Effect of Intersection Congestion on Accident Rates

J. W. HALL AND MARGARITA POLANCO DE HURTADO

Although there is general agreement that accident rates are highest during the periods of the day when traffic volumes are low, the change in accident rates as facilities become more congested is poorly understood. The peak-hour accident rates at several hundred signalized intersections in Albuquerque were examined in relation to their level of congestion, as reflected by volume/capacity (v/c) ratios. Accident rates exhibited a small but significant positive correlation with the amount of entering traffic. On average, intersection accident rates are at a minimum in the range $0.6 \leq v/c \leq 0.8$. However, equations developed for estimating accident rates as a function of v/c had such high standard errors that they could not be used for predictive purposes.

Balancing the competing demands for roadway improvements is a difficult task. As peak-period traffic flows continue to increase, engineers endeavor to improve roadway operation by reducing the extent and duration of congestion while trying to increase safety for all road users. The sets of treatments that can produce smooth traffic flow or improved highway safety are reasonably well established. Operating under financial constraints, however, a traffic engineer may be forced to choose between an expenditure to enhance safety and one to upgrade highway traffic flow. Certain traffic flow improvements may also enhance safety, but little is known about the interaction between safety and traffic flow treatments for roadway sections or spots. This project was undertaken to determine the existence and nature of any relationship between the degree of congestion and the level of safety at urban signalized intersections.

BACKGROUND

The relationship between traffic flow and accident experience is poorly understood, especially under conditions in which traffic flow approaches capacity. There is convincing evidence that accident rates are highest at night, when traffic flows are relatively low. This may be due to sleepy or impaired drivers, the difficulties of driving in the darkness, or the small denominator in the accident rate equation. It is clear, however, that most capacity-type improvements will not be of significant benefit during low-volume nighttime conditions.

The technical literature provides little guidance on what to expect near the other boundary condition, at which the ratio of traffic volume to capacity (v/c) approaches 1. Higher traffic volumes and the larger denominator in the accident rate equation would tend to decrease the accident rate. However, the stop-and-go traffic conditions that prevail as facilities become congested provide many opportunities for collisions. In these situations, improvements to facility capacity would decrease the incidence of stop-and-go driving, but their effect on accident experience is less obvious. One might conclude that a facility with better traffic flow must inherently provide safer operation. Indeed, the 1965 *Highway Capacity Manual* (HCM) stated that level of service (LOS) is "a qualitative measure of the effect of a number of factors, which include speed and travel time, traffic interruptions, freedom to maneuver, safety, driving comfort and convenience, and operating costs" (*1*). However, the manual failed to provide convincing support for this statement.

Realistically, there may be trade-offs between factors that improve traffic flow and those that improve traffic safety. One example comes from the increasingly popular treatments to enhance traffic flow on urban freeways. There is evidence that, other factors being equal, travel lanes 12 ft wide are safer than narrower lanes. It is also clear that a roadway with three 12-ft travel lanes and wide shoulders can be restriped to provide four 11-ft lanes and narrower shoulders. Conventional wisdom suggests that such a change would enhance capacity at the expense of safety. Using procedures of the 1985 HCM, the calculated capacity increases by approximately 28 percent (*2*). However, evaluations of 11 installations of this type found that the accident rate was *reduced* by 33 percent (*3*). Apparently, the reduced stop-and-go driving brought about by the capacity improvement more than counterbalanced the potential detriment to safety associated with narrower lanes. Of course, the real world rarely provides opportunities to evaluate the preferred alternative of changing from three congested 12-ft lanes to four free-flowing 12-ft lanes.

A previous study in New Mexico attempted to identify a relationship between traffic flow and accident rates on rural roads (*4*). The study found that the highest accident rates occurred during the low-volume hours between midnight and 6 a.m. Accident rates on these roads tended to decrease during the higher-volume daytime hours. Traffic volumes at the study sites rarely approached v/c ratios as high as 0.2, so it was not possible to examine highway safety under congested traffic flow conditions. However, a pilot study of four urban intersections, undertaken as part of this project, suggested that accident rates begin to increase at higher v/c ratios.

