effective lane width are relatively unimportant roadway elements for predicting traffic accident rates. However, commercial driveways can be used to predict accident rates on 2-lane sections.
2. The most important roadway element in predicting traffic accident rates for urban sections is the number of commercial units adjacent to the sections. The number of commercial units becomes a better predictor as the number of lanes increases and as the average daily traffic increases.

Horn, J. W., Cribbings, P. D., Blackburn, J. D., and Vick, C. E., Jr. Effects of Commercial Roadside Development on Traffic Flow in North Carolina. HRB Bulletin 303, Highway Research Board, 1961.

This report documents a study of the magnitude and severity of problems associated with commercial roadside development in North Carolina. This research evaluated the effects of this development by means of a study of speed and delay through nine selected test sites. A test section was defined as a section of commercially developed, two-lane roadway at least one-half mile in length with (1) a maximum legal speed of 55 mph; (2) medium to heavy traffic volumes; and (3) a minimum number of traffic signals, major intersections, or appreciable horizontal or vertical curves. Results are based on data collected through the use of two techniques: (1) the average-car method and (2) the maximum-car method. The "average-car" was driven at a speed representing the average speed of the overall traffic. The "maximum-car" was driven as close to the maximum legal speed limit as possible. Two methods were used because the data collected by the average-car method did not differentiate between delays caused by physical traffic movements and delays caused by psychological factors.

A speed and delay recorder was mounted in both test vehicles to measure eight types of impedances along each test section. The types of impedances were: left turn exiting, right turn exiting, approaching left turn, crossing, slow vehicles, and miscellaneous. Slow vehicles were the most frequent impedance, causing 68.9 percent of the total delays on all test sections. Right and left turns (made from the lane that the test vehicle occupied) were the only other major impedances; they amounted for 26.5 percent of the total delays when combined.

A "least squares" regression analysis for the speed versus impedance was used to derive equations for the calculation of average speed and maximum speed along both developed and undeveloped road sections. In order to use the average and maximum speed equations, it was necessary to know the numbers of turns along a road section. Seven equations were used to predict the turning movements for specific businesses (service stations, supermarkets, restaurants, cafes and drive-ins, grocery and grocery-service stations, furniture and restaurant supply stores, and

miscellaneous business). These equations relate the number of turns to the specific business income and the street traffic volume, both over a specific time interval. A comparison was made between theoretical estimates and data collected during field studies of right and left turns, average speed, and maximum speed. From this comparison, the following conclusions were drawn:

1. The equation of average and maximum speeds for developed and undeveloped sections are adequate for predicting these speeds.
2. The seven turning movement equations can be used to predict, within a reasonable degree of accuracy, the number of turns to be expected at any of the seven types of businesses.
3. The percentage distribution of occurrence of the eight types of impedance and the speed and delay characteristics for each type are essentially the same for any developed section of highway similar to the study sections.

Klar, Herbert J. . Designing Safe and Efficient High Volume Driveways and Intersections. Traffic Engineering, January 1973, pp. 32-37.

Safe and efficient signalized driveway designs are discussed. The designs are predicated on two principles: (1) that only two-phase signal equipment of the actuated type is needed; and (2) that all roadways providing access to the large traffic generator will be initially or eventually converted to at least four-lane divided operation in the vicinity of the complex. Actuated signal equipment, generally of the semi-actuated type, reduces the main artery "red" to a minimum and displays it only when needed by a waiting and conflicting pedestrian or vehicle. Four or more lanes of divided roadway with a center island width sufficient to permit pedestrians to stand comfortably in the island area or to permit the use of protected two-lane left turn slots gives the roadway the characteristics of two one-way streets a block apart, with the width (length) of the block ranging between 20 and 36 feet, depending on the pedestrian area and/or the number of left turn lanes required. Several different fundamental designs are discussed as well as illustrated.

