- Campbell, B.J. (1994). Relationships Between Traffic Congestion and Safety: A Discussion of Issues and Past Research. Chapel Hill, NC: University of North Carolina Highway Safety Research Center.

RELATIONSHIPS BETWEEN TRAFFIC CONGESTION AND SAFETY: A DISCUSSION OF ISSUES AND PAST RESEARCH

by
B.J. Campbell
UNC Highway Safety Research Center

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Apparently the principal impetus for IVHS is not that of improving safety on the USA highway transportation network, but rather to increase mean operating speed and to increase highway capacity, thus allowing higher volumes without a comparable increase in congestion.

Under historical circumstances, such changes would result in more accidents rather than fewer, and since it is politically difficult to advocate enhanced mobility at the expense of safety, therefore IVHS must necessarily be concerned with the safety implications of measures implemented to improve traffic movement.

Here are some questions as to what might be the expected effect on safety if some of the basic IVHS goals are met.

Question 1. What would be the safety effect if IVHS increases volume without increasing capacity?

The general answer is that increasing volume is associated with increased accidents. In Traffic Control and Roadway Elements: Their Relationship to Highway Safety (Revised); Chapter Two, Traffic Volume, 1969, there is a review of the literature prior to 1969. Several studies address the relationship between accidents and traffic volume as indicted by Average Daily Traffic (ADT). The review states that the best estimate of studies published up to that time is that there is an exponentially increase in accident rate with increasing ADT. This 1969 review demurs from an earlier review (Traffic Control and Roadway Elements: Their Relationship to Highway Safety, 1963) which had indicated a leveling off and decline in accident rate at very high ADT's.

The review points out that such research has certain inherent problems. That is, roadway sections with higher versus lower ADT's may also differ in several respects other than traffic volume. This could include vehicle mix, roadside development, trip purpose, driver characteristics, etc. The thought persists that some of these other factors associated with ADT may have produced the accident trends noted rather than traffic volume per se. When one visualizes low traffic volume, one can imagine a rural facility, where speed can be high and resulting accidents severe -- perhaps single vehicle accidents in many cases. By contrast, when one visualizes high volume, urban areas come to mind, peak-hour driving, multiple-vehicle collisions, often involving rear end collisions, and often of mercifully mild outcome in terms of injury. Thus, one is left to speculate that other factors may mediate the relationship between accident rate and ADT or at least add to it.

Question 2. What would be the safety effect if IVHS increases volume and capacity?

IVHS is intended to do more than just increase volume, it is intended to increase capacity as well. Thus, it is hoped that by use of a number of systems to increase the smoothness of traffic flow, it will be possible to increase the capacity of a given facility without "laying down more concrete". Here it might be well to remind ourselves of the practical meaning of the term capacity. Generally, it is said that the capacity of a free flow rural highway lane is about 2,000 vehicles per hour if 1.5 second headways are maintained.

It is well to remember the obvious fact that lane capacity really addresses the macro characteristics of human behavior rather than anything about fluid flow or particle movement. The number of vehicles that can pass a point in a lane at a given speed is dictated by the headway keeping behavior of the drivers in the system. Drivers seem to usually maintain headways of sufficient time-distance to afford whatever perceived degree of safety they feel is necessary. This limits the number of vehicles that pass a point in a given time. This empirically observed capacity limit is far less than what would be possible if vehicles passed by with zero headway. Then, at 60 mph, the capacity would be about 15,000 vehicles per hour (assuming an average length of 20 ft per vehicle).

Thus, the system actually operates at a capacity that is just a fraction of what is possible, and that large difference amounts to a safety factor imposed by the collective behavior of facility users. This observed operational safety margin is consistent with that urged in safety doctrine. Thus, from introductory driver education onwards, drivers are urged to maintain headways of one car length per 10 mph of speed. This amounts to a headway of about 1.5 seconds. The doctrine also includes the validating rationale that this degree of headway is consonant with the complex reaction time required by the driver to perceive and react to a disruption ahead that requires braking. One wonders whether the prevailing headways are a result of the doctrine, or whether they are an outgrowth of trial and error by road users who formulate headway strategies that meet their requirements for perceived safety, and that this works out to be an amount that fits the doctrine.

