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Safety Considerations in the Use of On-Street Parking

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The research was intended to examine relations among parking configurations (angle, parallel, or no parking), parking density, traffic flow, street width, pedestrian activity, and highway safety. The variables found in this research to be associated with accident rates include (a) functional classification of streets, (b) parking use, and (c) abutting land use. An important and surprising fact is that parking configuration did not emerge as a variable that in itself was related to accident rate. Increased parking use was found to result in significantly higher accident rates, as many as 900 000 space hours per kilometer per year (1 500 000 space hours per mile per year). Streets abutting land uses that generate high parking turnovers and pedestrian activity have higher accident rates than those abutting lower-intensity land uses. Heavily used parallel-parking areas were found to have accident rates comparable to heavily used high-angle-parking areas. Prohibition of parking resulted in the lowest accident rates measured. Parking-related midblock accidents accounted for 49 percent of all accidents along major streets, 68 percent along collector streets, and 72 percent along local streets.

In the early days of urban development, when densities were relatively low, motorists could often park their automobiles on streets near their destinations. As densities have increased, however, curb spaces have become inadequate and parking itself has become a major urban land use. The cost of remaining on-street parking is high in terms of traffic congestion and accidents.

Traffic operations are now commonly evaluated as described by the 1965 Highway Capacity Manual (HCM) (1), which recognizes that curb parking has a significant effect on the capacity and service volumes of highways. The safety aspects of parking practices, however, have not been given equal attention in traffic engineering literature. No widely accepted relations have been identified among parking configurations (diagonal, flat angle, parallel, etc.), parking density, traffic flow, pedestrian activity, and highway safety. The need for such definitions, however, is emphasized by the large number of accidents involving curb parking. One source (2) has estimated that about 20 percent of all urban accidents are related to curb parking. Five primary causes were identified:

1. Vehicles parked in the roadway present obstacles and serve to narrow the usable width of the roadway and to restrict the flow of traffic. Such parking also restricts right-turn movements into and out of side streets, driveways, and alleys. Furthermore, parked vehicles may be struck, or their presence may cause sideswipe or rear-end accidents.
2. Vehicles leaving the parked position disrupt the traffic flow and, by increasing congestion, lead to rear-end and sideswipe collisions.
3. Vehicles entering the parked position frequently require automobiles approaching in the lane adjacent to the parking lane to slow or stop. Parking maneuvers are especially hazardous because they usually involve a backing-and-turning movement. Rear-end and sideswipe collisions can readily result from this maneuver.
4. Drivers or back-seat passengers getting out of parked vehicles on the street side present an added obstacle in the roadway. Not only are the door and the alighting passengers in danger of being struck, but passing traffic may have to swerve or stop suddenly. This causes both rear-end and sideswipe collisions.
5. The sight distance of pedestrians—many of them children—attempting to cross the roadway from between parked vehicles is reduced, and the motorist may not see such pedestrians in time to avoid collision. A danger from impaired view also exists when vehicles are parked close to intersections and driveways. Depending on street grades and speeds, curb parking can create a hazardous sight obstruction if allowed on a major route within even a hundred meters of an egress point.

HCM and other traffic engineering manuals state that parallel parking is the preferred arrangement for any on-street parking adjacent to traveled lanes. The angle-parking alternative has usually been considered undesirable from a safety and capacity standpoint.

The belief that safety and capacity are compromised in the presence of diagonal parking is based on studies from the late 1940s through 1960s and, to a larger degree, on intuitive judgment. However, many early studies of diagonal parking were limited in scope. In particular, Main Street, U.S.A., was almost universally the type of street where diagonal parking was developed and evaluated, but use on local urban residential streets presents a different situation than use on business streets.

An urban pedestrian accident countermeasures study (3) concluded that under certain conditions pedestrian behavior could be favorably modified if parallel parking were replaced by diagonal parking. Crossing pedestrians were reported to have significantly increased their scanning of oncoming traffic at locations where diagonal parking replaced parallel parking. Other favorable behavioral changes were also identified.

Diagonal parking spaces also have the benefit of allowing occupants to enter and exit from the vehicle from either side without entering the traveled way. This and other findings relative to parking arrangements are documented in a Texas study by Zeigler (4), who concluded that flat-angle (22.5°) parking did not affect safety or capacity of the travel lane more adversely than parallel parking.

It should be recognized that, although parallel parking is generally accepted as preferable to the angle layout, there are certain operational disadvantages to this arrangement. The parallel-parking maneuver requires a considerable amount of time and therefore disrupts the flow of traffic. Many drivers are not skillful in the backing maneuver and need to make many tries.

Cities do not have funds to provide adequate off-street parking and to eliminate all curb parking. On the other hand, much curb parking should probably be eliminated because of delay to through traffic and hazards to both pedestrians and vehicles. In addition to roadways in the central business district (CBD), and other major roads, critical areas for parking studies include congested industrial and residential areas.

This study was undertaken because of the lack of widely accepted documented data relating to the safety aspects of on-street vehicle parking, the current involvement of the Federal Highway Administration (FHWA) in reviewing traffic operations on routes other than federally aided primary and secondary highways, and a general need for an evaluation of curb-parking arrangements. Two objects of this study were to determine the safety and operational characteristics of alternatives to curb parking and to develop an unbiased data base on these safety and operational characteristics that would allow comparative analyses of types of parking, operational characteristics, and accident types. Two tasks were included in the study: an on-street parking literature review and accident data collection and analyses.

CURB-PARKING LITERATURE REVIEW

During this study phase, several hundred research reports and technical articles were identified, sixty-five of which included information of specific value. These were abstracted. The following is a summary of some major findings from the literature review.