These include the following:

1. Pedestrian crossings;
2. Simple "tee" type driveway;
3. English style "tee" type driveway;
4. Double "tee" type driveways;
5. Separate entrance - exit driveways; and
6. Double left turn with "U" turn.

McConnell, W. A. and Bauer, L. A. Passenger Car Overhang and Underclearance as Related to Driveway Design Profile: Volumes I and II. Highway Research Board Bulletin 195, National Academy of Sciences, National Research Council. Washington, D. C., 1958, pp. 14-29.

Section I of this report documents an investigation carried out to examine trends in the dimensions of underclearances of vehicles. This investigation revealed that the changes in underclearances over the past ten years have been fairly insignificant and that cars are reaching the minimum clearances which will allow them to operate on existing streets. Improvements in vehicle suspension systems seem to have had the most effect in reducing the underclearances and the margins necessary for jounce and dive. Three clearances and three angles were measured for four loadings or vehicle responses. The angles and clearances were:

1. front clearance
2. approach angle
3. center clearance
4. ramp angle
5. rear clearance
6. departure angle

The loadings or vehicle responses were normal load, front dive, rear jounce and full jounce. From the measurements of this study it was possible to establish the vertical radius between the roadway and driveway to permit smooth entry. It was also possible to determine the vertical radius required at the break-over point of a driveway.

Section II deals more specifically with the grades necessary to allow a vehicle to enter and proceed down the driveway with the least amount of interference. The authors suggest some of the major problems and a set of percent slopes which makes a driveway operate efficiently.

McGuirk, William W. Evaluation of Factors Influencing Driveway Accidents. Joint Highway Research Project, File 8-S-16, Project C-36-59P. May 3, 1973, pp. 1-130.

This research study was undertaken to examine the significance of driveway accidents on urban arterial highways to(1) examine the relationship between the driveway accident rate and the average spacing between an adjacent intersection leg, and(2) reveal those characteristics of the roadway and its abutting environment having the most significant effect upon the driveway accident rate. The overall objective was to disclose factors which, when properly employed, will serve to effect a significant reduction in the driveway accident rate.

The accident characteristics determined by this study of 100 Indiana roadway sections were found to be comparable to the findings published by Paul Box in his earlier driveway accident studies. Driveway accidents represented 13.9 percent of all traffic accidents on the selected roadway sections. The fewest number of accidents occurred on Sunday, while a significantly higher number occurred on Fridays and Saturdays. There were no recorded fatalities from a driveway accident during the four year study; however, 14.4 percent of the accidents did result in some type of personal injury. Left turn movements, to or from a driveway, resulted in 64.6 percent of all driveway accidents and 76.0 percent of driveway injury accidents. 53.5 percent of the driveway accidents involved vehicles entering a driveway, and 43.5 percent involved vehicles leaving a driveway. Obscured vision was found to be a significant factor in 13.5 percent of all reported driveway accidents.

The reduction of the statistical data mentioned above, combined with other data collected during the study, brought about the following conclusions:

1. The driveway accident rate was found to decrease when the average spacing (over a section of arterial highway) between adjacent driveways increases.
2. The driveway accident rate was found to decrease when the average spacing (over a section of arterial highway) between driveways and adjacent intersection legs increases.

3. The number of accidents will decrease when one or more of the following variables is influenced in the prescribed manner:
 - 1) the number of commercial driveways per mile is reduced;
 - 2) the number of through traffic lanes is reduced;
 - 3) the number of total intersections per mile is reduced;
 - 4) the number of total driveways per mile is reduced; and/or
 - 5) the arterial highway ADT is reduced.

The above variables are listed in order of decreasing influence on a highway section's driveway accident rate (accidents/mile/year).

McQuirk, William W. and Satterly, Gilbert T., Jr. Evaluation of Factors Influencing Driveway Accidents. Transportation Research Record 601, 1976, pp. 66-72.

