Volume-to-Capacity Ratio and Traffic Accidents on Interurban Four-Lane Highways in Greece

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Traffic volume is a measure of exposure widely used at present in traffic accident analysis. However, the same traffic volume on road sections with different capacities creates different operating conditions, and, therefore, different probabilities for accidents. Thus, the volume-to-capacity (V/C) ratio may offer a better measure of exposure than traffic volume per se. Recent work by the Transportation Planning and Engineering Department of the Faculty of Civil Engineering at the National Technical University of Athens on the relationship between traffic accidents and V/C ratio on an interurban four-lane undivided national highway in Greece is presented and compared with previous work by the department. It has been found that the rates for all traffic accidents at nonhazardous locations are almost constant, up to a V/C ratio of 0.65, and increase considerably for higher ratios, more than doubling when V/C > 1.0. The same pattern of relationship between accident rates and V/C ratio also occurs at locations that are found to be hazardous by the quality control technique, and when only certain specific categories of accidents are analyzed, such as day and night, or dry and wet pavement accidents. Most of the accidents occurring at higher V/C ratios were of the rear-end type, while at lower V/C ratios, head-on and out-of-control accidents prevailed.

A serious problem in traffic accident analysis concerns the selection of a proper exposure measure. Currently, traffic volume is widely used as a measure of exposure. Accident rates on a road section are expressed in accidents per million vehicle kilometers. Such a rate implies that traffic accidents increase in proportion to traffic flows, which is an oversimplified assumption that is invalid as a rule.

The same traffic flow occurring on road sections with different capacities creates different operating conditions, and, therefore, different probabilities for accidents. In other words the volume-to-capacity (V/C) ratio, which is one of the parameters affecting the level of service (LOS), may offer a better measure of exposure than traffic volume per se.

In the 1965 *Highway Capacity Manual* (HCM) *(1)* the V/C ratio was extensively used to define LOS, although the concept of LOS was introduced as "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 cost" (*1*, p. 7). In the 1985 HCM *(2)* the measures used to define LOS are more in line with the foregoing definition and therefore the volume and volume-based measures are used less. Thus, the definition of LOS has now become a more complex procedure. In this paper, however, LOS is related to the V/C ratio, which can more easily be quantified. Therefore, it was considered more appropriate to discuss the relationship between traffic accidents and the V/C ratio than that between traffic accidents and LOS.

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By introducing V/C ratio as a measure of exposure instead of the traffic volume, accident analysis takes into account the effect on traffic operations of (a) roadway characteristics, such as number and width of lanes, lateral clearances, grades, and so forth, and (b) traffic characteristics, such as percentage of heavy vehicles, and peak hour factor, that is, those factors that considerably influence traffic capacity.

In spite of the fact that an emphasis is given to the concept of LOS and to its effects on traffic operations, to date little has been done to investigate the relationship between LOS or related measures of effectiveness, such as V/C ratio, and accidents. Simple questions such as whether total accidents or casualties are increasing as capacity is approached because of the deterioration of operating conditions and the greater traffic density, or whether they are decreasing due to the reduced speeds and speed differentials have not been extensively investigated to reach any definite conclusions.

Since 1981 the Transportation Planning and Engineering Department of the Faculty of Civil Engineering in the National Technical University of Athens has been investigating the relationship between traffic accidents and LOS. The effort is currently being accomplished through diploma and Ph.D. theses, using the accident records of the traffic police and the manual hourly classification counts conducted by the Ministry of Public Works at all the toll stations of the National Road Network and at all signalized intersections.

Findings reported in two diploma theses on two four-lane sections of the Greek National Road Network *(3, 4)*, and in an M.S. thesis on a selected number of urban signalized intersections in Athens, Greece, and Birmingham, United Kingdom *(5)*, are presented in two previous works *(6, 7)*.

Findings of a recently completed, more extensive analysis on a four-lane highway section *(8)* are presented in this paper, and the results are compared with the aforementioned works on similar highway sections, summarizing all findings. It should be pointed out that the present study, as well as those mentioned in the previous paragraph relates each accident to the traffic flow and composition at the hour the accident took place. This is possible in the case of interurban highways *(3, 4, 8)* because of the existing 24-hr manual classification counts throughout the year. Furthermore, accidents are related to grades and lateral clearances at the location where they occurred, all other geometric characteristics being the same at the examined sections. Thus, it is possible to correlate the accidents to the real operating conditions at the time and location where they occurred and not to annual averages for the highway section examined.

DATA COLLECTION

The Study Section

An 18-km section (24 to 42 km) of the four-lane, undivided national highway between Athens and Corinth was selected for this study for the following reasons:

1. The section comprises a toll station where hourly traffic flows and traffic composition are recorded on a permanent basis; and
2. Except for two interchanges, one at each end of the examined section, there are no other intersections in the study area and therefore traffic flows are constant along the whole length examined.

The section examined was divided into 17 1-km subsections, plus two 0.5-km subsections, the latter comprising the interchanges at both ends of the study section.

The Study Period

The study covered the 89-month period from January 1, 1975, to May 31, 1982. Before this period the road was converted from a two-lane highway with shoulders to a four-lane, undivided highway without paved shoulders. During the period examined no major improvements have taken place.

Geometric Characteristics

The lane width and the distances of lateral clearances were measured for each of the 19 subsections examined. The typical lane width of the highway is 3.70 m for the inner (high-speed) lanes and only 3.30 m for the outer lanes. The latter width is further reduced at four bridge locations. Lateral clearances are reduced in almost every subsection because of the lack of shoulders and the existence of safety barriers and other obstacles at distances of less than 1.80 m from the pavement edge.