In any case, if measures are introduced to increase highway capacity, then the nature of the measures would necessarily be such as to induce drivers to reduce the headway they will accept -- to make drivers feel sufficiently safe that they would "risk" keeping shorter headways. One can imagine the kind of driving environment in which that might happen. One feature would be such that the driver would be able to "see" far enough ahead to have time to lower the speed and thus increase the following distance in time to avoid colliding with the vehicle ahead, and to do so with a sufficiently gradual deceleration that the following vehicle could likewise adjust.

Or one might visualize a system in which braking would begin automatically so that "platoon braking" might occur without materially changing prevailing headways. Another feature of such a system would be that driver experience with the system would inspire confidence that smooth flow is likely to prevail over long periods of time -- flow in which vehicles move at the same speed, there is little lane shifting, and little in the way of longitudinal "compression waves" working back through the traffic stream.

The requirements in these hypothetical situations underline the fact that currently drivers believe that there will be roughness of flow ahead induced by speed changes, lane changes, etc.. Coping with these irregularities requires large headways.

Present literature shows that accidents are complexly related to such changes in traffic density. In fact, the literature on hourly volume and congestion as related to accidents is more instructive to consider than ADT.

In Traffic Control and Roadway Elements: Their Relationship to Highway Safety (Revised); Chapter Two, Traffic Volume, 1969, the review addressed accident rates as a function of hourly traffic volume. Hourly volume is perhaps a better indicator of level of service, and provides a better indication of the relationship between accidents and traffic density and speed. However, the results of such research are mixed. The above review document refers to work by Belmont in 1953. He studied non intersection accidents, during daylight, good weather, on rural two lane tangent sections. He reported that accidents increased in an almost linear fashion up to the level of 650 vehicles per hour -- the point of congestion, apparently, and accidents decreased at volumes above that level. Apparently in that daylight, free flow situation speeds began to drop when "congestion" levels were reached, and accidents then dropped.

Another study, on the New Jersey Turnpike, was not confined just to daytime as was the study by Belmont, but rather covered a 3.3 mile section throughout the 24 hour period. Accident rate (per 100 million vehicle miles of travel) was found to be high -- 400 to 800 accidents per 100 million at volume levels from 250 to 750 per hour. Accidents were lower (about 200 accidents per 100 million) at volumes of 1000 to 2000 per hour. Above 2000 vehicles per hour accidents were higher, reaching the same accident rates seen at the lower traffic volumes. (See Figure 1 reproduced from the above cited document.)

A more recent study provides similar data. It is entitled Accident Analysis on Two Non-Controlled Access National Highways in Greece, 1983.

This study deals with volume, level of service, and accidents on a National Highway in Greece -- the highway from Athens to Corinth. The study showed a U-shaped distribution of accident rate per unit kilometer exposure related to hourly traffic volume. At low volumes -- 500 per hour - the rate was about double the amount at the lowest point on the curve. Accident rate was least at a volume of about 1,500 vehicles per hour. Then the accident rate rises steadily to around 3,500 vehicles per hour, reaching a rate about 50% higher than at the low volume. Then the rate falls again at volume levels above 3,500 vehicles per hour. The accident rate at the highest volume level still exceeded by 10-20% the accident rate at the lowest volume.

As to level of service, the accident rate curve shows an almost linear drop from Level of service A through D -- declining about 25%. The curve rises thereafter through level of service E and F reaching an accident rate at level of service F that is about three times the accident rate of level of service A. (See Figures 2 and 3 reproduced from the above cited document.)

It should be pointed out that the distribution of the <u>time</u> of accident occurrence may be related to traffic volume. On the NJ Turnpike, one would assume that low volume conditions tend to occur at night time -- after midnight perhaps. Given the fact that accident rates are higher at that time, one would hypothesize that factors other than just traffic volume are more important in dictating the high accident rates associated with the low volume levels on the NJ Turnpike. Further, one might assume that the distribution of accident <u>type</u> would differ according to traffic volume. At low volumes, one would assume that accidents are more severe. At higher volumes one might assume that the accidents are perhaps more mild, more rear end, more peak hour related.