STUDY PROCEDURE

The current study was undertaken to evaluate the variation in accident rates that accompanies changes in the degree of

J. W. Hall, Department of Civil Engineering, University of New Mexico, Albuquerque, N.M. 87131. M. P. de Hurtado, Department of Civil Engineering, University of Cauca, Popayan, Colombia.

congestion, as reflected by the v/c ratio. To examine the traffic flow–safety relationship over a complete range of v/c ratios, this study was restricted to urban intersections. The initial study plan relied on secondary sources to assemble peak-period traffic volume and accident data for signalized intersections in Albuquerque. With supplementary data necessary to calculate intersection capacity, these data would be used to determine capacity, v/c ratios, and accident rates. It quickly became apparent that the city of Albuquerque had relatively few recent traffic volume counts that would meet the needs of this study. In fall 1989, however, the city initiated a contract with a consultant to collect peak-period traffic volumes and capacity information at approximately 445 signalized intersections; these data were made available to this project.

An accident analysis for Bernalillo County, which includes Albuquerque, was undertaken to assess the variation in crash experience by hour of day and to determine other crash characteristics of general interest. During 1987–1989, there were 65,500 reported traffic accidents in the county; 98 percent of these were in Albuquerque. The morning and evening peak traffic periods (7:00 to 9:00 a.m. and 4:00 to 6:00 p.m.) accounted for 28 percent of all accidents. In Albuquerque, 36 percent of the crashes occurred at intersections and an additional 25 percent were described as intersection-related (occurring within 200 ft of an intersection).

The data bases that emerged from the collective efforts of the researchers and the city's consultant consisted of the following:

1. A listing of 1987–1989 Albuquerque intersection and intersection-related traffic accidents during weekday peak periods; the data included single- and multiple-vehicle accidents and pedestrian accidents. The data base was subsequently restricted to crashes at signalized intersections during the morning and evening peak hours.
2. The 1990 weekday peak-hour intersection volumes for all of these intersections.
3. The morning and evening peak-hour v/c ratios for each signalized intersection, calculated using the procedures of the 1985 HCM and the design and operational characteristics of the individual intersections (*2*).
4. Morning and evening peak-hour accident rates for each intersection, using the peak-hour accident and traffic volume data just described.

A preliminary screening of the traffic volume, v/c, and accident data bases identified several problems that led to the exclusion of certain observations from the subsequent analysis. Several traffic signals, primarily near shopping centers, operate in a flashing mode during the morning peak and in a normal mode during the afternoon peak; to make the samples comparable, these intersections were excluded. Approximately 40 intersections had traffic signals installed between 1987 and 1989, but because the volume data collected in 1989–1990 may not reflect the conditions at these intersections over the analysis period, these intersections were also dropped from consideration. Finally, intersections of city streets and freeway on- and off-ramps were excluded; volume data for these locations appear to be reliable, but experience has shown that computerized accident location information for these sites is often incorrect. These exclusions reduced the sample size to 326 signalized intersections.

CHARACTERISTICS OF DATA BASES

The accident record file does not identify all signalized intersections, so it was necessary to match the traffic volume file with the intersection accident data base manually to determine the number of weekday accidents occurring at each location during its morning and evening peak hours. The resultant information (consisting of the entering volumes, the estimated entering traffic for the 3-year study period, the number of accidents, and the v/c ratios) was summarized on separate spreadsheets for the morning and evening peak hours.

The signalized intersections considered encompass a wide variety of design and operational characteristics. Speed limits on the approaches vary from 25 to 50 mph. The approaches themselves range from single lanes shared by through, left-turn, and right-turn traffic to those with multiple through lanes, dual left-turn lanes, and exclusive right-turn lanes. In accord with the traffic volume counting techniques used by the consultant, the 60-min peak hours could begin at any 15-min interval between 7:00 and 8:00 in the morning and 4:00 and 5:00 in the afternoon. The most common peak-hour beginning times were 7:15 and 7:30 a.m. (each accounting for 40 percent of the morning peak hours) and 4:30 p.m. (half of the afternoon peak hours). Table 1 shows the average and range of values for the peak-hour entering volume on all approaches, the peak-hour accidents, and the accident rate per million entering vehicles (mev).