Grades and corresponding lengths were estimated for each subsection from the design of the profile of the highway. Grades in the examined section vary from 1 to 4 percent.

Traffic Flows and Vehicle Classification

Hourly traffic flows per direction were available from manual classification counts on a 24-hr basis in the toll station at 27 km from 1977 to 1982. Daily traffic flows by type of vehicle were available for the whole study period.

Both hourly and daily flows were available for the nine categories of vehicles illustrated in Figure 1. This is the classification used by the Greek Ministry of Public Works in counts since 1979. A more detailed classification was used earlier,

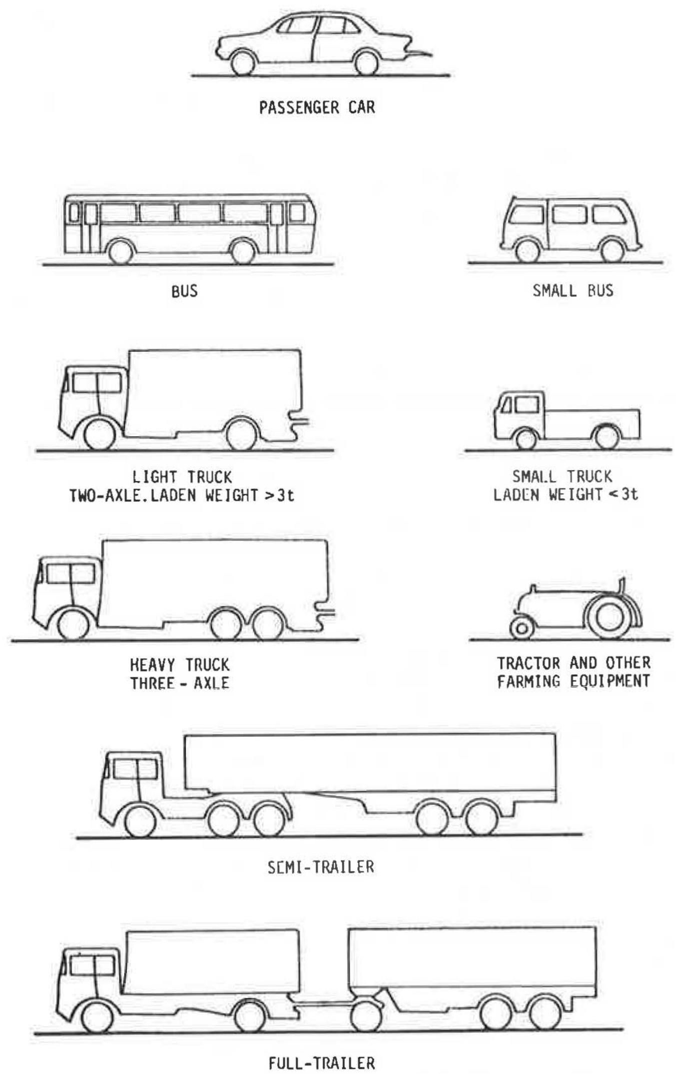


FIGURE 1 Vehicle classification used in the manual counts conducted by the Greek Ministry of Public Works.

which, however, can be easily converted to the one currently used.

The aforementioned categories can be related to those used by the 1985 *Highway Capacity Manual*, except for the category of light trucks (two-axle, laden weight > 3 tons), which may belong either to the light or to the typical truck category of the 1985 HCM. For this reason, a sample survey of two-axle light trucks of the Greek classification was conducted on the examined highway section. License plate numbers were surveyed for both directions of traffic and the corresponding horsepower and laden weight were defined from the car registration data bank kept in the Greek Ministry of Communications. Considering the Lb/HP ratio, the light trucks, as defined by the Greek classification, were divided into the 1985 HCM categories of light trucks [< 150 weight-to-horsepower ratio (Lb/HP)] and typical trucks (> 150 Lb/HP). It was found that the proportion, p, of light trucks of the Greek definition belonging to the typical truck category of the 1985 HCM definition decreased from 0.85 for the vehicles registered in 1975 to 0.71 for those registered in 1982.

Furthermore, because the number of heavy trucks according to the 1985 HCM—that is, the total of the Greek categories for heavy trucks, semitrailers, trucks with trailers, and tractors and other farming equipment—was very small, this category was incorporated into the typical truck category. Therefore, two categories of trucks were finally used in the capacity analysis according to the 1985 HCM:

1. Light trucks (100 Lb/HP) = small trucks + 0.27 light trucks, and
2. Typical trucks (200 Lb/HP) = 0.73 light trucks + heavy vehicles + semitrailers + trucks with trailers + tractors and other farming equipment.

In the case when there were more light trucks than typical trucks within the hour examined, all trucks were classified as light; otherwise they were classified as typical. Accordingly, the corresponding passenger car equivalents were selected from Tables 7-5 or 7-4 of the 1985 HCM, for each highway subsection, using the grades and corresponding lengths for this subsection.

Because of the lack of hourly traffic flows for the years 1975, 1976, and 1978, traffic flows and vehicle classification for all years were stored in the computer on a daily, not an hourly, basis. Hourly traffic flows were stored only for the years 1977, 1979, 1980, 1981, and 1982 and were grouped into 10 characteristic weeks. Hourly traffic flows for the remaining years were computed on the basis of the daily traffic flows and the hourly variations observed in the corresponding characteristic week. Holidays were examined separately through eight more characteristic groups comprising one or more such special days. Two-direction flows were stored in the computer and classified into passenger cars, buses, light trucks, and typical trucks.