Overall Parking Accidents

Early data from a sample of 10 large cities revealed that curb-parking accidents represent 5-28 percent of total accidents (5). Later data for one of the largest cities found moving vehicles striking parked vehicles to cause 2 percent of all fatal, 6 percent of all injury, and 26 percent of all property-damage-only accidents in the city (6). A smaller community identified 43 percent of all local- and collector-street accidents to involve curb parking (7). In the same city [see the table below (1 km = 0.62 mile)], frequencies of 8.7 parking accidents/km (14.0/mile) were found on major streets, but only 1.1/km (1.8/mile) on local and collector streets (8).

Street Classification	Average Daily Traffic	Average Trip Length
Major	>5000	1.6 km or more
Collector	1000-4000	0.8 km or less
Local	<1000	Very short

The overall picture of curb-parking accidents, as related in the literature, is grim. This type of collision generally represents about 20-25 percent of urban non-freeway accidents. A significant proportion of these produce injuries. Furthermore, a distinct probability exists that many accidents related to curb parking are not reported as such, because a parked vehicle was not actually contacted (even though it posed a sight restriction).

Angle-Parking Accidents

Studies in nine Utah cities showed that changes from angle to parallel layout were accompanied by a reduction in parking accidents of 57 percent and a 31 percent overall decrease in injury or fatal accidents for the study section (9). A similar study of two business blocks in Salem, Oregon, revealed a 65 percent reduction in parking accidents.

Analysis of accidents in the Abilene, Texas, CBD in the mid-1970s showed average annual accident frequencies of 3.4/street-km (5.4/street-mile) for angle parking versus 0.9/street-km (1.4/street-mile) for parallel parking. When expressed on a rate basis, the angle-parking streets had 176 accidents/million vehicle-km (MVKM) [284 accidents/million vehicle miles (MVM)], compared to 73/MVKM (116/MVM) for parallel parking.

Ten reports on angle parking that represented many times that number of studies were nearly unanimous in finding extremely high frequencies of accidents compared with parallel parking. However, adequate data were not identified to distinguish any differences in accident frequency or rate as a function of varying angles from the curb.

Flat-Angle Parking

A 1971 report challenged the conclusions of many previous studies of angle parking and the assumption that safety and delay characteristics apply equally to all angle-parking arrangements (4). The arrangement tested differs from most angle parking in that the spaces were laid out at an angle of 22.5° to the curb line, as opposed to the more conventional angle. This layout has been called flat-angle parking. The reported operating experience with this parking layout indicated that it offered advantages over typical angle parking and parallel parking. The following conclusions were reported:

1. Flat-angle parking does not adversely affect the safety or capacity of travel lanes when compared with the generally accepted arrangement of parallel parking. This is true, provided that adequate widths for travel lanes are available.
2. Flat-angle parking results in improved safety for pedestrians entering or leaving parked vehicles.
3. Flat-angle parking results in less disruption of traffic flow than does parallel parking.

Based on the generally favorable results of their limited testing of flat-angle parking in Huntsville, the Texas Highway Department in February 1972 submitted a recommendation that a more extensive evaluation of the advantages and disadvantages of flat-angle versus parallel parking be undertaken.

Curb-Parking Policies

The literature indicates that, while evidence concerning the problems created by curb parking has been accumulating, most cities have been taking steps to encourage or force the development of off-street parking facilities through zoning controls. This will take many decades. In the interim, curb parking will continue to exist in commercial and industrial areas, along parts of major street systems, and on practically all local residential streets.

The curb parking policies of the cities, states, and the federal government, as identified in the literature search, may be summarized as follows:

1. High hazard associated with curb parking in general, and especially with angle parking, is understood;
2. The congestion effect of curb parking is of concern;
3. Positive steps are being taken to reduce future curb-parking demand by enactment and enforcement of zoning controls that require off-street parking supply for new developments,
4. Extensive use of rush-hour or total parking prohibitions is being made;
5. Permission for new angle-parking installations is to be refused; and
6. Limited programs that eliminate existing angle parking or convert to parallel parking have been set up.

STREET- AND ACCIDENT-DATA COLLECTION

A second phase of this project was to determine the magnitude and characteristics of accidents occurring on urban streets and to relate these to varying parking configurations, land uses, street widths, and street classifications. Street and accident data were gathered from more than 270 km (170 miles) of urban streets. A summary of collected data follows.

Field Selection Criteria

Cities were identified for study on the basis of the availability of location-specific accident files, study potential (streets of varying widths, land uses, and parking angles), and range of city size. Regions of the country were selected to represent different climatic conditions.

Study sites were chosen in five states and data were collected from 10 cities: Miami, Coral Gables, West Palm Beach, and Clearwater, Florida; Abilene and Wichita Falls, Texas; Tempe, Arizona; Naperville and Skokie, Illinois; and Jackson, Mississippi.

Within each city, specific streets were identified by driving surveys. General development densities of various land uses were noted, as were parking and curb types. Only paved streets were used, and nearly all of them had curbs. Wherever possible, streets with vertical face curbs 10-18 cm (4-7 in) high were selected.

Study streets had generally consistent land use along each side, but some mixtures of different uses on each side were included. Local residential streets absorbing spillover parking from nearby commercial areas were largely avoided. Streets were not studied if changes in surfacing, pavement, or land use were known to have occurred during the study period.

In the residential areas, a selection of property values was attempted; that is, we investigated both those areas with older homes and those in the higher-value subdivisions. A sensible mixture of straight and curvilinear local streets was selected in each area, and the greatest possible range of local street widths was sampled.

Mixtures of cross streets (short blocks) and long streets that had primary home frontage were selected. Also included were locations where each home had a front driveway rather than an alley garage.