A surprising number of sites had no peak-hour traffic accidents in or within 200 ft of the signalized intersection during the entire study period. Of the 326 intersections, 60 (18 percent) had no accidents during the morning peak hour and 45 (14 percent) had no accidents during the evening peak hour. Overall, the sites averaged 2.7 accidents during the morning peak hour and 3.9 accidents during the evening peak hour. The signalized intersection accidents in this sample account for about 27 percent of Albuquerque's non-Interstate accidents during the morning and evening peak hours.

PRELIMINARY ANALYSES

The initial step in the analysis compared an intersection's peak-hour crash frequency with its entering volume during the same hour. Both the number of accidents and entering traffic volume are discrete variables, but volume, which ranges

TABLE 1 Peak-Hour Characteristics of 326 Study Intersections

	Morning	Evening
Entering Volume (vph)		
Lowest	209	309
Average	2240	2840
Highest	5877	7474
Accidents		
Lowest	0	0
Average	2.7	3.9
Highest	14	27
Total Accidents	890	1274
Accident Rate (per mev)		
Lowest	0.00	0.00
Average	1.56	1.76
Highest	5.85	14.41

from 200 to 7,500 vehicles per hour, effectively behaves like a continuous variable. Figure 1 plots the 3-year accident frequency as a function of entering traffic volumes for the morning peak hour. The plot clearly demonstrates the discrete nature of the accident frequency in comparison with the continuous nature of the volume variable. The figure includes a least-squares regression line relating entering traffic volume to accident frequency. This line was forced to go through the origin because the calculated intercept value was not significantly different from zero. Predictably, this line shows that crash frequency increases with higher entering traffic volumes; the plot for the evening peak hour is similar. The equations relating accident frequency (A) to peak-hour volume (V) are as follows:

Morning:

$$A = +1.26 * V/1{,}000 \tag{1}$$

Evening:

$$A = +1.44 * V/1{,}000 \tag{2}$$

The r^2-value for Equation 1 is .43, indicating that 43 percent of the observed variation in the number of morning peak-hour accidents is explained (but not necessarily caused) by changes in the entering traffic volume. The corresponding coefficient for the evening peak hour is .38. Both coefficients are statistically significant. Equations 1 and 2 suggest that, on average, the number of peak-hour accidents during a 3-year period will increase by 1.3 to 1.4 for each additional 1,000 vehicles per hour of entering traffic. Although these results are in reasonable agreement with intuition, and the equations provide an indicator of the expected accident changes associated with increases in volume, the scatter exhibited in Figure 1 limits the credibility of such a prediction.

It is potentially more meaningful to examine the variation in signalized intersection accident rates with increases in traffic volume. With the data available to this study, accident rates were calculated on the basis of the number of mev during weekday peak hours over the 3-year study period. As shown in Table 1, peak-hour rates at individual intersections ranged from 0.0 to 5.85 accidents per mev (morning) and 14.41 accidents per mev (evening). Average peak-hour accident rates were 1.56 and 1.76 accidents per mev for the morning and evening, respectively. Although intersection volume data for non–peak hours are not available for comparison, a coarse analysis of Bernalillo County's travel-based accident rate variations with time of day shows that rates during other daytime hours are somewhat lower.

The distribution of morning peak-hour entering traffic volumes and intersection accident rates is presented in Figure 2. Because of the discrete nature of the number of accidents, n, many of the individual data points appear to fall on a family of curves. Assuming 260 weekdays for each of the 3 years in the study period and a peak-hour entering volume of V, the weekday peak-hour accident rate (R) is given by

$$R = (n * 1{,}000{,}000)/(3 * 260 * V) = 1{,}282.05 * n/V \tag{3}$$

For $n = 3$, the accident rate as a function of the entering traffic is given by

$$R = 3{,}846.15/V \tag{4}$$

The relationship in Equation 4 is plotted as a dotted line in Figure 2. The corresponding curves for values of $n \leq 9$ are evident from the data points in the figure. The dashed line toward the bottom of Figure 2 represents the least-squares regression; its small slope (0.00012) is statistically significant ($t = 2.05$). In other words, intersection peak-hour accident rates and the volume of entering traffic are not independent; instead, they have a small positive correlation. The relationship for the evening peak hour is quite similar; the slope of the regression line is 0.00015, and it is significantly different from zero ($t = 2.71$). Statistically, therefore, accident rates do increase as the volume of traffic entering the intersection increases. However, the practical significance is questionable, since the peak-hour intersection accident rate would increase by only 0.12 to 0.15 for every additional 1,000 entering vehicles.