A Chicago study reviewed in that article found that on about half the streets studied the accidents increased with volume, but on the other half they did not. A study on the Lodge Freeway in Detroit showed that rear end crashes increased with volume. Thus, the literature does not reveal a simple relationship between accidents and hourly volume. In fact, it is easy to see that <u>other</u> factors mediate the relationship between accidents and volume. A study on the Ford Freeway in Detroit showed that the relationship between accident rate and volume varied considerably according to time of day, with more accidents than volume would predict in the afternoon and fewer accidents than volume would predict during the middle of the day. (See Figure 4 reproduced from the above cited document.)

Note that, back in the 1960's when these studies were conducted, it may be that trip purpose differed greatly by hour, and perhaps also sex of driver. Evening rush hour drivers were probably more frequently male than the total driving population would have indicated, and during the middle of the day, female drivers were probably relatively more in evidence. This could easily account for the accident differences seen at that time 30-40 years ago. One wonders whether the outcome would be different were that study to be replicated today.

From consideration of hourly volumes, it is a short step to consideration of "congestion". Here congestion is defined as the ratio between volume and capacity -- V/C. The 1963 review reports less success among studies that purport to study accidents in relationship to congestion. Some studies tend to support the notion that accident rate increases with congestion, but, as the review document states (page 6), "-- students have directed their attention to this question with a notable lack of success." According to this 1963 review, both Schoppert and Woo "were unable to find a strong correlation between accidents and congestion in studying two lane rural highways. Both used an index compounded of traffic volume and capacity. On the other hand, Rykken in a Minnesota study reported a very good relationship for similar highways." (page 6). (See Figure 5 reproduced from the above cited document.)

Question 3. Does congestion, defined here as the ratio of volume to capacity, absolutely have to increase when the V/C ratio approaches 1.0?

It is a rather compelling notion that the accident situation would change as congestion increases. It seems intuitively obvious that in the face of considerable congestion, most drivers will significantly reduce their speed. Minor accidents, particularly rear end collisions of a chain collision nature, would be thought to increase, and finally traffic would be reduced to a crawl -- where finally both accidents and traffic movement drop to zero.

Before this level of congestion occurs, however, accidents might well be assumed to increase -- this assumed to occur at levels of congestion before speeds drop significantly. However, under an IVHS regime, the very relationship between volume and capacity might change. If the effect of traffic smoothing is to increase both volume and capacity, the nature of the V/C relationship to accidents would have to be empirically determined. If the relationship remains similar, some gain will still have been achieved in that the congestion and its effects would merely be transferred to a higher level. Thus, if capacity is raised to 4,000 vehicles per hour, and volume is increased to 3,000 vehicles, then maybe the relationship between V and C is the same, but now the congestion and its consequences occur at higher volume levels.

IVHS might even change the very nature of the relationship between the two variables. It might be that the system would produce high speed and high volume at near capacity but without appreciable increases in accidents. Perhaps that is precisely what is visualized for an automatic highway. Is it acceptable if, as a result of IVHS, traffic movement is enhanced and accidents increase, but the accidents increase no more than in proportion to the increased traffic movement?

One early "IVHS" system was reported in 1969 concerning a freeway in the vicinity of Houston, Texas (Freeway Operations on the Gulf Freeway Ramp Control System, 1969)

The Gulf Freeway is a major traffic facility for access to Houston, Texas, and this study reported results of equipping a 3.5 mile freeway section with devices such as to permit traffic sensing and computer-controlled ramp metering. This automatic freeway ramp control entered the operational phase during the summer of 1965.

The morning rush hour, addressed in this study, was defined as 6:30-8:30 AM, and the ramp metering process was active from 7:00 to 8:00 AM. Five minute volumes during the period of ramp control were in excess of 430 vehicles per five minutes. The number of lanes is not specified, but one assumes that it might be three lanes in each direction, and presumably these volumes are not per-lane volumes, but rather total roadway volumes in the inbound direction.

Four significant findings were reported and are quoted here from page 25 in that report:

1. Total travel increased by 10% during 6:30-8:30 AM period and 16% during 7:00-8:00 AM period.

2. Average speed during control period increased 12.2 mph to 32.6 mph.

3. Accidents during control decreased 27%. (Reviewer's note: A similar accident decrease was <u>not</u> noted during the other part of the rush hour. Also note that the police there do not report crashes during peak periods. I wonder if that was also true as far back as the late 1960's?)

4. Violation of ramp signals ranged from 1% to 13%.

<u>Question 4. How is increased traffic movement to be defined</u>?