Traffic Accidents

Traffic accident data were collected from the original source where they were recorded, that is from the Traffic Department Police in the cities of Megara and Eleusis that cover the sections from 24 to 30 km and from 30 to 42 km, respectively. A total of 778 accidents were recorded during the study period. For each accident, data on date and hour, location, type, results, and weather and light (day or night) conditions were collected and stored in the computer.

A linear correlation of the number of accidents recorded each year at the two police departments showed a satisfactory consistency (Figure 2), indicating that both departments register a comparable percentage of the total accidents.

Weather Conditions and Pavement

Although weather conditions were recorded for each accident, relevant information was also collected from the meteorological station at Eleusis (near 24 km), to find and store in the computer the rainy periods, expressed in hours, for the whole study period.

Information on weather conditions given in the accident files was checked against that from the Meteorological Service, and minor corrections were made for a few cases when necessary.

After each rain period with a duration of more than 0.5 hr,

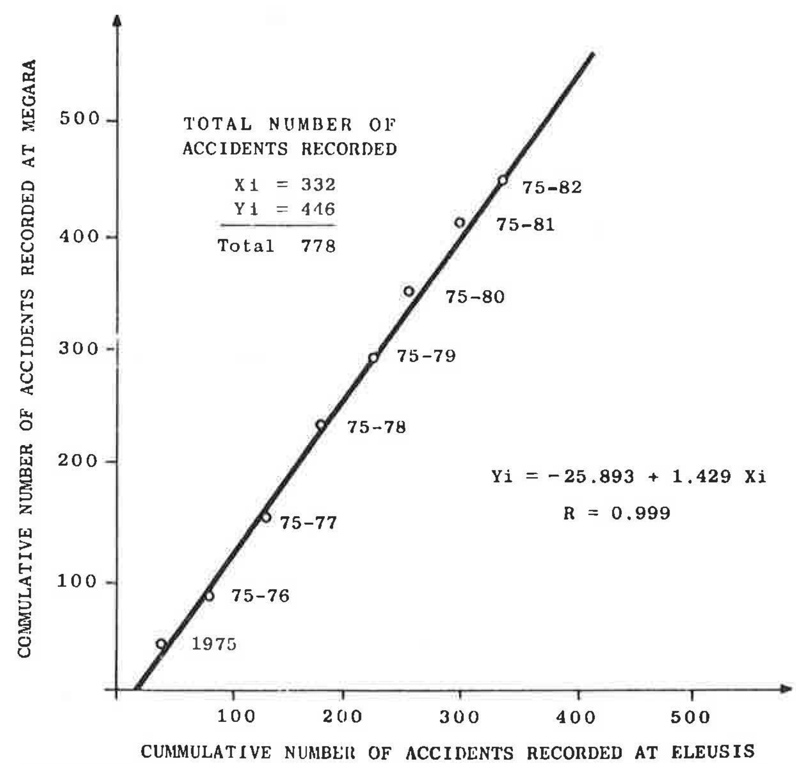


FIGURE 2 Linear correlation between the number of accidents recorded at the Eleusis and Megara Traffic Police Departments.

the road surface was considered wet for a period of 1 hr for the months from March to August and for a period of 2 hr for the rest of the year.

Light Conditions

The examined section of the highway was not lighted. Day and night conditions were recorded for each accident. Furthermore, day and night conditions were defined and stored in the computer for each hour of the study period, based on the following data and assumptions:

1. Sunrise and sunset times are collected for each day of the year from the Meteorological Service;
2. According to Greek law, the night period is assumed to start 0.5 hr after sunset and to end 0.5 hr before sunrise; and
3. All the transition hours between day and night are classified as day when day conditions exist for at least 30 min, otherwise they are classified as night.

METHODOLOGY AND PROCESSING

Grouping of Subsections

A quality control at a confidence level of 0.05 was carried out in order to identify possible hazardous locations that might have altered the results of the analysis on the effect of V/C ratio on traffic accidents. The results, shown in Figure 3, indicate that, besides the two interchanges at the ends of the examined section and the toll station at 27 km, there are two more hazardous locations at 28 and 33 km. The former includes the highest grade of the examined section (4 percent), and the latter a curve with wrongly sloped superelevation. Thus, the following eight groups of subsections were considered in the analysis:

- Group 1: 24 and 42 km—Two interchanges. Hazardous locations with the highest accident rates.
- Group 2: 27 km—Toll station. Hazardous location.
- Group 3: 28 km—Hazardous location (highest grade, 4 percent).
- Group 4: 33 km—Hazardous location on a curve with wrong superelevation.
- Group 5: 25 km—Transition section after the interchange at 24 km.
- Group 6: 34, 35, 40, and 41 km—Narrow bridges.
- Group 7: 26, 31, 32, 36, 37, and 38 km—Straight alignment.
- Group 8: 29, 30, and 39 km—Curves.