Full control of access will lower the number of accidents that occur on urban arterial highways. However, both land access and traffic movement must be allowed on this type of facility, so the causes of resulting traffic accidents must be identified and the deficiencies must be corrected. Although driveway related accidents account for almost 14 percent of the total arterial highway traffic accidents, relatively little has been written to identify their major causes. Based on data from 10 central Indiana cities, it is shown that the driveway accident rates tend to decrease as the spacings between driveways or driveways and adjacent intersections increase.

Multiple regression analysis was used to develop a series of mathematical models relating the driveway accident rate to the physical and environmental features and the traffic characteristics of the roadway. These models can be used to predict the driveway accident rate on different types of facilities. This procedure reveals that driveway accident rates decrease as the number of commercial driveways per mile decreases, as the number of through traffic lanes decreases, as the number of total intersections per mile increases, as the number of total driveways per mile decreases, and as the traffic volume on the arterial highway decreases. The models indicate that each commercial driveway to an arterial street adds between 0.1 and 0.5 driveway accidents per year, depending primarily on the ADT and the number of traffic lanes on the arterial.

The results of this study provide the engineer or public official with tools to better identify the circumstances related to driveway accidents, to predict driveway accident rates, and to estimate the effectiveness of measures to reduce such accidents.

McReynolds, Marshall B. and Hanna, John T. Driveway Control in Richmond, Virginia. Traffic Engineering, October 1950, pp. 11-12.

Prior to 1948, the city of Richmond, Virginia had little control over driveway construction from a traffic engineering and safety standpoint. In 1948, however, the city adopted a driveway policy as a means of curtailing repetition of the undesirable traffic conditions being created by the misuse of access points to and from city streets. A few of the basic guidelines outlined in the policy statement were as follows:

1. The maximum width of any driveway should be 35 feet. This width accommodates vehicles of the maximum length authorized by the Virginia State Motor Code at the most desirable speeds.
2. Curb lengths should be provided in multiples of 20 feet between driveways. This permits passenger vehicles to park at the curb between driveways without blocking the driveways and thereby restricting their usage.
3. Driveways to public off-street parking facilities should meet the following design standards.
 - a. Entrance only driveway width -- 18 feet
 - b. Exit only driveway width -- 16 feet
 - c. Combined entrance and exit driveway width -- 24 feet
4. Driveways which are intended to serve as an entrance only or exit only drive should be appropriately signed by and at the expense of the property owner.
5. Whenever feasible, driveways should be constructed on the minor street.
6. When granting driveways to provide access to large off-street parking facilities located on property abutting intersecting streets, the entrance only driveways should be established on the major street frontage and combined entrance and exit driveways on the minor street frontage. Experience shows that vehicles can not egress safely in a reasonable period of time on a major arterial thoroughfare.
7. Driveways located near intersections should begin a minimum distance of 5 feet from the intersecting property line or curb return, whichever is greatest. This provides an area on the sidewalk for future installation of traffic control signs and signals, street lights, fire alarms, and fire hydrants.

8. Driveways to parking facilities should be located a minimum distance of 25 feet from street intersection property lines. Mid-block construction of driveways is encouraged.
9. Residential driveways were established to be a uniform width of 12 feet. Wherever suitable, abutting alleys have been provided at public expense by the city; their use for access to residential property is encouraged.
10. Where driveways are granted on residential streets, the property owner is requested to provide an off-street cul-de-sac to permit vehicles to egress forward into the street from the driveways.

Marconi, William. Driveway Accidents in San Francisco. Traffic Engineering, January, 1967, pp. 45-47.