It would be possible to have 1,000 vehicles per hour to move past a point at high speeds in free flow, and to have the same number pass a point at slow speeds during rush hour congestion. So it is not sufficient just to consider the number of vehicles passing a point in a given time.

In physics one usually takes into account both mass and speed in describing a dynamic system. In traffic engineering, volume, traffic density, and speed are inter-related. Speed begins to drop at a certain level of traffic volume or density. Also, density increases past a certain level, traffic volume (i.e., flow through a segment) begins to decrease due to traffic congestion. A key question then is how should we define traffic movement, and what is its accident effect?

References

1. Traffic Control and Roadway Elements: Their Relationship to Highway Safety (Revised); Chapter Two, Traffic Volume: Automotive Safety Foundation, Washington, D.C., 1969.

2. Traffic Control and Roadway Elements: Their Relationship to Highway Safety, The Automotive Safety Foundation, Washington, D.C., 1963.

3. Accident Analysis on Two Non-Controlled Access National Highways in Greece, J. M. Frantzeskakis, ITE Journal, February 1983, pp 26-32.

4. Impact of Passing-Climbing Lanes on Traffic Flow on Upgrades, A. Polus and I. Reshentik, Transportation Research, 1987, Volume 21A, No. 6, pp. 401-410.

5. Multilane Design Alternatives for Improving Suburban Highways, D.W. Harwood, National Cooperative Highway Research Program Report 282, Transportation Research Board, Washington, DC.

6. Freeway Operations on the Gulf Freeway Ramp Control System, Goolsby, M.E. and McCasland, W.R., Research Report 24-25, Study 2-8-61-24, Texas Transportation Institute, Texas A & M University, College Station, Texas, August, 1969.

APPENDIX A - INDIVIDUAL PAPER REVIEWS

1. Traffic Control and Roadway Elements: Their Relationship to Highway Safety (Revised); Chapter Two, Traffic Volume: Automotive Safety Foundation, Washington, D.C., 1969

This document is a review of the literature prior to 1969, and serves to update the chapter on Traffic Volume in the earlier book with the same title and publisher. Several studies are reviewed relative to the relationship between accidents and ADT. The review states that the best estimate of studies up to that point suggests an exponentially increasing accident rate with increasing ADT, and demurs from the earlier indications of a leveling off and decline in accident rate at very high ADT's.

It is noted by this reviewer that an inherent problem in research such as this is that roadway sections with higher versus lower ADT's may differ in several respects in addition to traffic volume (which is ostensibly the independent variable). This could include vehicle mix, roadside development, trip purpose, driver characteristics, etc. One is left with the uneasy thought that some of these other characteristics may have produced the effects noted rather than traffic volume, or at least may have interacted with traffic volume in producing the effect.

The review also includes data which shows that injury does not vary appreciably with ADT. There is no particular reason a priori to expect any kind of relationship unless it be one mediated by speed. However, note that the injury measure is very crude -- the percent of accidents in which anyone in any vehicle is injured. That is a criterion rather easily met in most any kind of accident and, indeed, the curves show that about 50% of the crashes met this criterion. So the measure may not be very sensitive. Also, these studies were carried out in an era in which few of the crashworthiness features, now common in cars, had yet been installed. Further, virtually the entire driving population was unbelted. It may be that results of an identical study would be different today.

The review also addressed accident rates as a function of hourly traffic volume. Hourly volume is probably a better indicator of level of service, and provides a better indication of the relationship between accidents and traffic density and speed. However, the results of such research are quite mixed. The document being reviewed cites work by Belmont in 1953. He studied non intersection accidents, during daylight, good weather, on rural two lane tangent sections. He reported that accidents increased in an almost linear fashion up to the level of 650 vehicles per hour -- the point of congestion, apparently, and accidents decreased at volumes above that level. Apparently in that free flow situation in the daylight, speeds began to drop when congestion levels were reached, and accidents then dropped.

Another study, on the New Jersey Turnpike was not confined just to daytime, but covered a 3.3 mile section throughout the 24 hour periods. Accident rate (accidents per 100 million vehicle miles of travel) was found to be high -- 400 to 800 accidents per 100 million, at volume levels from 250 to 750 per hour, lower (about 200 accidents per 100 million) at volumes of 1,000 to 2,000 per hour, and then higher again above 2,000 per hour, reaching the same higher levels as seen at the lower volumes.