Computation of Maximum Service Flows

Service flows, SF_i, per direction for each LOS i were computed for all 19 subsections examined using the known formula and procedures of the 1985 HCM for four-lane highways (*9*, page 7-7):

$$SF_i = c_j \times (V/C)_i \times N \times f_w \times f_{HV} \times f_E \times f_p \quad (1)$$

where

c_j = capacity per lane under ideal conditions for the design speed j. For the accepted design speed of 60 mph; c_j = 2,000 vehicle/hr/lane;

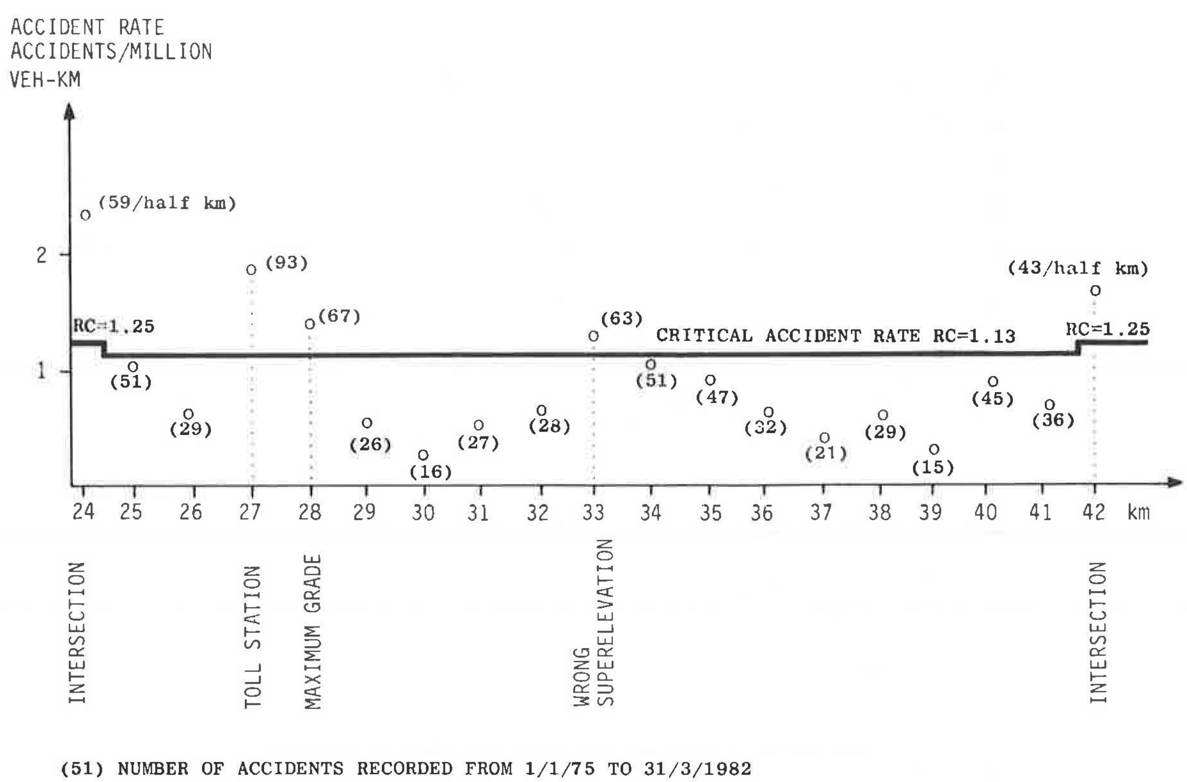


FIGURE 3 Quality control diagram of the examined highway section.

N = 2, the number of lanes per direction;
$(V/C)_i$ = maximum V/C ratio allowable while maintaining LOS i;
f_w = adjustment factor for restricted lane widths, lateral clearances, or both. It varies in this study from 0.793 to 1.000;
f_{HV} = adjustment factor for heavy vehicles, such as trucks and buses, recreational vehicles being very few;
f_E = 0.95, adjustment factor for an undivided rural highway; and
f_p = 1.00, assuming that the road serves mainly commuters and other regular users.

Accident Rates

Accident rates per million vehicle-kilometers were computed using the known formula $R_s = A \times 10^6/T \times V \times L$, which was transformed into

$$R_{s(ijk)} = A_{ijk} \times 10^6/L_k \times \Sigma V_j \quad (2)$$

where

$R_{s(ijk)}$ = the average accident rate for the category i of accidents in the various hours j and the highway subsection group k examined;
A_{ijk} = the number of accidents of category i in the various hours j and the subsection group k examined. Head-on collisions were multiplied by two because traffic flows were examined per direction and the contributing vehicles are considered in the flows of both directions;
v_j = the hourly traffic volume for each hour j examined; and
L = the length in kilometers of the examined subsection group or combination of groups.

By applying the foregoing formula it was possible to compute average accident rates for the following:

1. Various categories i of accidents, that is, fatal accidents, accidents with injuries, or damage-only accidents.
2. Accidents occurring at various time periods j with different (a) operating conditions (various V/C ratios and LOS), (b) weather conditions (good weather, rain, or snow), and (c) light conditions (day or night).
3. Accidents occurring at each of the eight subsection groups established earlier or at any combination of these groups (e.g., at interchanges, in the subsection comprising the toll station, or on all nonhazardous locations, etc.).

In a generalized way Equation 2 could be written as follows:

$$R_s = A \times 10^6/(VKM) \quad (3)$$

where

R_s = the average number of accidents per million vehicle-kilometers for a certain category under certain conditions and on a certain examined section,
A = the number of accidents of this category occurring under the examined conditions on the examined section, and
(VKM) = the number of vehicle-kilometers on the examined section under the conditions examined.

The following categories of conditions were examined separately for each of the subsection groups established earlier.

1. Each LOS defined on the basis of the following corresponding maximum values of the V/C ratio (*9*, Table 7.1). $A \leq 0.33$, $B \leq 0.50$, $C \leq 0.65$, $D \leq 0.80$, $E \leq 1.00$, and $F \geq 1.00$.
2. Day and night.
3. Dry and wet pavement.