A primary conclusion from this analysis is that little of the variation in intersection peak-hour accident rates can be explained by changes in the amount of entering traffic. Considering the wide differences in the design and operating characteristics of urban intersections, this is not particularly surprising. Nevertheless, it is appropriate to consider other

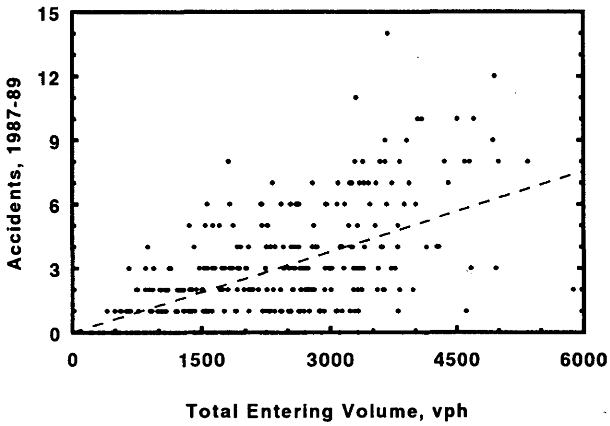

FIGURE 1 Morning peak-hour accidents.

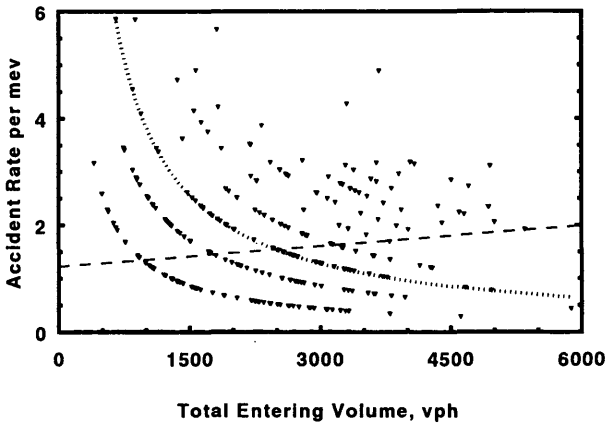

FIGURE 2 Morning peak-hour accident rates.

factors that may account for this variation. As discussed earlier, one factor that may help explain different levels of accident experience at intersections is the amount of intersection congestion, which is reflected by the *v/c* ratio.

INTERSECTION CAPACITY ANALYSIS

The 1985 HCM identifies many variables that can influence the quality of intersection operation, including signal timing, lane width, approach grades, vehicle types, and demand for turning traffic movements. As part of its contract with the city of Albuquerque, the consultant assembled the relevant data at signalized intersections. Certain pieces of information, such as traffic volume, were collected in the field for each intersection. Geometric data were gathered from existing city files, and other data of lesser importance (e.g., percentage of heavy vehicles in the traffic stream) were collected using sampling techniques. The actual analyses were performed using the Highway Capacity Software, a widely used set of computer programs that replicate the analysis procedures of the 1985 HCM.

The intersection of Tramway Boulevard and Manitoba Street in northeast Albuquerque serves as a straightforward example to highlight *v/c* analysis and the effects of traffic growth. This four-leg intersection does not have significant problems with accidents or capacity; however, its relatively simple design facilitates a description of capacity analysis. The intersection has an exclusive left-turn lane and a single through/right-turn lane for north- and southbound traffic on Tramway. The east- and westbound approaches on Manitoba also have two lanes. When the intersection was counted in December 1989, the total entering volume during the evening peak hour was 1,794 vehicles, more than half of which were traveling northbound on Tramway.