San Francisco's driveway accident experience during 1964 is examined. Of the 21,400 recorded accidents, 282 (1.3%) were directly associated with a movement into or out of a driveway; however, accident records did not indicate the number of accidents caused by, but not involving, vehicles entering or leaving driveways. Of drivers involved in the 282 driveway-related accidents, 67% were leaving and 18% were entering driveways. The action of the remainder of the drivers (15%) was unknown. About 50% of the reported accidents occurred at home driveways, while parking lots, gas stations, truck loading facilities and drive-ins accounted for the rest. For this reason, about 50% of the accidents occurred at driveways which were less than 14 feet wide (typical home driveway width). On a rate basis, gas stations and parking facility driveways were found to be no more hazardous than home driveways. The author concludes that in built-up urban areas where speeds are low, driveway accidents do not appear to be an important factor in the total accident picture.

Marks, Harold. Protection of Highway Utility. Highway Research Board. NCHRP Report 121, 1971, pp. 1-15.

This report covers phase two of a two part effort which had the objective of identifying and analyzing the relationships between transportation facilities and land use. The purpose of the study was to recommend principles and guidelines for developing land use controls and other techniques that would be effective in the protection of highway utility. The research effort was conceptual in nature and presents a variety of ideas and proposals by which utility can be protected. The resulting guidelines and recommendation can be incorporated into the procedures and practice of land use and highway administration.

Phase one of the study, published as NCHRP Report 31, identified eight primary problem areas. Three of these problem areas are directly related to land access as well as land use; they are:

1. The problem of the all purpose street that attempts to serve all movement access and service functions.
2. The problem of excessive conflicts between access demand and traffic movement requirements.
3. The problem of intersectional bottlenecks created by inadequate intersection capacities.

This last problem relates to the access question since driveways can be viewed as a minor intersection (or major one, at large traffic generators). Phase two of the study begins to set out recommendations on how to solve these problems. These recommendations fall into various categories such as: traffic generation, functional classification, access design, arterial design, transportation-corridor capacity, freeway interchanges and land use controls. Because of the diversity of the problems and recommended solutions, the study suggests that a multi-disciplinary approach be used, trying to obtain good planning from both areas of land use and highway administration. There are very few technological problems hampering the solution of these problem areas; however, there are some major policy problems to overcome.

Marks, Harold. Traffic Circulation Planning for Communities. Motor Vehicle Manufacturers Association, Inc., 1974, pp. 232-253.

The functional classification system for roadways categorizes streets in terms of their relationship to the movement of through traffic or the access to adjacent land. Primary and secondary arterials function to move through traffic, while collectors and local streets function to allow access to property. Therefore, access control along arterials is critical in order to reduce congestion and side friction. The major factors that cities need to control are access point spacing and driveway design. Driveway design standards are often written such that they do not recognize the difference between public and private driveways; therefore, a commercial driveway might be designed to the same criteria as a single-family residential driveway.

Since each driveway or access point is like an intersection, access point spacing must be integrated into the street system intersection spacing. There are five major objectives involved in access point spacing:

1. Intersection Safety - Maximum intersection safety is achieved by concentrating vehicle and pedestrian cross traffic at signal-controlled intersections of major streets and highways. Crossing at an intermediate point (mid-block crossing) is hazardous because traffic gaps are minimal and the continuous flow of vehicles presents a formidable barrier.
2. Intersection Spacing - The highest quality of flow for through traffic on an arterial highway would be achieved if there were no driveways and few intersections. A reasonable compromise between the conflicting requirements of mobility and access is achieved by providing the maximum degree of accessibility that does not interfere with through traffic flow.
3. Driveway Spacing - The quality of accessibility is not measured by the number of driveways. A multiplicity of driveways results in traffic control anarchy and traffic turbulence. Good accessibility can be obtained by concentrating traffic/access conflicts at specific points that can be efficiently controlled and regulated.
4. Spacing Variations - Although it is generally the case that the highest through volume is desired, sometimes the through traffic flow is low and more access can be allowed. If concentrations of access traffic are heavy, it may be very difficult to accommodate all of the turning movements at widely

spaced intervals. In these cases, more frequent spacing of access points may increase the traffic flow by allowing more gaps for turning traffic.