Areas ranged from those having practically no curb parking to those having very dense curb parking.

Major routes were selected in terms of varying widths, parking characteristics, land use, and traffic volumes. Both one- and two-way streets were included as were those with and without barrier medians or two-way left-turn lanes.

A fair distance along major routes with curb-parking prohibitions was selected in order to allow for an assessment of the types of accidents and rates typically observed in the absence of curb parking.

Wherever angle parking was available and proper control conditions existed, studies were made of the various angles to the maximum extent possible.

Coding and Field Measurement

Study sections, or blocks, were composed of segments ranging from a single short city block to as many as a dozen continuous blocks of consistent land use, street width, functional classification, traffic volumes, and other characteristics.

The street width in each section was measured, and, for most, the number of legal parking spaces on each side was counted by a driving survey. Allowance was made for clearance from driveways, stop signs, and fire hydrants, in accordance with local practice in each city and with prevailing car sizes. These data, plus information on land use, parking regulations, one- or two-way traffic flow, and median type, were recorded on field sheets.

The section lengths were taken from city maps or plat books. Traffic-volume data were secured where available and averaged as needed to apply to the midyear of the accident study period. In all cases, land uses were taken as a surrogate value for pedestrian traffic counts; i.e., retail, commercial, apartment, and single-family residential uses represent descending magnitudes of pedestrian volume.

Where curb-parking stalls were painted, the pertinent dimensions were measured. At a few locations where no curbing existed but the shoulder areas were paved for direct pull-off, the typical distance from the bumper line of parked cars to the edge of the traveled way was measured. Such parking exists in many areas, but it usually is so irregular and setback variations occur so often—every 50 m or so (100-200 ft)—that no analysis of accident patterns would be meaningful.

Parking Checks

The number of curb-parked automobiles was counted during three time periods on typical weekdays. The midmorning check was taken between 9:00 and 11:30 a.m., the afternoon check between 1:00 and 4:00 p.m., and the night check between midnight and 6:00 a.m.

By using an analysis from previous but unpublished research by Paul C. Box, it was possible to calculate a multiplier factor for residential areas and to develop and estimate the annual space hours of curb parking for each section. The number of vehicles parked in each of the three study periods was summed for each section and multiplied by 9.4 to arrive at the estimated number of daily space hours. This figure was then multiplied by 360 to provide an estimate of the annual space hours.

The annual space-hour estimate for retail areas was developed by multiplying each of the three parking check periods by 8 and summing. This figure in turn was multiplied by 310, making allowance for lower parking demand on Sundays and holidays and correcting for the longer night period represented by the night check, to give an estimate of annual space hours. For example, on some weekdays, retail stores in a given area may close at 6:00 p.m. and on other days remain open until 9:00 p.m. Thus, the length of night parking can last for nearly 12 h instead of 8 h. This is, of course, controlled by the degree to which recreation-oriented curb parking for theaters, bowling alleys, taverns, etc., exists.

Accident-Data Criteria and Coding

Two year-long periods were used as a basic minimum for data collection. However, in a few cases where before-and-after conditions were present, only one year was used for each time period.

The tabulation in all cases came directly from police reports, usually in location-specific files in the traffic engineer's office. In some cases, original police files were found useful. In order to examine the frequency of parking-related intersection accidents as well as midblock and nonparking intersection collisions, data were sampled for all accidents occurring in certain areas. This was done both in business and in local residential areas.

Information obtained from each accident report included the month and year, severity (property damage, injury, or fatality), location (intersection, midblock), type of accident (vehicle-vehicle, vehicle-parked car, etc.), and parking involvement (parking, unparking, opening door, etc.).

Summary of Street Data

Table 1 shows the kilometers of data collected, by city and type of street. The breakout of distances for one-way streets versus two-way streets, by functional classification, is given below (1 km = 0.62 mile).

Street Classification	No. of Street Kilometers: One-Way	Two-Way	Total
Major	17.23	52.13	69.36
Collector	1.88	29.19	31.07
Local	3.20	170.80	174.01
Total	22.31	252.13	274.44

About one-fourth of the major streets selected were one-way. Only 6 percent of the collectors and 2 percent of the local streets we measured were one-way, in consideration of the lower distances traveled on such streets across the country.

The distances for each width, in 0.6-m (2-ft) increments, by functional classification, were also tabulated. Even though the scheduled collection of only 40 km (25 miles) of major street data was increased to 69 km (43 miles), it was still not possible to collect equal quantities of data for each of the numerous widths found in typical American cities. The problem was compounded by necessities for variable land use and parking regulations.

Table 2 shows street kilometers of data collected by land use as related to functional classification. Most sections selected had common land uses on both sides of the street. The 9 percent of distance related to all other uses refers principally to mixed land uses for which we found too small a sample to be analyzed.

Summary of Accident Data

A total of 4804 accidents were tabulated on the inventoried streets of the 10 cities during their respective study periods. Of these, 3594 were either midblock accidents or intersection accidents in which curb parking was considered to have been a factor. The remaining 1210 were intersection accidents not involving curb parking that occurred on selected streets in Miami, Coral Gables, Clearwater, and Abilene. These were streets in areas where all accident data were tabulated—midblock and intersection—in order to derive the ratio of parking-related accidents to total collisions.

Tabulations of these selected data were analyzed to see whether the accident breakdowns obtained in this study were similar to those reported in other research. The proportions of midblock versus intersection accidents by street classification were found to agree well with those of other studies.

After reviewing these initial data, we determined that additional intersection accident data would not be coded unless they were parking related. Thus, all accident data and analyses subsequently presented will include all midblock accidents plus only those intersection accidents considered to be parking related. As previously stated, a total of 3594 of these accidents were identified in the study.