For each of the aforementioned categories and for each subsection group, the number of accidents and the corresponding vehicle-kilometers were computed. Subsequently, accident rates were estimated according to Equation 3 for all examined cases. A minimum of at least seven accidents was considered necessary to have a meaningful accident rate. Under the latter condition, accidents with casualties (fatal, or with injuries, or both), not including damage-only accidents, were also examined separately.

ANALYSIS OF RESULTS

The results of the study are presented in a series of diagrams where the average accident rate for each LOS is plotted against the average V/C ratio corresponding to this LOS. The values of the V/C ratio for the limits of each LOS are those suggested by the 1985 *Highway Capacity Manual* for multilane highways with a 60 mph design speed (*9*, Table 7.1). The number of accidents occurring on each LOS is shown as a measure of the confidence with which the corresponding value of the accident rate can be viewed.

In cases where the whole examined section of the highway is considered, the four more hazardous locations deriving from the quality control analysis (24.0–24.5, 26.5–27.5, 27.5–28.5, and 41.5–42.0 km) were excluded to avoid any irregularities created by the special characteristics of these locations.

It should be pointed out that a thorough checking of the hourly variations of traffic flows during peak periods showed that in no case were hourly flows decreasing within an extended peak period. Thus, there were no hours when the V/C ratio was lower than 1.0 due to congestion. The check was necessary to avoid any possible misinterpretation that a congestion period at LOS F was a period of any other LOS with a low V/C ratio.

Total Accidents and Accidents with Casualties

Based on the foregoing discussion, the relationship between accident rates and LOS in the nonhazardous locations examined for all accidents, as well as for the accidents with casualties only (fatalities and injuries) is shown in Figure 4. In the same diagram the same relationship is illustrated for a 28-km-

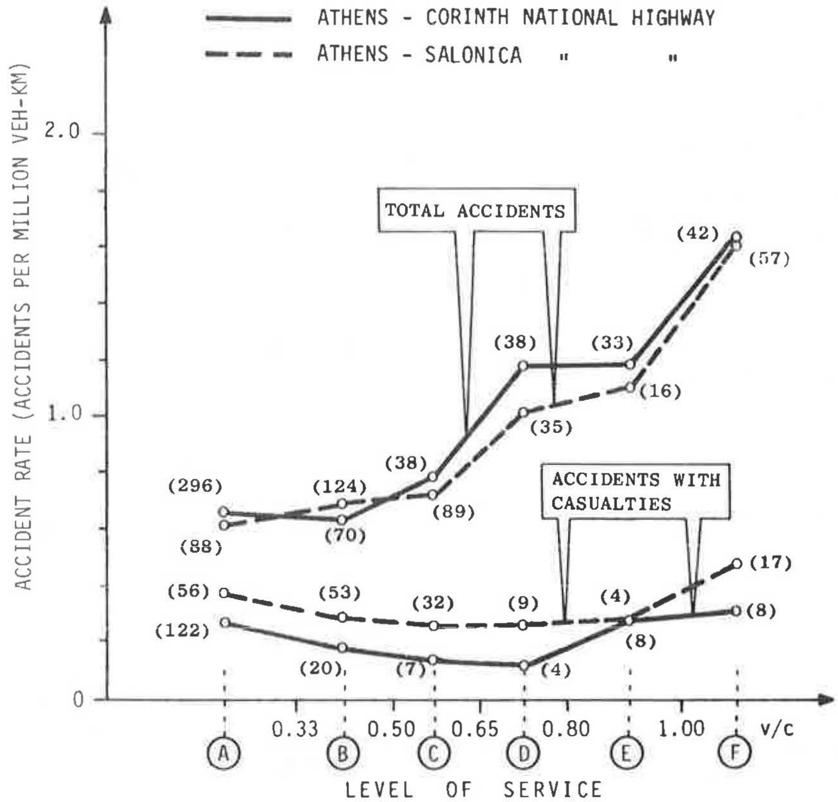


FIGURE 4 Total accidents with casualties.

long section of the similar four-lane, undivided national Athens–Salonica highway for the period 1979–1981 when 409 accidents were recorded; 171 were with casualties *(4)*.

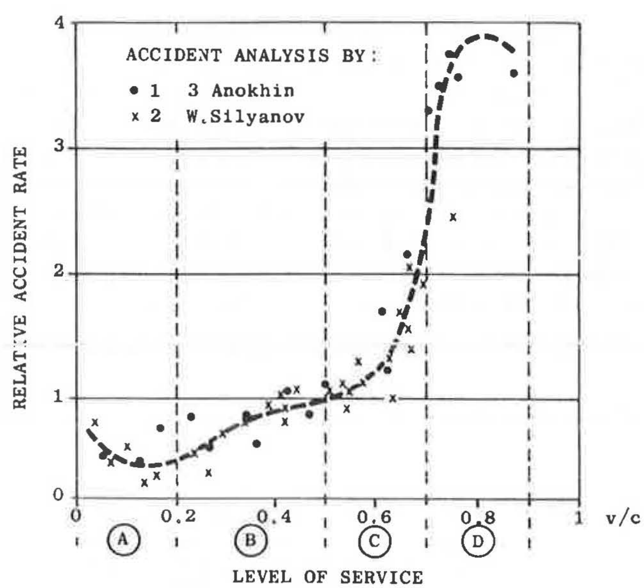
In spite of some methodological differences between the current study and that of the Athens–Salonica highway *(4)*—for example, in the latter, capacities were estimated according to the 1965 *Highway Capacity Manual*—there is a striking similarity between the accident rate lines derived from the two studies, clearly showing the following:

1. Total accidents—Accident rates do not differ significantly for LOS A, B, and C up to a V/C ratio of 0.65. In both studies, accident rates vary between 0.61 and 0.78 accidents per million vehicle-kilometers. Rates are almost double (1.06–1.17) for LOS D, remain almost the same for LOS E, and then increase again considerably for LOS F (1.60–1.62).
2. Accident with casualties—The variation of the accident rate for the various LOS is smaller than in the previous case, namely between 0.12 and 0.31 for Athens–Corinth and between 0.28 and 0.48 for Athens–Salonica. However, an increase of accidents in the lowest and highest LOS is observed in both cases, resulting in a U-shaped curve. The increase of accident rates for casualties at the higher LOS A and B may be explained by the higher speeds and speed differentials, and by the fact that these LOS occur mainly during the night when traffic flows are reduced but driving conditions are adverse.