5. Directional Driveways - Directional driveways limit some of the turning movements into or out of a parcel of property. Directional driveways are best when used at large traffic generators where it is relatively easy to predict specific needs and operational characteristics.

The primary objective in designing site access is to provide an opportunity for both left and right turns at the entrances and exits. The most critical element is the available frontage length (so driveways can be located an appropriate distance from major intersections). The development of one quadrant at an intersection is more likely to offer these opportunities than the development of several sites in adjoining corner quadrants. Small sites dilute the traffic volumes at each driveway, but create more conflict points for the arterial. The larger site allows for better driveway and access design.

May, John J. A Determination of an Accident Prone Location - A Statistical Method. Traffic Engineering, February 1964, pp. 25-28.

A statistical method of identifying an accident-prone location, be it a highway intersection or a section of open highway, is presented. The method compares accident rates with the traffic volumes for series of highway intersections or sections, and based on this comparison, a regression line which predicts accident rates is computed. The accident rates are defined as accidents per million vehicles per year at intersections and accidents per hundred million vehicle miles per year on sections of open highway. A location (intersection or section) is identified as accident prone if its rate is greater than one standard deviation above the regression line.

The regression lines developed for both intersection accidents and accidents on the open highway show that, with an increase in traffic volumes, there is an associated increase in accident rates. Accident statistics collected during a thirteen year period (1949 through 1961) on the rural state highway system in the State of Illinois were used to develop this paper.

The author also shows that a three year accident history is the minimum needed to justify making improvements based on accident experience. Little accuracy can be gained by using a longer study period.

Schoppert, David W. Traffic Control and Roadway Elements - Their Relationship to Highway Safety. The Automotive Safety Foundation, 1963, pp. 65.

A driveway is, in effect, a low volume intersection and as such has an accident potential which should be measurable. Studies have found that driveways contribute to accident totals out of all proportion to the volume of traffic they serve. Certainly, these findings point out the wisdom of using service roads to collect driveway traffic and introduce it into the highway at selected points. In Los Angeles County, roadway sections with direct driveway connections had 58 accidents over a three year period, while comparable sections with service roads had only 9.

In addition to the use of service roads, it is common practice to limit the width of driveways, particularly those serving roadside businesses along major highways. Most municipal and state highway departments have established regulatory guidelines for the width and design of commercial driveway entrances. Apparently these have been developed from experience because research findings comparing accident rates for one width or style with another are inconclusive.

Staffield, Paul R. Accidents Related to Access Points and Advertising Signs. Traffic Quarterly, January 1953, pp. 59-74.

In cooperation with the Bureau of Public Roads, Minnesota undertook a study to determine the degree of relationship that exists between highway accidents and geometric design features. The study analyzed 713 accidents that occurred during 1948 and 1949 on 420 miles of two-lane highway (U.S. 52) which carried fewer than 5000 vehicles per day. Access points were one of the roadside features on which information was obtained. Any location at which access to the study roadway was provided was considered to be an access point. Field entrances, together with access points serving farm dwellings, accounted for nearly 72 percent of the total number of access points.

Accident rates increased as the number of access points per mile increased. Accident rates for sections without access points and for sections with access points serving non-commercial activities were not significantly different. This would seem to indicate that access points used relatively infrequently do not make a major contribution to the accident potential of a rural road section. However, the accident rates for the sections with access points serving commercial activities were twice as great as the rates for the other groups. This difference reflects the greater frequency of use of the access points serving commercial activities. The increased turning movements out of and into the through traffic stream create conditions of hazard which may be continuously present at such locations.

Frequent driveways, intended to give optional and ready access (but are too often poorly designed and maintained), provide numerous points of possible interference with the through traffic flow. For example, nearly 16 percent of all the accidents occurred on the 6 percent of the mileage within 300 feet of an access point serving a commercial activity and over 34 percent of the intersectional accidents occurred at the 21 percent of the intersections influenced by roadside commercial activities.