Table 3 shows the tabulation of accidents for all streets (except intersection, non-parking-related collisions) by accident severity, street classification, and parking involvement.

ACCIDENT ANALYSIS

Description of Classification Variables

In order to make comparisons between different locations, the street condition was defined by each of the following factors: (a) street classification, (b) parking arrangement, (c) land use, and (d) parking use. The functional classifications major, collector, and local were also used. Data from these groups were analyzed separately.

Parking arrangements were grouped into six types: no parking, parallel parking, parallel parking with neutral zones (skips), 22.5°-angle parking, 30°-angle parking, and high-angle parking (combining both 45°- and 60°-angle parking). Different parking conditions could prevail on opposite sides of the street, so 15 combinations of these six conditions can be found in the data.

The land uses chosen explicitly for study were retail, office, single-family residential, apartments, motel, industrial, and school or park. Because of limited samples, the last three types were combined into a miscellaneous category. In all, there were 15 combinations of these five types.

Parking use was measured according to the annual space hours per kilometer for each study location. To allow for sampling error and to simplify the analysis, use-level values were assigned one of the four levels below (1 km = 0.62 mile).

Annual Space Hours Occupied per Kilometer (millions)	Parking-Use Level
0-0.6	1
0.6-3.1	2
3.1-6.2	3
>6.2	4

Combining the groups of streets, parking, land use, and parking use results in some 2700 potential configurations. This is approximately three times the number of study locations, and many were not found.

Among the additional factors originally considered for use in the analysis were average daily traffic (ADT), width of street, driving width, one-way or two-way flow, and length of study (in kilometer years) for each location. Except for traffic volume, there were no discernible relations between any of these factors and the accident rate, and thus they were excluded from the analysis.

Response Variables

The response variable originally used with major and collector streets was accidents per million vehicle kilometers (acc/MVKM) [per million miles (acc/MVM)]. Lacking traffic counts for local streets, we chose the response variable originally used for these streets, accidents per kilometer per year (acc/KMY) [per mile per year (acc/MY)].

However, it should be noted that all data collection and analysis were done with customary units of measure. The conversion to metric units was made for purposes of this publication. Any effort to perform additional analysis of these data will require that all data presented be reconverted to customary units before analysis is begun. Since the transformation used in the analysis was made prior to the conversion to metric units, all units in this section on response variables and the included transformation equations are shown in customary units for the sake of clarity.

There were two anomalies in these response variables that must be noted. The first, present in both acc/MVKM and acc/KMY and characteristic of accident data in general, is a proportionality between the mean and the variance of accident-rate sets. This means that, if there are two groups (such as A and B) for which the accident rate was measured, and A had a higher average accident rate than B, then A also had a greater variation among the individual location accident rates than B. This anomaly traditionally requires a transformation on the response variable. The description of the transformation and the rationale behind it follow.

The analysis of variance (ANOVA) technique is based on comparing variances computed in different ways. In an ANOVA, the data are grouped into cells and the variance of the data is computed within each cell; then the variance of the data is computed between the cells by using the cell means. The variance based on the cell mean is then compared with the average of the variances within each cell. If there is a significant difference between the cell means, then these two ways of calculating the variance will yield different values. Because of this comparison procedure, a key assumption is that the variability of the responses within each cell is essentially the same for all cells.

This translates into the requirement that the variation

Table 1. Street kilometers by functional classification and city.

Area	Street Kilometers: Major	Collector	Local	Total
Florida				
Miami and Coral Gables	15.67	0.00	17.31	32.98
West Palm Beach	1.08	5.52	10.42	17.02
Clearwater	10.85	2.67	19.13	32.65
Texas				
Abilene	10.19	3.85	37.22	51.26
Wichita Falls	6.31	1.21	13.27	20.79
Arizona				
Tempe	0.00	15.15	9.64	24.79
Illinois				
Naperville	2.46	0.00	11.51	13.97
Skokie	13.35	0.00	37.51	49.06
Mississippi				
Jackson	9.45	2.67	19.80	31.92
Total	69.36	31.07	174.01	274.44

Note: 1 km = 0.62 mile.

Table 2. Street kilometers by land use and functional classification.

Land Use	Street Kilometers: Major	Collector	Local	Total	Proportion (%)
Retail only	18.86	0.00	0.47	19.33	7
Retail mixed with office, motel, or industrial	5.54	0.34	0.27	6.15	2
Office only	6.39	1.19	1.37	8.95	3
Single-family residential only	18.19	20.59	149.94	188.72	69
Apartment	4.28	2.20	12.88	19.36	7
Apartment mixed with single-family residential	2.88	1.05	4.19	8.12	3
All other	13.22	5.70	4.89	23.81	9
Total	69.36	31.07	174.01	274.44	100

Note: 1 km = 0.62 mile.

Table 3. All midblock and parking-involved accidents by severity, street classification, and parking involvement.

Street Class	Severity: Property Damage Only: Other	Parking Involved	Sub-Total	Injury[a]: Other	Parking Involved	Sub-Total	Combined: Other	Parking Involved	Total	Proportion Parking Involved (%)
Local	133	396	529	37	37	74	170	433	603	72
Collector	60	150	210	15	8	23	75	158	233	68
Major	1094	1229	2323	323	112	435	1417	1341	2758	49
Total	1287	1775	3062	375	157	532	1662	1932	3594	54

[a]One recorded fatal accident on a major street in "other" category.

Figure 1. Mean versus standard deviation for accident rates.