It is interesting to note that accident analyses conducted by Anokhin and Silyanov in the USSR have shown similar results up to a V/C ratio of 0.8 *(10)*. In fact, as shown in Figure 5, accident rates were found to increase only slightly for LOS A, B, and C, up to a V/C value of 0.6. From this point, the increase was very rapid, leading to an almost fourfold increase if the accident rate for V/C = 0.8 at LOS D, for example.

Day and Night Accidents

For the same two studies on four-lane Greek highways, the accident rates for day and night are shown separately in Figure 6. Day accidents follow more or less the pattern shown pre-



Source : (10)

FIGURE 5 Total accidents based on experience in the USSR.

viously for total accidents, with a more pronounced increase of accident rates at and beyond capacity (LOS F).

Night accidents show a more irregular pattern, with a decrease of the accident rates at and beyond capacity. However, such a decrease, and, generally speaking, all the observed irregularities, may have been caused by the limited number of cases examined. In fact, accident rates in LOS C to F were based on 5 to 15 accidents only for each LOS. A chi-squared test on the difference in day and night accidents has shown that this difference is significant at the 0.05 confidence level only for LOS B. The difference becomes significant also for LOS D, if accidents occurring at dry pavement conditions only are examined.

Dry and Wet Pavement Accidents

Accident rates on dry pavements show the same general pattern of increase as capacity is approached (Figure 7). A meaningful analysis of accident rates for wet pavement conditions is not possible because of the limited number of accidents in various LOS except for LOS A. Even the grouping shown in Figure 7 cannot overcome this difficulty. It is, however, obvious that a significant increase in accident rates occurs under wet pavement conditions. The low friction factor of pavements in Greece greatly contributes to this situation. Tests conducted in June 1979 at various locations on the examined highway section showed a friction factor at 40 mph varying between 0.16 and 0.23.

Accidents at Hazardous Locations

An analysis was also made on the hazardous locations that were excluded from the previous analysis. More specifically, the hazardous locations at 24.0–24.5 km and 41.5–42.0 km (interchanges), and 26.5–27.5 km (toll station) and 27.5–28.5 km (maximum grade) were examined (Figure 8). Furthermore, the accident rates at the four locations of the narrow bridges are also shown and are higher than the average rates without exceeding the critical values of the quality control analysis for a 0.05 significance.

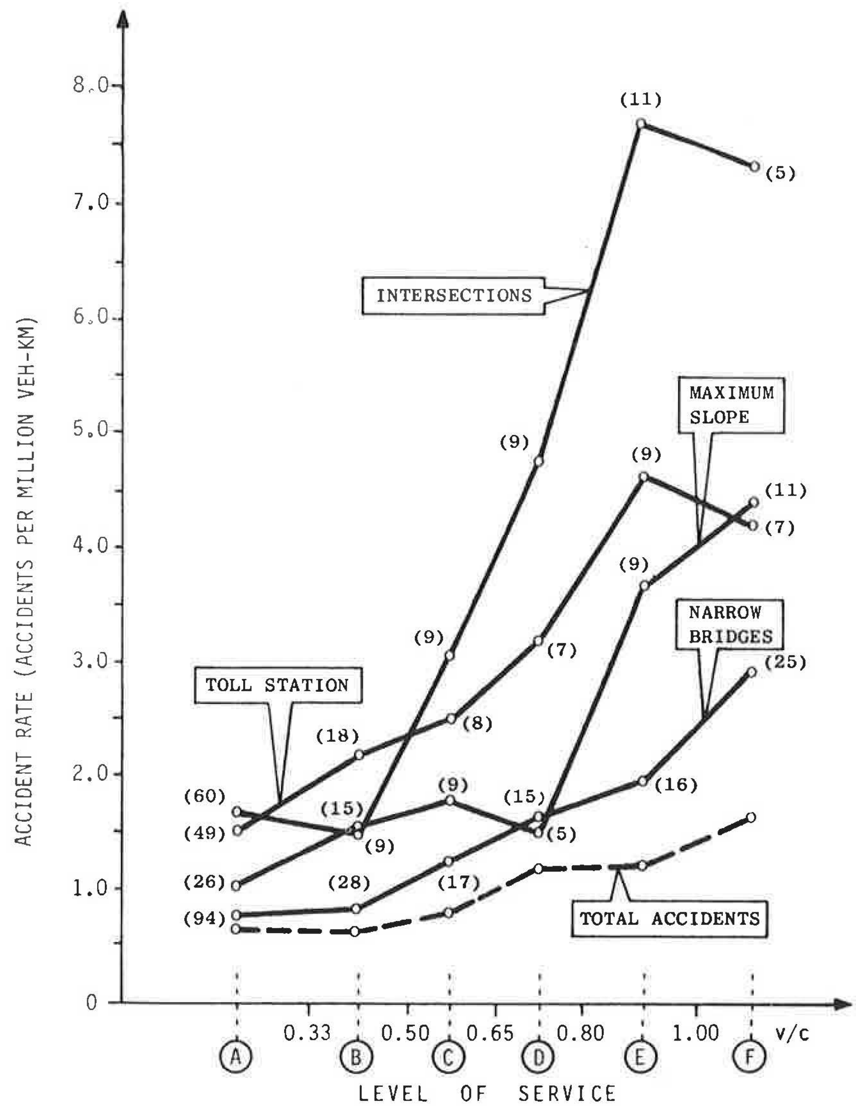


FIGURE 8 Accidents at hazardous locations.