(Note that one may assume that the distribution of times of occurrence and the distribution of accident type differs according to volume. At low volumes one would assume that night accidents predominate, and that accidents are more severe. At higher volumes one might assume that the accidents are more mild, more day time, and more rear end. However the study doesn't say so evidently.)

A Chicago study reviewed found that on about half the streets studied, the accidents increased with volume, but on the other half they did not. A study on the Lodge Freeway in Detroit showed that rear end crashes increased with volume. It is easy to see, however, that other factors mediate the relationship between accidents and volume. A study on the Ford Freeway in Detroit showed that the relationship between accidents and volume varied according to time of day, with more accidents than volume would be predicted in the afternoon and less than volume would be predicted during the middle of the day. It was noted that when hourly volume is high (versus low) it is likely that other differences exist as well -- time of day, vehicle mix differences, etc.

Finally it is noted that accidents vary by time of day in a way that is substantially different from the manner in which traffic volume varies. Accidents are high relative to volume at evening rush hour, and lower than volume would indicate during the middle of the day. Note that, back in the 1960's when these studies were done, it is likely that trip purpose differed greatly by hour, and probably also sex of driver. Evening rush hour drivers were probably more frequently male than the driving population would have indicated, and during the middle of the day, female drivers were probably relatively more in evidence. This could easily account for the accident differences.

2. Traffic Control and Roadway Elements: Their Relationship to Highway Safety, The Automotive Safety Foundation, Washington, D.C., 1963.

This book reviews research from the early 1960's all the way back into the 1930's in some cases. With regard to traffic volume and its relationship to accidents, the reviewers cite the relationship of an increase in accident rates with volume, but report that some authors show a decline in the rates above certain high ADT levels. They state however that not all research shows that. They also point out the probable influence of other variables. Thus, they say that, "Since lane width, shoulder width, sight distance and many other features are determined by traffic volume, they cannot be considered independent of it." (page 4).

The review reports less success among studies that purport to study accidents in relationship to congestion. Here authors attempt to express jointly the volume and the capacity of a road and thus have a measure presumably related to congestion. Some studies tend to support this notion that accident rate should increase with congestion, and some research tends to support that view, but, as the book says, (page 6) " -- students have directed their attention to this question with a notable lack of success." The relationship is not always confirmed and appears to be non-linear when it is in evidence (of course would be the response of this reviewer -- nothing is linear!).

According to this review, both Schoppert and Woo "were unable to find a strong correlation between accidents and congestion in studying two lane rural highways. Both used and index compounded of traffic volume and capacity. On the other hand, Rykken in a Minnesota study reported a very good relationship for similar highways.

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As to level of service, the accident rate curve shows an almost linear drop from Level of service A through D -- declining about 25%. The curve rises thereafter through level of service E and F reaching an accident rate at level of service F that is about three times three accident rate of level of service A.

4. Impact of Passing-Climbing Lanes on Traffic Flow on Upgrades, A. Polus and I. Reshentik, Transportation Research, 1987, Volume 21A, No. 6, pp. 401-410.

This study dealt with the effects of installing passing lanes on upgrades and its effects on opportunities to pass, delay, and consequently level of service. It was found, as might be expected, that increasing opportunities to pass did indeed decrease delays, and that even if only 20-30% of the stretch provided an opportunity to pass, delays could be reduced up to 50%.

This study did not directly address safety, but the authors cited other work, one particular study that compared 13 treated and 13 untreated sites and which found that in 11 of the 13 instances, accidents were less at the treated site. The differences were not statistically significant, however.

Of course, one need not expect the process of reducing congestion necessarily to reduce accidents. One might be quite content to "hold the line" on accidents as one reduced congestion. In fact, if congestion-reduction measures served to increase traffic volume, then one might feel that the effort was a success if accidents merely increased in proportion to the increased traffic volume.

5. Multilane Design Alternatives for Improving Suburban Highways, D.W. Harwood, National Cooperative Highway Research Program Report 282, Transportation Research Board, Washington, DC.

I have skimmed the report and I can't see any indication of the effects of level of service or the effects of volume on accident rates.

6. Freeway Operations on the Gulf Freeway Ramp Control System, Goolsby, M.E. and McCasland, W.R., Research Report 24-25, Study 2-8-61-24, Texas Transportation Institute, Texas A & M University, College Station, Texas, August, 1969.