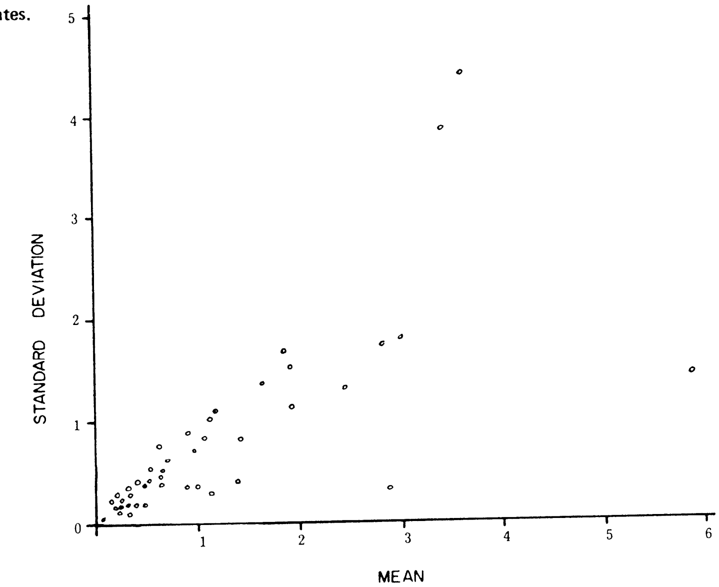
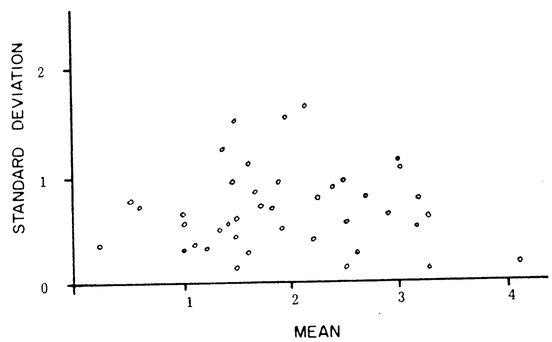


Figure 2. Mean versus standard deviation for transformed accident rate Y.



of accidents per MVKM between locations in a given street group is roughly the same for all different groups. If the variability of the responses in a cell is proportional to the mean response for that cell, and if two cells have different mean responses, then they have different variances. This was the case with the parking study data. It is the average of these different variances that forms the "background noise" against which the difference in the means must be measured. This proportionality between the cell means and the cell variation results in a drastic reduction in the sensitivity of the ANOVA procedure.

For the parking study data (and typically for most accident data) the variation in the accident rate was proportional to the average accident rate when similar locations were considered as a group. For those groupings with more than one location, the group mean is plotted against the group standard deviation, as in Figure 1. The proportionality is clearly seen in the wedge shape of the points in this graph. (If the variation were roughly constant, regardless of the mean, then this graph would show a horizontal band.)

The traditional solution to this problem is to make a nonlinear transformation of the original response variable. By this means, the skewness of the response variable can be minimized, thus stabilizing the variation within each cell while maintaining the intrinsic relation between the individual responses within each cell. For these data, the transformations used were Y = ln (acc/MVKM + 1) and Z = ln (acc/KMY + 1). Figure 2 shows the standard deviation versus the mean for the Y values for each of the groupings used in Figure 1. Here the desired horizontal band is present.

By analyzing the groups with Y or Z as the response, the variability of the response is effectively homogenized for the various groups. This homogeneous variation within each group produced an amount of background noise considerably lower than would have been produced by an analysis that used the untransformed accident rates. Because differences in groups have to be detected in the presence of this background noise, the reduction leads to a more sensitive analysis. For this reason, the responses used in the analysis were the transformed accident rates Y and Z.

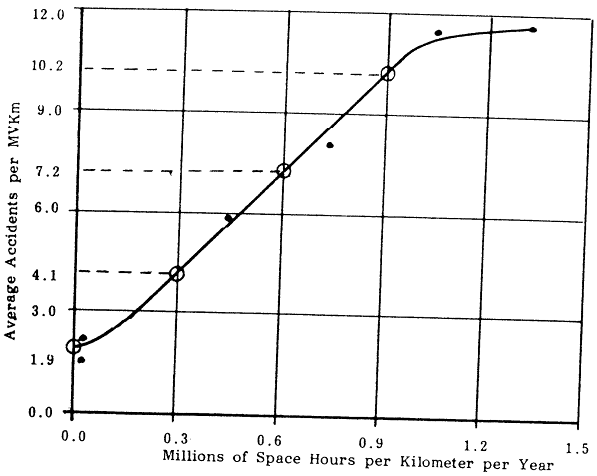
The second anomaly, which occurred only with the acc/MVKM values, consisted of a shift in accident rates with low volumes. For locations of less than 5000 ADT, both the minimum and the maximum accident rates increased as ADT dropped. For those locations of more than 5000 ADT, both the minimum and the maximum accident rates were constant as ADT increased. This problem occurs in both the raw and the transformed rates, which suggests that acc/MVKM cannot be used across all ADT levels for comparisons between locations.

Analysis Procedure

After transforming the response variable, the data were separated according to street classification and each portion was analyzed.

First, those specific comparisons between levels of one factor that could be made while the other factors were held constant were identified. Then, by using ANOVA on different street configurations, these specific comparisons were examined for significance by using a Bonferroni procedure (11). After this, a Scheffé post hoc analysis was performed to look for general patterns of differences among the street configurations. A brief description of these procedures follows.

Figure 3. Accident rates versus parking use on major streets for all land uses.