The Highway Capacity Software adjusts the individual approach volumes on the basis of such factors as the grade of the approach roadway, the peak-hour factor, and the traffic platoon arrival type; it subsequently calculates measures of performance by lane, lane group, and approach. In 1989 this intersection was operating at LOS A during the evening peak hour, with an average delay of 3.9 sec vehicle and a *v/c* ratio of 0.614. These operating parameters would be considered quite good. As land use in the vicinity continues to develop, however, the peak-hour traffic volume using the Tramway-Manitoba intersection will increase and operating conditions will probably deteriorate. It is difficult to predict precisely how fast the traffic will grow or how the growth will be distributed among the various intersection approaches and movements. For illustrative purposes, the intersection geometrics and signal timing were held constant while the traffic volumes for all movements were increased in 5 percent increments. The capacity analyses were redone for each higher volume level up to a 63 percent increase (total entering volume of 2,925 vehicles per hour), when the intersection was operating at capacity ($v/c = 1.0$ and delay = 65.2 sec vehicle). With progressive increases in volume, the *v/c* ratio increased in a linear manner. On the other hand, the average delay per vehicle exhibited only a moderate increase for volumes up to 30 percent higher than current values; beyond this point, delays increased substantially. The projected changes in *v/c* ratio and delay with increases in entering volume are shown in Figure 3. The dotted lines in the figure represent the limits for LOS ranges.

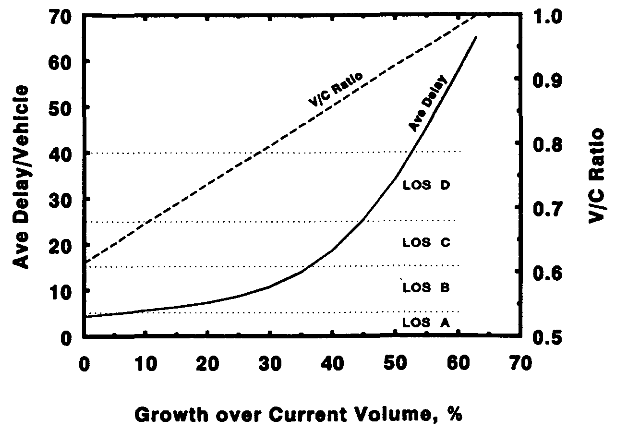

FIGURE 3 Effects of volume increases.

The deterioration in intersection operation at higher volumes is not surprising. Similar results could be expected at more complicated intersections with more lanes and more elaborate signal timing. It is less obvious, however, that according to the techniques of the 1985 HCM, intersection operation can deteriorate significantly with increasing volumes on just a single approach. At the Tramway-Manitoba intersection, for example, if only the northbound volumes are increased by 63 percent while volumes on the other three approaches are held steady, the total volume entering the intersection will increase by 33 percent. If the geometrics and signal timing are held constant, the *v/c* ratio will increase to 0.983 while the average delay will be 64.1 sec—results very close to those obtained for the previous example, even though the total volume is substantially less. This example demonstrates high demand on a single approach can be sufficient to produce a high *v/c* ratio for the entire intersection. In addition, relatively minor changes in signal timing to improve the operation of a high-volume approach (while adversely affecting the other, lower-volume approaches) can significantly reduce the *v/c* ratio and delay for the entire intersection. The sensitivity of *v/c* ratios to these parameters should be kept in mind when interpreting the subsequent analyses of accident rates and congestion.

OPERATION AT HIGH *v/c* RATIOS

In theory, the actual volume entering an intersection should be less than the intersection's capacity. In practice, intersections at which the entering volume exceeds the calculated capacity are routine. These results could be due to one or both of the following factors:

1. Errors in collecting processing data; relatively small data discrepancies can result in sizable changes in the calculated capacity.
2. The inability of the techniques of the 1985 HCM to account properly for all of the parameters that may influence intersection capacity.