The Gulf Freeway is a major traffic facility for Access to Houston Texas, and in this study a 3.5 mile section was equipped with devices such as to permit traffic sensing and computer controlled ramp metering. Freeway control entered the operational phase during the summer of 1965.

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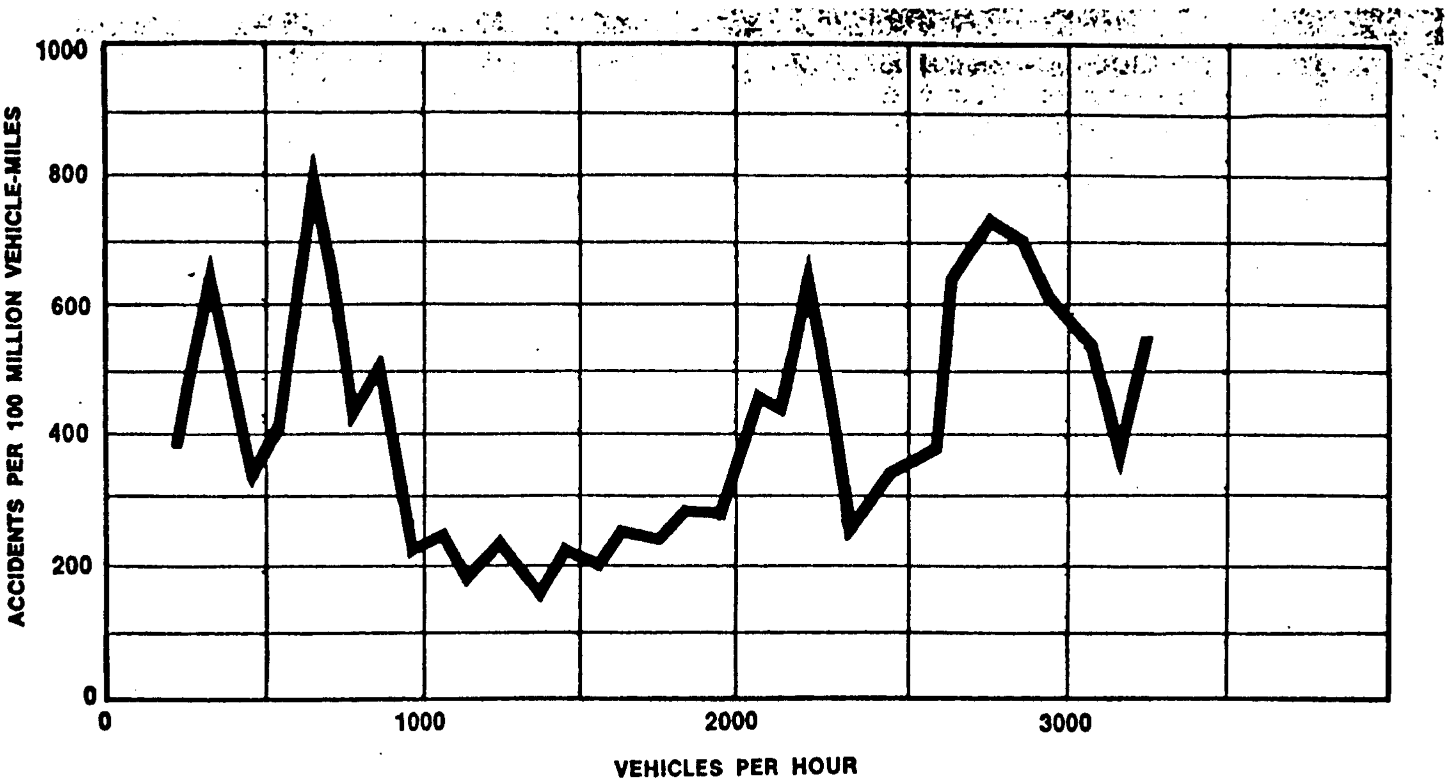


Figure 1. Accident rates and hourly volume.

Source: "Relationship of accident rates and accident involvements with hourly volumes," by David W. Gwynn, Traffic Quarterly, Vol. 21, No. 3, July 1967, p. 411.