Bonferroni Procedure

The Bonferroni procedure is a modification of variance that allows specific comparisons, planned in advance, to be made. Because these comparisons may not be independent of each other, an adjustment is made in the effective significance level used for each comparison. Specifically, a sum of squares with one degree of freedom is calculated for each comparison. When divided by the mean square error term from the overall ANOVA, the resulting statistic follows an F-distribution under the null hypothesis. This statistic is then compared with the critical point from the appropriate F-distribution by using a significance level of alpha.

As these tests are carried out on the individual comparisons, the probability of a type 1 error increases. Moreover, the dependence of the various comparisons makes it impossible to calculate a true overall alpha level, although an upper bound on this level may be found by simply summing the alpha values of the individual tests.

Scheffé Procedure

The Scheffé procedure is a post hoc procedure that allows questions to be asked after the preliminary analysis of the data has been completed. In effect, any comparisons of cells or any comparison between different collections of cells may be made. For any one comparison a sum of squares is obtained as before, and this is compared with a critical value based on an F-distribution. The Scheffé procedure differs from the Bonferroni procedure in the way in which the critical value is calculated. This value is inflated to give a true overall significance level (equal to the specified value) when all possible comparisons are simultaneously considered. If only a few comparisons are to be made, this procedure is very conservative. However, it does have the advantage of allowing the ranking of cell means and of asking specific questions based on these ranked cell means.

The essential conservativeness of the Scheffé procedure means that the results obtained are good, but its sensitivity suffers as a consequence. Thus, it is used in addition to the more sensitive Bonferroni procedure.

Major Street Analysis

Parking Use

The factor showing the greatest effect on accident rate was the parking-use level. All pair-wise comparisons between the four levels of use showed differences significant at the 0.025 level.

The typical pattern of the relation between accident rate and use is summarized below for parallel parking in retail areas (1 km = 0.62 mile).

Parking Use (millions)	No. of Locations	Average Acc/MVKM	Average ADT
0.0	2	1.0	10 800
0.2	6	3.0	16 000
0.5	20	7.0	13 500
1.9	23	8.3	11 500

As use increases, the accident rate also increases. Figure 3 illustrates flattening of the curve at higher levels of use.

Land Use

In examining the effect of land use on accident rate, 16 comparisons were tested. These were chosen out of the 90 or so possible comparisons because of their ease of interpretation. Most of those not examined involved comparisons between nonhomogeneous or nonsimilar land uses or both. Of the comparisons tested, three were significant at the 0.05 level. These are described below.

1. Retail versus office: Sixty retail locations had an average accident rate of 7.3/MVKM (11.8/MVM), and 21 office locations had an average rate of 5.2/MVKM (8.4/MVM). Except for locations with no parking, or with low use, the accident rates for retail land use were always higher than for office use. This is to be expected, considering the higher parking activity associated with retail operations.
2. Retail versus apartment: Sixty-two retail locations had an average accident rate of 6.3/MVKM (10.1/MVM), and 19 apartment streets had an average rate of 3.3 MVKM (5.4/MVM). The results tend to match expectations; i.e., higher accident rates are associated with higher retail parking activity.
3. Miscellaneous versus apartment: Five locations with industrial, motel, or school or park land uses were grouped for comparison with 10 apartment land-use locations. The average accident rates were respectively 6.6 and 2.3 MVKM (10.7 and 3.7/MVM). The higher-activity uses again show higher accident rates.

Parking Arrangements

In examining the effect of parking type on accident rate, some contrasts were feasible. However, these effectively made only 14 basic comparisons, three of which had differences in accident rates significant at the 0.025 level. These are described below; however, in all cases there is an inconsistency in ADT that will be discussed later.

1. No parking versus parallel parking with skips: Data for 17 locations with no parking were compared with two streets with parallel parking and neutral zones, while land use and use level were held constant. The use level of 25 000 annual space hours per kilometer (40 000/mile) for the parallel parking locations was very low relative to other locations. The streets with no

parking had an accident rate of 2.1/MVKM (3.4/MVM), while the ones with parallel parking and neutral zones had an average rate of 8.9/MVKM (14.3/MVM).

2. Parallel parking versus 22.5°-angle parking: The groupings used in this comparison involved 38 locations with parallel parking and 28 locations with 22.5°-angle parking. The locations with parallel parking had an accident rate of 6.6 versus 10.7/MVKM (10.7 versus 17.2/MVM) for streets with 22.5°-angle parking.

3. Angle parking of 22.5° versus 30°: Holding land use and use levels constant provided 22 locations with 22.5°-angle parking and five locations with 30°-angle parking. The locations with 22.5°-angle parking had an average accident rate of 11.7 versus 2.0/MVKM (18.9 versus 3.3/MVM) for the 30°-angle parking. This finding is very surprising.

One hindrance to a straightforward interpretation of these results is that, in each case, the parking type with the higher accident rates has an ADT of 5000 or less. Thus, these differences in parking types are confounded with differences in ADT levels.

To more fully appreciate the ambiguity caused by the low ADT values, the comparison between parallel and high-angle parking may be considered. This comparison involved 51 and 10 locations of average accident rates of 6.2 and 4.7 acc/MVKM (10.0 and 7.6 acc/MVM), respectively. This difference is not significant, and there were no ADT values below 5000. Thus, those comparisons that might have been expected to be significant were not, while those comparisons that might have reasonably been expected not to be significant (such as 22.5°- versus 30°-angle parking) were found to be significant. Moreover, if a significance level of 0.10 is used, then all of the Bonferroni comparisons for parking type that involved ADT less than 5000 would have been significant, while all of those above 5000 would have been insignificant.

The simplest explanation of these results for parking type is that these data do not support the concept that any differences are due to parking type, but rather that those comparisons found to be significant are all attributable to differences in ADT.