Although it is outside this project's scope to resolve either of these potential problems, the fact that peak-hour *v/c* ratios

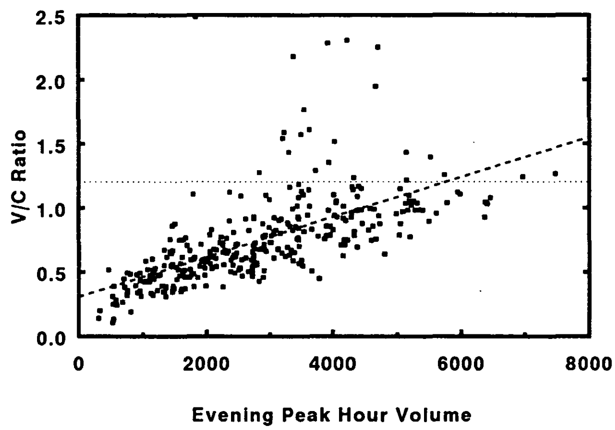

FIGURE 4 Entering volume versus *v/c*.

exceed unity at 10 percent of the Albuquerque study intersections during the morning and at 18 percent of them during the evening suggests that this situation is fairly common. The 1985 HCM indicates that some of its analysis procedures may not produce reliable results when the *v/c* ratio exceeds 1.2.

Before proceeding, it is appropriate to consider how the *v/c* ratio relates to the actual volume of traffic entering an intersection. Ideally, intersections should be designed to accommodate their peak-hour volumes; those with relatively lower demand volumes would have smaller capacities, and those with larger demands would be built and operated to provide greater capacities. Within limits of good design practice, high-volume intersections might use multiple approach lanes, exclusive right-turn lanes, or dual left-turn lanes. If this ideal were achieved, all signalized intersections would provide similar levels of service during peak hours and their *v/c* ratios would be independent of the entering traffic volume. A review of the data, however, found a strong positive correlation between peak-hour entering traffic volumes and *v/c* ratios. Figure 4 shows the distribution of these two parameters during the evening peak hour. The dashed least-squares regression line in the figure has an r^2 of .40, indicating a highly significant relationship between peak-hour volume and *v/c* ratio. In practical terms, this implies that capacity deficiencies rarely exist at moderate-volume intersections but that they are routine at high-volume intersections. Unfortunately, many of the busiest intersections have already been modified to enhance capacity.

Figure 4 also demonstrates the spread of evening peak-hour *v/c* ratios, with values ranging from 0.11 to 2.49. There are 23 intersections with *v/c* ratios greater than 1.20, including five with ratios in excess of 2.0. To avoid the bias that these outliers may introduce into subsequent analyses, and in compliance with the general admonitions in the 1985 HCM, intersections with peak-hour *v/c* ratios greater than 1.2 were deleted from further consideration. The remaining intersections have average *v/c* ratios of 0.60 during the morning peak hour and 0.68 during the evening peak hour.

ACCIDENT RATES AND *v/c* RATIOS

The intersections remaining in the data bases after these deletions had a mean rate of 1.54 accidents per mev and a *v/c* ratio of 0.60 in the morning; the comparable values for the evening were 1.79 and 0.68, respectively. These data support the conclusion that congestion does affect accident rates. Specifically, average accident rates are 16 percent higher in the evening peak hour than in the morning and average *v/c* ratios are 13 percent higher. Because these comparisons involve almost identical sets of intersections, it is tempting to attribute the higher evening accident rates to an increase in congestion. In actuality, however, the difference may be due to other differences, such as changes in human behavior characteristics, between the two peak periods.

The data bases described earlier were used in an effort to identify the existence of a relationship between peak-hour accident rates and intersection congestion. A plot of these variables for the evening peak hours is presented in Figure 5. The scattered data points do not suggest any obvious functional relationship between *v/c* ratios and intersection accident rates. The least-squares linear regression line has a positive slope, but the r^2-value is only .01. Application of least-squares techniques to determine the best quadratic relationship between these parameters yielded a line nearly identical to the linear relationship. Results during the morning peak hours were equally disappointing. These findings indicate that changes in the *v/c* ratio over the range 0 to 1.2 explain a negligible amount of the variation in accident rates.

The difficulty in establishing a functional relationship between *v/c* ratios and accident rates may be partly due to the inclusion of individual intersections that pose absolutely no problem from the perspective of either safety or capacity. Since one of the practical objectives of this research was to help the engineer faced with the dilemma of devoting scarce resources to the improvement of either safety or capacity, it seems reasonable to focus on intersections that may be deficient in either or both of these areas. It is unlikely, for example, that an engineer would undertake safety improvements for an intersection that had no peak-hour accidents during the previous 3-year period or capacity improvements at an intersection operating at LOS A. Near the other extreme, intersections with 10 peak-hour accidents or ones operating at LOS D would be good candidates for further study and possible treatment.