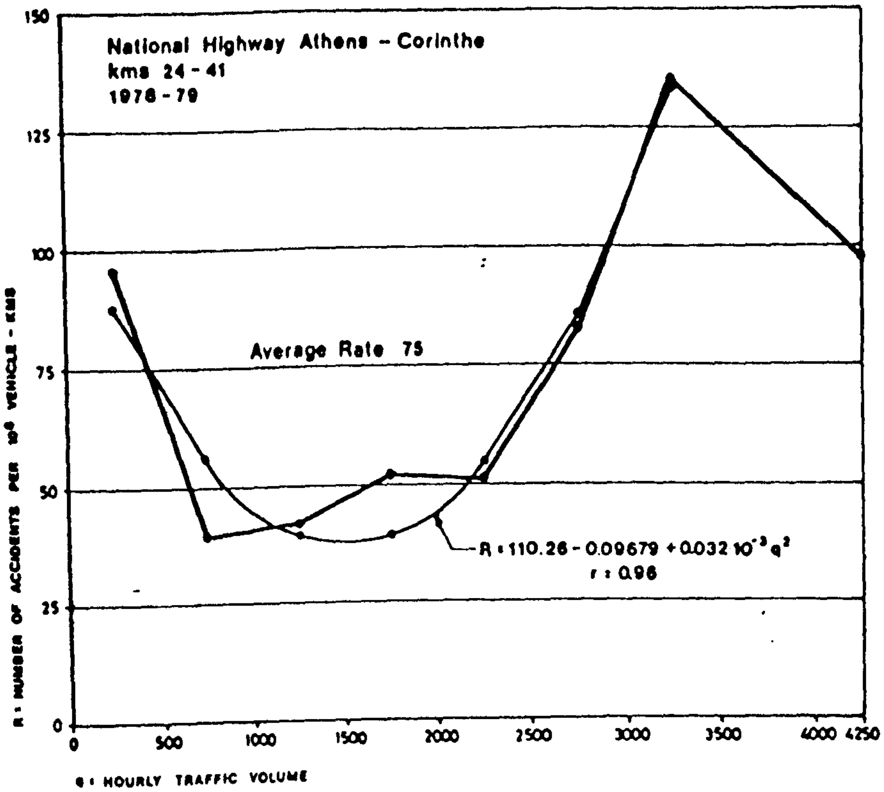


Figure 2. Correlation of accident rates to hourly traffic volumes.

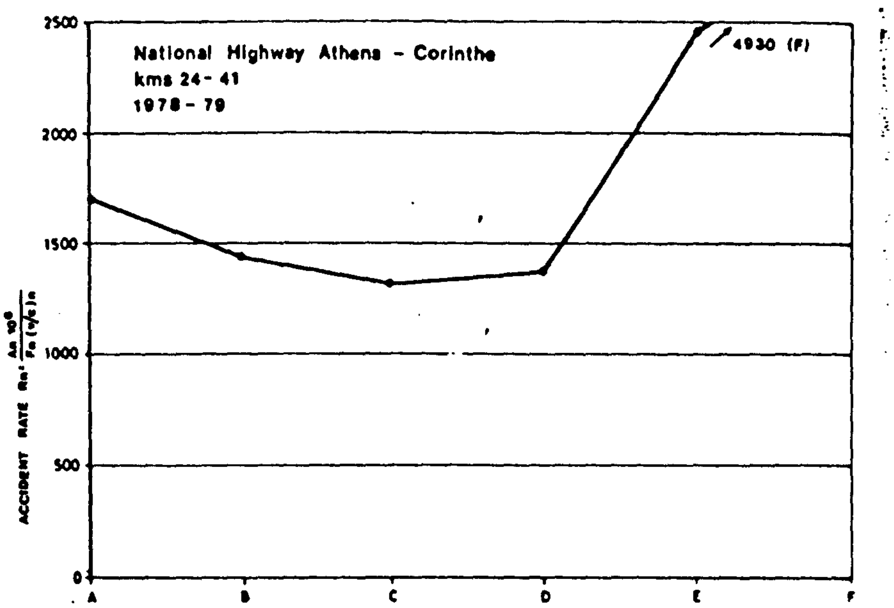


Figure 3. Correlation of accident rates to level of service.