The Scheffé analysis only added one detail to the above results. While the general pattern of increasing accident rates that coincided with increasing use levels was again apparent, this relationship did not continue for the higher use levels; for use above 1.5 million, the accident rate was essentially consistent.

Accident Rates for Combinations of Land Uses

In the examination of traffic safety and operations as related to street improvements, the local public agency has only limited control of land use. In most cases, the uses already exist, as does the curb-parking demand, which is a product of inadequate off-street supply. Therefore, it is appropriate to consider which reductions in accident rates might be achieved by a policy of developing additional off-street parking and removing curb parking as part of a general street-improvement program.

Improvements are usually made on major streets. Therefore, acc/MVKM has been combined by land use, as a function of curb-parking use, which is the dominant factor.

Figure 3 shows the combination of all land uses and represents the potential average accident reduction. Note that these are actual rather than transformed rates. The four intercepts noted correspond to use levels of 0.0, 0.3, 0.6, and 0.9 million space hours per kilometer per year. The average effect of prohibiting parking, where existing demand is at these levels, may be directly calculated from the graph. The reduction in the accident rate would amount to 54, 74, and 81 percent, respectively.

Accident rates are often calculated for a route by including intersection accidents. We and other researchers have found that about 40 percent of accidents occur at midblock, so the overall effect of curb-parking prohibition along a street should be a reduction in the rate of approximately 8 percent for 0.3 million use, 29 percent for 0.6 million, and 32 percent for 0.9 million.

Collector-Street Analysis

The number of Bonferroni comparisons that could be made for the collector streets was very small because of the limited number of groupings. Of the parking-type, land-use, and use comparisons available, the only significant difference was found between office and single-family residential land use. The one office location had an accident rate of 15.9/MVKM (25.6/MVM), while the 12 residential locations had an average rate of 0.3/MVKM (0.5/MVM). All locations involved had parallel parking and uses in the range of 0.06-0.31 million annual space hours per kilometer (0.1-0.5 million space-h/mile).

The Scheffé analysis for collector streets divided the 23 different configurations into three groups; the first and last differed significantly at the 0.05 level. The middle group was indistinguishable from either the first or the last group. Table 4 lists the configurations in order of increasing accident rate and identifies the groups.

1. Group 1 contained 25 study locations in 5 different configurations and had average accident rates from 0.0 to 0.9 acc/MVKM (0.0 to 1.5 acc/MVM).

2. Group 2 contained 5 study locations in 4 different configurations and had accident rates from 3.0 to 5.0/MVKM (4.8 to 8.0/MVM). These configurations were indistinguishable from those in group 1 or 3.

3. Group 3 contained 20 study locations in 14 different configurations and had accident rates from 7.9 to 63.0/MVKM (12.7 to 101.5/MVM). Eighteen of these locations had used levels of more than 300 000 annual space hours per kilometer (500 000/mile).

Thus, based on the Scheffé analysis, it can be seen that collector streets with single-family residential land use and low use levels of on-street parking are significantly safer than those with moderate or high use and non-single-family residential land uses. Furthermore, for non-single-family residential land uses, accident rates were somewhat inversely proportional to ADT. Single-family residential data did not show this same dependence on ADT, however.

Local-Street Analysis

Because of a lack of ADT data, the response variable in the local-street analyses was initially taken to be accidents per kilometer per year. Again, to meet the assumptions of the ANOVA technique, a transformation was required. The transformation (customary) used was $Z = \ln(\text{acc/MY} + 1)$. By using Z, selected comparisons were examined by the Bonferroni technique, and then a Scheffé post hoc analysis was carried out to discern overall patterns.

Parking Use

Of the six possible comparisons between use levels, five

Table 4. Configurations ranked by acc/MVKM on collector streets.

Parking Type	Land Use	Parking Use (annual space-h/km 000 000s)	Number of Locations	Average Accidents/ MVKM	Average ADT
Group 1					
Parallel	School and park	0.0	1	0.0	3000
Parallel	School and single-family residential	0.11	2	0.0	3100
Parallel	Single-family residential	0.13	12	0.3	3025
No parking	Retail and apartment	0.00	1	0.8	4300
Parallel	Single-family residential	0.02	9	0.9	2050
Group 2					
Parallel	Single-family residential and apartment	0.14	1	3.0	1500
Parallel	Retail and office	0.14	1	3.9	2700
Parallel	Apartment	0.55	2	5.0	2800
22.5° angle	Office	0.02	1	5.0	1500
Group 3					
Parallel	Office and motel	0.30	1	7.9	2000
Parallel	Retail and apartment	0.71	1	9.3	1200
Parallel	Motel	0.40	1	11.7	2700
Parallel	Apartment	0.88	3	12.2	1170
Parallel with skips	Motel	0.37	1	15.0	2000
Parallel	Office	0.17	1	15.8	3100
Parallel	Office	0.71	1	18.6	1500
Parallel	Office and industry	0.81	1	23.6	1900
High angle	Apartment	1.38	5	25.5	1840
High angle	Retail and apartment	1.16	1	29.6	1600
Parallel and high angle	Office and school	0.61	1	44.8	1000
Parallel one side	Office	0.55	1	52.5	800
Parallel	Office	0.58	1	55.3	600
High angle	Industry	1.60	1	63.0	700

Note: 1 km = 0.62 mile.

were significant at the 0.05 level or better. Once again, as the number of annual space hours per kilometer increased, the accident rate (in accidents per kilometer per year) increased, as shown below (1 km = 0.62 mile).

Parking Use (millions)	No. of Locations	Average Acc/KMY
<0.06	96	0.4
0.06-0.31	217	0.6
0.31-0.62	81	1.3
>1.62	75	2.5

Land Use

There were 10 of these comparisons, of which 7 were not significant. The three comparisons that were significant, however, show single-family residential land use to be safer than retail, apartment, or single-family and apartment land uses, as described below.