Stover, V. G. Regulation of Access Along Arterials. Texas Transportation Researcher, TTI, October 1969, pp. 3-5.

Major transportation arteries have a service life that is much longer than the geometric design life of the traveled-way. Because of the length of the service life, the land uses around a facility are likely to change, often increasing the volumes beyond the capacity of the roadway. The experience with zoning indicates that this exercise of the police power has little hope for preserving the traffic capability of major roadways. Therefore, guidelines for the location of access points must be developed from the view of the balance between roadway operation and adjacent land use.

A master highway plan based on functional usage should be adopted by each government having administrative responsibility for highways or arterials. A policy on the degree of access control for each functional class should be adopted simultaneously. By adopting such a plan and the accompanying policies, a certain degree of stability is assured to investors and developers in regard to land use along these roadways. However, these stringent policies and standards must be uniformly applied.

Some examples of policies which would maintain stability in regard to access are:

1. No private access shall be allowed along a major arterial unless it is to serve a high volume traffic generator, then it should be located such that it conforms to other intersection spacings.
2. In the consideration of a driveway permit where direct access is requested, a review of the entire site plan should be required in order to determine the effectiveness of the internal circulation system in conjunction with the driveway location and design.
3. Full coordination of all aspects of driveway design and internal circulation can be accomplished by requiring joint driveway and building permits.
4. Driveways are issued use-specific permits which are automatically void if the land use changes. This allows the city a chance to review the new use and its access needs.

In administration of driveway standards and guidelines, it is important to recognize the need to coordinate a two-part review: one by the office of

the traffic or city engineer; the other by the planning and zoning commission. By involving both of these groups, the conflicts between movement and access can be minimized or eliminated.

Stover, V. G. and Goodknight, J. C. Well Designed Access Driveways Improve Traffic Operation and Commerce. Texas Transportation Researcher, TTI, July 1969, pp. 8-11.

This article addresses the problems related to access and the need to implement standards for direct access driveways. Currently, urban arterials serve two conflicting functions: through movement and land access. If uncontrolled, these conflicting functions lead to obsolescence of the arterial, which is detrimental to both the arterial users and property owners. In order to reduce the impact of these conflicting functions, special attention must be paid to the design, location and spacing of driveways.

One way to approach the problems of driveway design and location is to reduce the frequency and severity of driveway accidents. This can be accomplished by:

1. Reducing the speed differential between through vehicles and those using the driveways.
2. Eliminating encroachment of turning vehicles on adjacent lanes.
3. Prohibiting the use of the street as part of the internal circulation system.
4. Providing sufficient space between driveways to avoid conflicts between vehicles using adjacent driveways.
5. Prohibit parking along and backing into arterial streets.

After fulfilling the above criteria and the driveway is in place, then maintenance becomes a critical factor in the efficient operation of the driveway. Problems such as potholes, unpaved sections and other irregularities can seriously impair the operation of the driveway. Many of these problems can be eliminated with controls for construction quality, but maintenance standards are also necessary.

Stover, Virgil G., Adkins, William G., and Goodknight, John C. Guidelines for Medial and Marginal Access Control on Major Roadways. NCHRP 93, 1970, pp. 1-117.

Access control is of principal importance in insuring that an arterial, once constructed and opened to traffic, will continue to have a high traffic movement capability. This document presents two sets of guidelines aimed at achieving a "balance" between the two conflicting functions of land access and through traffic movement along street and highway networks. One set of guidelines addresses the procedural and policy aspects of access control. The other set is concerned with the location, design, and construction of access points. The following summary includes the major points covered in the procedural and policy guidelines:

1. Access control policies and standards imposed on a roadway should be related to the functional classification of the facility.
2. Each jurisdiction should develop and adopt a highway plan of existing and proposed facilities indicating the functional classification of each facility. In conjunction with this, every jurisdiction should adopt a policy on the degree of access control required for each classification.
3. Geometric standards should be adopted concerning location, design, and construction for each functional classification group. The standards should be applied uniformly.
4. Building and driveway (curb cut) permits should be issued jointly and accompanied by an acceptable site development plan. Driveway permits should be issued for a specific land use and voided if the land use changes.
5. Local traffic and planning staff should work directly with the developer in arriving at a mutually agreeable plan for development or redevelopment of a site and the provision of access.