For peak-hour conditions in Albuquerque, the dividing line between safe and unsafe, or between uncongested and congested, is not obvious. The inherent reliability problems of accident-, volume-, and capacity-related data need to be rec-

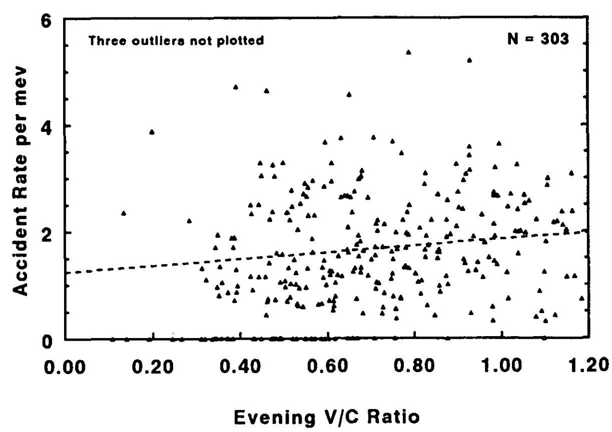

FIGURE 5 Evening *v/c* ratio versus accident rate.

ognized in making such a decision. High thresholds could be used to identify unsafe or congested intersections, but they would overlook sites that are approaching these undesirable conditions. Furthermore, the use of high accident rates or v/c ratios to distinguish good from bad operation would ignore many potentially troublesome locations. To avoid these problems, this project selected threshold values below which there should be universal agreement that the intersection is both safe and uncongested. Specifically, the modified sample was limited to those intersections with more than one peak-hour accident in the past 3 years *or* with a peak-hour v/c ratio greater than 0.5, roughly corresponding to the upper limit of LOS A.

These revised data bases included 242 intersections during the morning peak hour and 254 during the evening peak hour. Attempts to predict accident rates as a function of v/c ratio using linear regression techniques produced encouraging results, but the r^2-values were only $\approx .03$. Preliminary findings from an earlier study had indicated that the accident rates (R) were highest for low and high values of v/c and were lower at intermediate values (*4*). This type of relationship can be modeled with a quadratic equation of the form

$$R = a + b * (v/c) + c * (v/c)^2 \qquad (5)$$

Standard analysis techniques were used to find the best-fit quadratic equations for the morning and evening peak hours. The results were moderately successful; r^2-values were .12 and .09 in the morning and evening, respectively. The plot of evening accident rates as a function of v/c ratios is shown in Figure 6, along with the best-fit quadratic equation indicated by the dashed line. The corresponding morning plot is similar: both quadratic curves indicate a minimum accident rate in the vicinity of a v/c ratio of 0.8, with greater accident rates predicted for both higher and lower values of v/c.

Although the relationships indicated by the quadratic equations are statistically significant, they may have limited practical significance when applied to a particular location. Consider, for example, an intersection with an evening peak-hour v/c ratio of 0.8. Figure 6 shows that existing intersections with v/c ratios of 0.80 ± 0.03 have accident rates ranging from 0.40 to 3.14 per mev. For a v/c ratio of 0.8, the model predicts a rate of 1.33 accidents per mev. An analyst examining a particular intersection should, of course, be able to determine the current values of v/c and R at the location. However, the model provides limited guidance for estimating the accident rate if the v/c ratio is projected to increase in the future. For example, if v/c is predicted to grow from 0.8 to 1.0, the model indicates that, on the average, the accident rate will increase from 1.33 to 1.52 per mev. Unfortunately, the 90 percent confidence interval associated with this prediction is 1.52 ± 1.78, or -0.26 to 3.30 per mev. Thus, whereas the model supports the premise that the anticipated increase in the v/c ratio in this particular range will be accompanied by a higher accident rate, it is clearly not precise enough to use to predict future accident rates.