Source: ITE Journal/February 1983

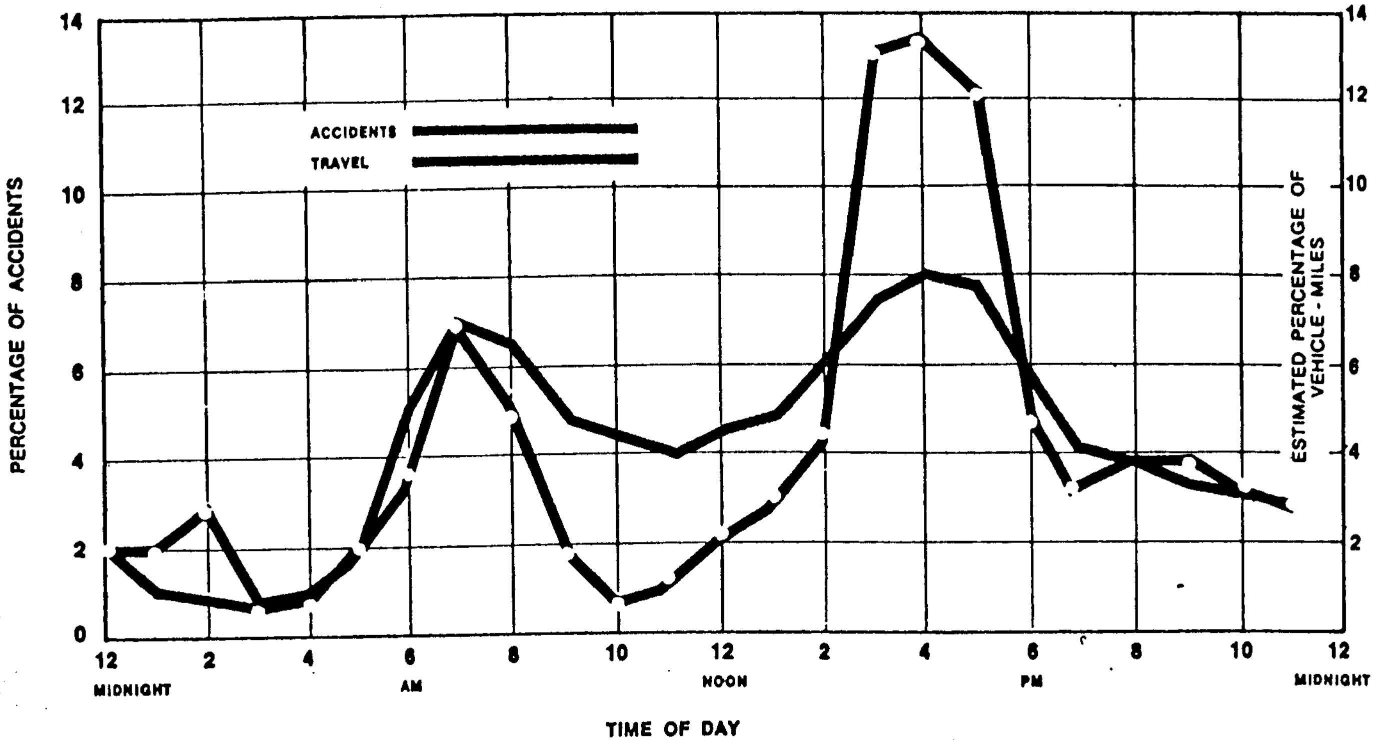
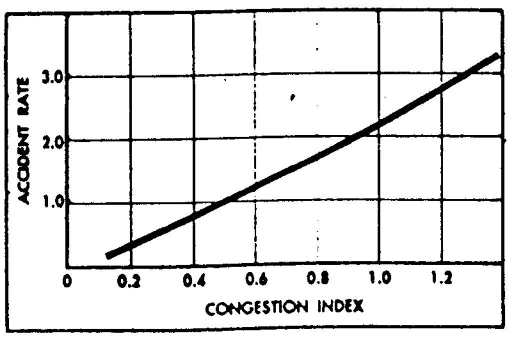


Figure 4. Accident, travel, and time of day.

Source: "Accident Analysis of an Urban Expressway System," by A.F. Malo and H.S. Mika, Highway Research Board, Bulletin 240, 1960. p. 35.



SOURCE: A Rural Highway Congestion Index and its Application, by K. B. Rykken. Highway Research Board. Proceedings, 1949.

Figure 5. Accident rates related to congestion.