Standards for the location, design and construction of access points should result in minimum interference to through traffic movement. It is important to recognize that driveways are basically intersections; therefore, the criteria relating to intersection design and spacing also

apply to driveway design and spacing. The study makes the following recommendations:

1. Separate right and left turn lanes should be provided at driveways on primary arterials.
2. Medians should be installed on primary arterials.
3. Minimum median width should be 14 feet in the vicinity of signalized locations.
4. All medians should be of the "bullet nose" design.
5. Geometric and construction standards for driveways should encourage proper use by the driver.
6. The driveway, as well as the circulation/parking area, should be properly maintained to reduce the number of accidents.

Specific design, location and cost data are presented in eight appendices. Some of the topics covered are: road user costs, nonuser impact, medial and marginal roadway elements, intersection spacing, current highway practice, direct access driveways and development trends.

Uckotter, D. A. Analysis of Motor Vehicle Accidents at Commercial Driveway Locations. Joint Highway Research Project, Final Report C-36-592, Purdue University, West Lafayette, Indiana, June 1974.

The purpose of this research project was to (1) determine the significance of commercial driveway accidents on arterial highways; (2) examine roadway, driveway and land use characteristics related to driveway accidents, and (3) determine which factors (land use, driveway and/or roadway) have a significant effect on driveway accidents. This study was a continuation of the research project conducted by McGuirk entitled "Evaluation of Factors Influencing Driveway Accidents." The study procedure was similar to that used by McGuirk, with two modifications. First, only commercial driveways were evaluated. Second, the traffic volumes at driveways were included in the list of variables to predict driveway accident rates.

Data necessary for the study were collected for 14 road sections in 5 central Indiana cities over a three year period. Regression analysis was performed to determine what elements would serve as good predictors of driveway accidents. A model was developed to predict the number of driveway accidents per mile per year of a roadway section serving commercial land uses.

One-third of the traffic accidents on the 14 street sections were driveway accidents. This percentage is much higher than indicated by most other recent driveway accident studies; however, when the data were broken down into the various movements (ingress, egress, left and right turns) the percentages reflected those determined by previous studies. Some of the typical data that reinforce the findings of earlier studies by Box and McGuirk are:

1. 91 percent of the accidents resulted in only property damage, while 9 percent involved personal injury;
2. Left turn movements were involved in 63 percent of the total driveway accidents and 71.4 percent of the personal injury accidents.
3. 53.4 percent of the accidents involved vehicles entering driveways, while 43.1 percent of the accidents involved vehicles leaving driveways.

Driveway volume depended upon many factors, including type and intensity of land use. Driveways serving shopping centers and industrial plants had the highest driveway volumes. As expected, the greatest number of accidents occurred at these high volume driveways (i.e., shopping centers, industrial plants, and dining and carry-out restaurants).

The number of driveway accidents tended to increase considerably as driveway volumes increased from 250 to 800 vehicles per day (VPD). Above 800 VPD, the number of driveway accidents was often less than at lower volumes, and increased more slowly with increasing driveway volume. In terms of accidents per 1000 driveway vehicles, accident rates at driveways with high volumes were lower than accident rates at low or medium volume driveways. This type of data supports the premise that driveways experiencing high volumes are generally of better design.

Wolfe, R. I. Effect of Ribbon Development on Traffic Flow. Traffic Quarterly, January 1964, pp. 105-117.