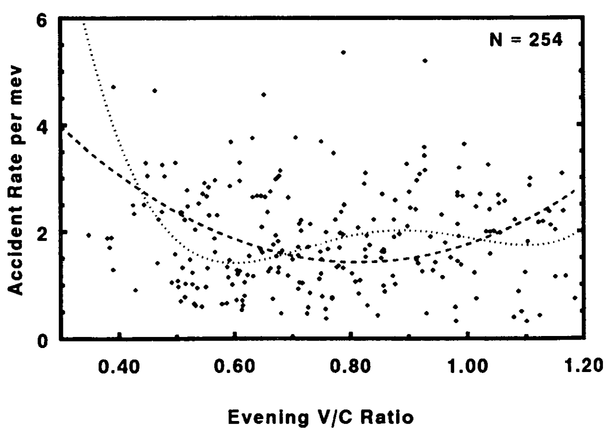

FIGURE 6 Sites with accidents or v/c greater than 0.5.

Given the wide scatter of the data, it is difficult to imagine that a superior (and realistic) model could be developed to describe accident rates as a function of v/c ratios. Nevertheless, from a mathematical perspective, the best-fit line can be improved by incorporating higher-order terms, such as $(v/c)^3$ and $(v/c)^4$, in an expanded version of Equation 5. One effect of adding these higher-order terms is to move the best-fit line "closer" to a greater number of data points, thus improving the r^2-values. Another effect is to increase the number of inflection points along the curve; not surprisingly, this results in a shift of the minimum accident rate to a lower value of v/c. For example, equations incorporating both $(v/c)^3$ and $(v/c)^4$ terms produce the dotted curve in Figure 6, with minimum accident rates in the vicinity of a v/c ratio of 0.6. Without arguing the relative merits of models of the form of Equation 5 versus those containing higher-order terms, it appears realistic to assume that minimum intersection accident rates during peak hours are most likely to occur for operating conditions in the range $0.6 \leq v/c \leq 0.8$.

CONCLUSIONS AND RECOMMENDATIONS

The research described in this report has attempted to develop a relationship between the level of congestion and the peak-hour accident rates at urban signalized intersections. Although this objective was not completely achieved, the project has developed some interesting and potentially useful information related to peak-hour accident experience. The relevant findings apply to peak-hour conditions in Albuquerque but should not be indiscriminately applied to other situations; they include the following:

1. More than 60 percent of the accidents in Albuquerque occur at intersections or are intersection-related.
2. The 60-min periods beginning at 7:15 and 7:30 a.m. each account for 40 percent of the morning peak hours at signalized intersections, and the hour beginning at 4:30 p.m. accounts for more than 50 percent of the evening peak hours.
3. More than a quarter of the peak-hour accidents occur at signalized intersections.
4. Accident rates at signalized intersections average 1.56 and 1.76 per mev during the morning and evening peak hours, respectively.
5. The number of peak-hour accidents at signalized intersections is highly correlated with the number of entering ve-

hicles; the peak-hour accident rate is weakly, but significantly, correlated with the number of entering vehicles.

6. Peak-hour *v/c* ratios vary widely among intersections; these ratios have a significant positive correlation with the volume of entering traffic.

7. Quadratic models explain approximately 10 percent of the observed variation in intersection peak-hour accident rates as a function of *v/c* ratios. However, the models are not sufficiently reliable to serve as predictive tools.

8. Minimum peak-hour accident rates tend to occur within the range $0.6 \leq v/c \leq 0.8$; higher *v/c* ratios tend to be associated with increasing accident rates.

There are several possibilities for extending the work initiated in this project. The project started with 445 signalized intersections, but more than 40 percent of them were dropped from the final analysis for the reasons cited earlier. With additional effort, including the manual review of hard copy accident reports, it might be possible to include some of the deleted intersections on interchange ramps and frontage roads. With the passing of time, it will be possible to include intersections that were signalized during recent years.

The analyses discussed in this report were based on accident information for 1987–1989 and traffic volume information for 1989–1990. Albuquerque plans to update its peak-period traffic volume data base annually by performing additional counts at a sample of intersections. If this is done, it will provide new volume and *v/c* data that could be used to monitor historical trends in the *v/c*–accident rate relationship at particular intersections. Although the sample sizes will be smaller than those available for this study, a detailed examination over time at specific intersections could avoid the influence of other factors, not studied in this project, that may contribute to crash occurrence.

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