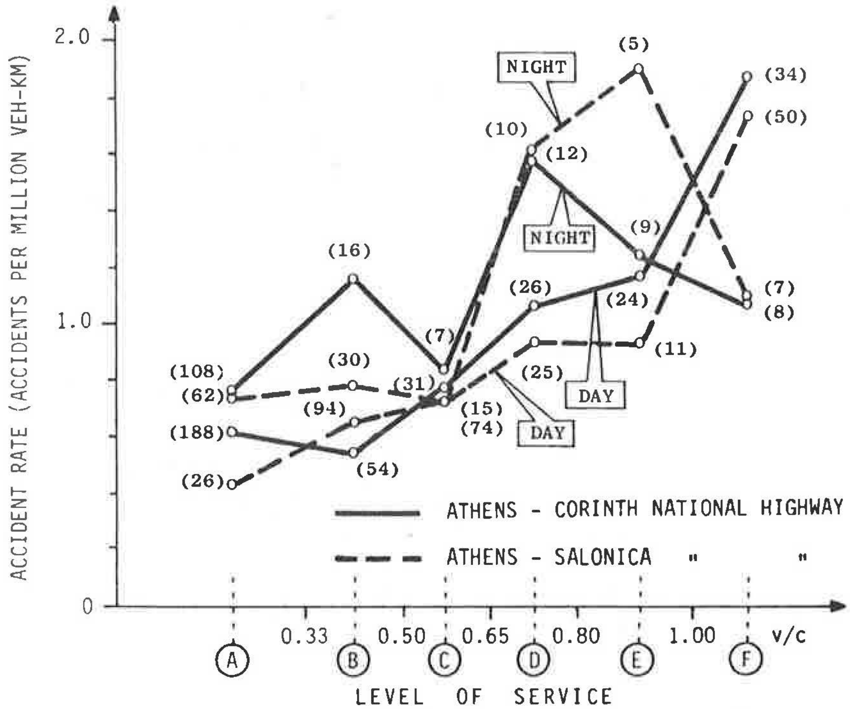


FIGURE 6 Day and night accidents.

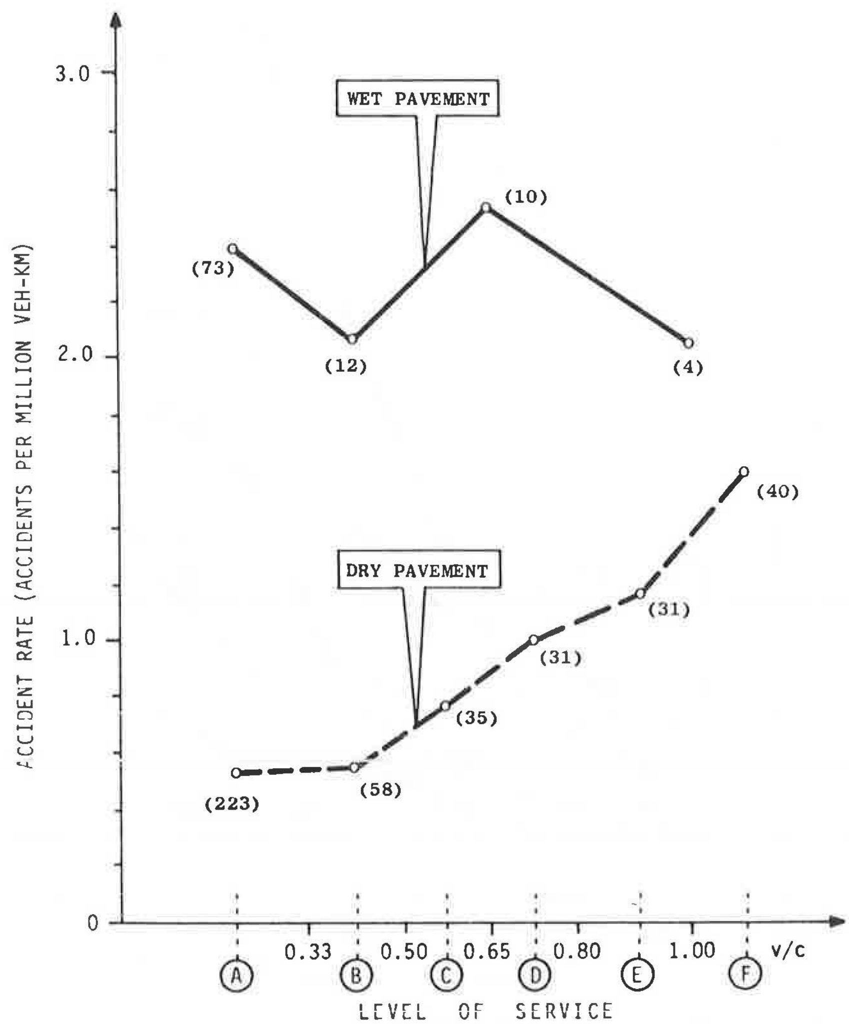


FIGURE 7 Accidents on dry and wet pavements.