Up to a certain critical point, ribbon development is of very minor consequence as far as quality of traffic service is concerned. Accidents are not appreciably increased in number, nor is the smooth flow of traffic or its speed appreciably impaired. If ribbon development is to be taken into account in highway planning, its character and effect on the quality of traffic service must be given precise, quantitative definition. On the highways studied in Ontario, characteristics of ribbon development include a greater build-up of roadside structures on the right hand side of the roadway leaving large cities, and in neighboring towns, a build-up of structures in the direction of a large city.

It would be desirable to state the effect of ribbon development as a coefficient of roadside friction which would take into account the effects of various combinations of roadside structures on highways of various types. On the 159 roadway sections studied, 14.8 percent of the accidents were attributed to roadside structures. Based on the type and frequency of roadside structures, a multiple regression equation was developed to predict the expected number of accidents on a roadway section. A second effect of ribbon development is the interference with the traffic stream caused by turning movements on to and off of the highway. In the data set, one turn in four or five at a commercial establishment other than a service station caused interference with the through traffic stream.

By using these two factors (predicted accident rate and interference with the traffic stream), a coefficient of roadside friction can be developed. If further work proves this technique to be valid, highway planners may be provided with a two factor coefficient of roadside friction. If either factor approaches a critical value, it will be a signal that remedial action must be taken.

Zimmerman, Mary Ann. A Study of Urban Arterial Design Standards. American Public Works Association, Chicago, Illinois, 1969, pp. 49-52.

This study, conducted by the Institute for Municipal Engineering, looked into the current design standards and practices of 24 states, cities, and counties in the United States. From the data collected, it was evident that the majority of jurisdictions recognized the problems created by side friction associated with access points such as driveways, and that steps are being taken to develop stronger programs of access control. While there was some similarity in the dimensions used by the jurisdictions, there was enough difference to establish general ranges for specific design features. Some of these ranges are exemplified below:

1. Driveway width requirements ranged between a minimum of 10 feet and a maximum of 35 feet at the right-of-way line.
2. Curb radii for driveways varied between 3 and 10 feet.
3. The number of driveways allowed per length of property frontage varied from one driveway for the first 52 feet of frontage, to one driveway for the first 100 feet of frontage. A general rule seemed to be that driveways are not allowed to cover more than 60% of the total property frontage.
4. The distance from an adjacent street intersection is generally measured from the end of the curb return radius and varied from 2 to 45 feet. One city allowed an encroachment of 5 feet into the corner radius if the radius was greater than 30 feet.
5. As a general rule, driveways are not permitted within 5 feet of the property line extension.
6. The minimum allowable spacing between adjacent driveways ranged from 5 feet to 30 feet.

A Policy and Standards For Entrances to State Highways. Public Works, December 1966, pp. 68-70.

Based upon engineering considerations in the public interest, the Massachusetts Department of Public Works has developed and published "definite standards and procedures governing the construction of entrances to State Highways, so as to regulate the traffic thereon, in entering or leaving the highway at any point of access." The fundamental objective of the policy is three-fold: (1) provide maximum protection to the public through the orderly control of traffic movement onto and from the highway; (2) provide a uniform practice throughout the State in the design and construction of entrances and exits; and (3) provide adequate drainage at all times.

Requirements are applicable to all commercial and industrial establishments, service areas and private residences having access to and/or from a state highway. They apply to requirements for drainage, geometric design, signing, types and quality of workmanship, materials used, and work performed in the areas providing ingress and egress to the properties.

To obtain a permit, the property owner must make a written application and submit a complete site plan and drainage details. Design standards are based on the type of road, design speed, and the rights of the highway user and the abutting property owners. No more than two driveways will be permitted for any one property parcel unless there is a clear necessity for additional drives. It is pointed out that one service road connecting with the approved entrance and exit can serve a number of establishments. Driveways are to be located to the best advantage with regard to highway alignment and profile, sight distance, and other factors.

Design standards for several types of driveways are illustrated. Any variation from this policy must be specifically approved by the Traffic Engineering Section of the Massachusetts Department of Public Works.