1. Retail versus single family: Three locations with retail land use were matched against 306 locations with single-family land use. The retail locations showed an average of 3.5 acc/KMY (5.7 acc/MY), while the single-family locations showed an average of 0.7 acc/KMY (1.1 acc/MY).
2. Single family versus single family and apartment: The 306 single-family locations had an average of 0.7 acc/KMY (1.1 acc/MY), while the 17 locations with a mixture of single-family and apartment land uses had an average of 2.3 acc/KMY (3.7 acc/MY).
3. Single family versus apartment: The 311 locations with single-family residential land use showed an average of 0.7 acc/KMY (1.1 acc/MY) versus 2.9 acc/KMY (4.7 acc/MY) for 54 apartment land-use locations.

Parking Types

The three local-street comparisons made for parking type were (a) parallel one side versus parallel both sides, (b) parallel versus parallel and high angle combined, and (c) parallel versus high angle. None were found to be significant.

The local-street configurations were then ranked according to their acc/KMY and compared by means of a Scheffé post hoc procedure. They could be divided into two groups, which were found to be significantly different at the 0.05 level. The safer group includes all single-family residential land uses, as well as one mixed single-family residential and apartment and some apartment land uses. These latter categories typically had use levels below 300 000 annual space hours per kilometer (500 000/mile). The more dangerous group included retail, office, and apartment land uses, almost all of which had uses above 300 000 annual space hours per kilometer. The general pattern of variation in accident rate with the changes in use and land use is shown in Table 5.

General Results of Analysis

The results suggest the following.

1. Parking use level is a significant factor for all street categories;
   a. No parking is clearly the safest.
   b. For up to approximately 900 000 space hours/KMY (1.5 million/MY), increases in use result in increases in accident rate.
   c. For use beyond that, the accident rate was not found to increase.
   d. The prohibition of curb parking along major streets, where the existing use is about 300 000 space hours/KMY (500 000/MY), could be expected to reduce midblock accident rates by up to 19 percent.
   e. Prohibitions on major streets with use of about 600 000 space hours/KMY (1 000 000/MY) or more could be expected to reduce midblock accident rates by up to 75 percent.

Table 5. Variations in acc/MVKM with changes in parking and land use.

Land Use	Parking Use (annual space-h/km 000 000s)	Number of Locations	Average Accidents/MVKM
Retail	0.159	1	0.0
Retail	0.358	1	8.18
Retail	0.978	1	12.99
Apartment	0.219	3	0.94
Apartment	0.469	9	1.32
Apartment	0.902	38	3.91
Apartment and single-family residential	0.121	3	1.02
Apartment and single-family residential	0.472	6	4.54
Apartment and single-family residential	0.884	8	1.68
Single-family residential	0.158	211	0.56
Single-family residential	0.456	66	1.01
Single-family residential	0.807	29	1.52

Note: 1 km = 0.62 mile.

f. Because midblock accidents were found to typically represent 40 percent of total (intersection plus midblock) collisions, the overall accident rate reduction could be up to 8 percent for the 300 000 space hours/KMY (500 000/MY) use level and up to 30 percent for the 600 000 space hours/KMY (1 000 000/MY) level.

2. For all streets, an increasing accident rate was generally associated with changes
   a. From single-family residential to apartment land use,
   b. From apartment to office land use, and
   c. From office to retail land use; and
   d. Since the above changes suggest increases in parking turnover rates and pedestrian activity, it seems appropriate that increases in these variables would be accompanied by increasing accident rates (i.e., the variables may be considered surrogates for increased turnover).
3. Parking configurations were not found to have any effect on accident rate when use, land use, and type of street were taken into account. The data suggest that any kind of on-street parking is unsafe. The level of use rather than the parking configuration appears to be the key to the midblock accident rate.
4. For parking uses beyond 600 000 space hours/KMY (1 000 000/MY) angle parking is no more hazardous than parallel parking, given similar land uses.

CONCLUSIONS

The research was intended to examine relationships among parking configurations (angle, parallel, or no parking), parking density, traffic flow, street width, pedestrian activity, and road safety.

The variables reported in this paper to be associated with accident rates include (a) functional classification of streets, (b) use of parking, and (c) abutting land use. Of major interest, and most surprising, is the fact that parking configuration did not emerge as a variable that in itself was related to the accident rate.

Increased parking use, i.e., space hours per kilometer per year, was found to result in significantly higher accident rates, up to approximately 900 000/KMY (1 500 000/MY). Streets abutting land uses that generate high parking turnovers and pedestrian activity (land use has been used as a surrogate for pedestrian volumes) have higher accident rates compared with lower-intensity uses. Heavily used parallel parking was found to produce accident rates comparable to heavily used high-angle parking, while a prohibition of parking resulted in the lowest accident rates measured. Parking-related midblock accidents accounted for 49 percent of all accidents along major streets, 68 percent along collector streets, and 72 percent along local streets.

The findings on parking use suggest that future studies of accidents related to parking configuration should include measurement of use. Moreover, studies of the effect of a change of parking in one block should include similar studies simultaneously made for nearby blocks. If a parking prohibition or a reduction of spaces caused by change from angle to parallel results in a higher use in adjacent blocks, accidents on such streets might increase. Thus, the overall impact of a change should be assessed and not just limited to the specific study site.

As a final note, future researchers using accident rate data should be aware of the possible need for a transformation of those data. Careful attention should be given to the statistical inferences underlying any analyses and to the proper techniques to be used in those analyses.

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