Although some irregularities, which may be caused by the small sample examined, exist on certain points of the accident rate lines for the aforementioned hazardous locations, they all follow the general pattern of increase as capacity is approached, that is, the same pattern found for nonhazardous locations, also illustrated in Figure 8.

Accidents by Type

The accidents recorded were grouped into the following three characteristic groups for which LOS may have a significant effect:

1. Head-on collision;
2. Out-of-control; and
3. Other (rear-end, side-swipe, and stopped-vehicle collisions).

The first two groups consist of accidents that can be assumed to occur at lower traffic flows and higher LOS, while the accidents of the types included in the third group may occur under heavy flows when capacity is approached. The results of the analysis on the type of accidents, which is illustrated in Figure 9, supports the foregoing assumption.

Similar results are also given in a relevant work by Silyanov *(10)*. It was found that in LOS A, overturns account for the 79.5 percent of all accidents, side-swipes without overturns account for 8.0 percent, and head-on collisions account for 5.3 percent. In LOS B these percentages are 20.1, 48.8, and 10.9, respectively. In the same work it was found that in LOS C and D rear-end collisions were the prevailing type of accidents.

FUTURE RESEARCH

The similarity in findings of the studies carried out at the National Technical University of Athens for four-lane, undivided highways in Greece, both for all accidents, as well as for certain categories of accidents (accidents at hazardous locations, day or night accidents, and accidents on dry pavements), supports the general conclusion that accident rates, although constant at the higher LOS (V/C ratio up to 0.65), increase considerably as capacity is approached. The same results were obtained for intercity roads in the USSR Further research is needed to check the validity of these findings for other types of intercity roads (freeways and two-lane roads) and for other countries.

Similar research is also needed for conditions at signalized intersections, which are quite different. There are indications that in this case accident rates decrease as traffic capacity is approached *(5, 7)*. A more detailed study in this respect is now being carried out at the National Technical University of Athens.

CONCLUSIONS

The results of a study on traffic accidents and corresponding hourly traffic flows and capacities for a period of 89 months on an 18-km long section of a four-lane, undivided national highway in Greece show that total traffic accident rates on nonhazardous locations are almost constant for LOS A, B, and C, that is, up to a V/C ratio of 0.65. For higher V/C ratios, the accident rates increase considerably and are more than double when V/C > 1.0.

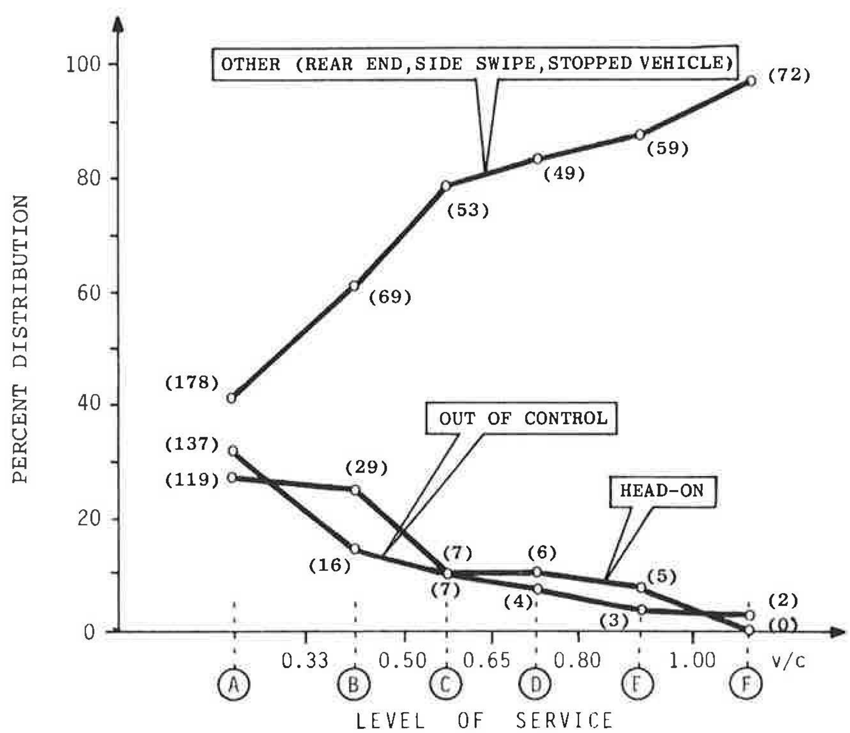


FIGURE 9 Percentage distribution of accidents by type for each LOS.

An analysis of accidents and flows carried out in the same study for hazardous locations, as well as for specific categories of traffic accidents such as day and night, and dry and wet pavement, showed that if the size of the sample was adequate, a similar pattern of relationship exists between accident rates and V/C ratio or LOS. A previous study on a 28-km long section of another four-lane, undivided national highway in Greece covering a period of 3 years also yielded similar results.

Accident rates for accidents with casualties only show a less pronounced variation against V/C ratio. In this case a moderate increase of accident rates is observed both in high and low V/C ratios, resulting in a U-shaped curve. The increase in low V/C ratios may be explained by the higher speeds and speed differentials, as well by the fact that lower V/C ratios occur mainly at night when driving conditions are adverse.

The type of accidents was found to be strongly related to the V/C ratio. Most of the accidents occurring at higher V/C ratios (lower LOS) were of the rear-end and side-swipe type, while at lower V/C ratios (higher LOS) head-on and out-of-control accidents prevailed.

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