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Exposure-Based Analysis of Motor Vehicle Accidents

PAUL P. JOVANIS AND JAMES DELLEUR

The concept of exposure to accident risk includes characteristics of the amount of travel, the conditions of travel, and the characteristics of the driver and vehicle undertaking the travel. An empirical investigation of this broad definition of exposure was conducted by using accident, travel, and environmental data from the Indiana Tollway for 1978. A comparison of automobile and truck accident involvement rates indicates that trucks generally have a higher overall accident rate, primarily due to a higher rate during clear weather. Comparison of automobile accident rates with the rates of two-axle, six-tired vehicles (small trucks) and five-axle vehicles (large trucks) showed that the small trucks had higher accident rates in all weather conditions than the automobiles or large trucks. The highest accident rates for each vehicle type occurred during snowy days. Automobiles had higher accident rates at night than during the day, whereas truck rates stayed the same or decreased at night. Regression analysis of automobile and truck accident rates indicated that the occurrence of snow was the single most significant exposure variable associated with an increase in accident rates. Automobile accident rates were found to increase significantly with truck vehicle miles of travel, a result consistent with concerns for mixing high levels of automobile and truck traffic. In general, automobile accidents were much more sensitive to travel conditions than truck accidents; this may be due to a combination of driver experience and/or vehicle technology. The study demonstrated that diverse existing data sources can be combined to investigate a broad definition of exposure and thus gain useful insights concerning accident patterns.

The safe, efficient use of the highway system requires the accommodation of vehicles of different sizes and weights serving different purposes. The trend in recent years is for automobiles used in passenger transportation to be lighter and smaller while trucks, particularly those used to haul intercity freight, are becoming larger and heavier. Pressure continues to increase truck size and weight limits beyond current levels (1). In addition to economic and regulatory issues concerning increased truck weights, there is a substantial controversy concerning the safety record of heavy and large trucks. A recent major study conducted for FHWA (2) has not completely resolved the safety issue due to apparent methodologic shortcomings (1,3).

Numerous studies (4-7) have compared various characteristics of truck accidents. Although these studies aid the understanding of truck safety issues, a major shortcoming is their lack of consideration of the amount of travel, typically measured by vehicle miles of travel (VMT). Not considering the amount of travel means that consideration is only given to the characteristics of the accidents that have occurred, not the vehicle miles and conditions of travel during which accidents have not occurred.

Later studies (8,9) use estimates of statewide VMT obtained from motor fuel sales tax receipts to consider the amount of travel. These estimates of VMT are intended to provide what is commonly described as a measure of "exposure" to potential accidents. Presumably, as the number of miles driven increases, the risk of potential accidents increases.

A more refined definition of exposure is given by de Silva (10), who refers to it as "the number and relative danger of the hazards he (the driver) encounters." Carroll (11) defines exposure as "the frequency of traffic events which create a risk of an accident" and suggests that distance or driving time should be classified by variables that denote relative risk--driver, vehicle, roadway, and environmental characteristics including traffic speed and density. Chapman (12) discusses these issues at length, concluding that the concept of exposure really combines the notions of the attributes of the driver and vehicle and the conditions of travel (e.g., day or night and rain, snow, or dry) as well as the amount of travel. Consideration of VMT alone does not capture the potentially important effects that conditions of travel may have on the relative risk or danger of an accident.

STUDY OBJECTIVE

Estimates of VMT do not lend themselves to detailed analysis of conditions of travel. The estimates are frequently obtained for a large spatial area (e.g., a state) as well as a long period of time (e.g., a year). This level of aggregation makes it difficult to obtain an accurate measure of the effects of other exposure-based variables, particularly weather and daylight or darkness. The estimates themselves may also be inaccurate since they are derived from other variables (e.g., gasoline or diesel fuel sales).

This research focused on an empirical investigation of a broader definition of exposure, emphasizing study of the accident experience of automobiles and trucks during different conditions of travel. Measured VMT for different classes of vehicles was the basis of the study. Weather and sunrise-sunset times were combined with VMT and police accident records. The study sought to explore the usefulness of combining diverse data sources to study exposure to accidents in the hope of gaining insights regarding the safety performance of different types of vehicles under various environmental conditions.

STUDY SITE

Several studies of truck safety (13-16) have used measured values of automobile and truck VMT obtained from closed-system toll roads. The closed toll systems classify all vehicles by type and precisely measure on-ramp to off-ramp trip length to determine the amount of the toll. The availability of accurate travel mileage data indicated that toll roads could be a primary data source for the study.

Several toll authorities were contacted to determine their willingness to cooperate with the study team and their ability to provide the accident and vehicle travel information required. The Indiana Tollway, a 160-mile-long east-west highway in northern Indiana, was selected because measured VMT was available for nine classes of vehicles differentiated by axle count. Although this classification did not differentiate some important truck types (e.g., five-axle doubles from five-axle tractor-semitrailers), it did permit computation of vehicle mileage for automobiles, large trucks (five-axle), and small trucks (two-axle, 6-tired). Comparison of these three vehicle types resulted in the inclusion of approximately 97 percent of the automobile vehicle miles and more than 80 percent of the truck vehicle miles.

Although it would have been desirable to obtain VMT for segments of the tollway (between entrance and exit ramps), the Tollway Authority data collection system computed daily VMT for the entire facility. Because more spatially disaggregated VMT could not be obtained, weather and sunrise-sunset data also had to be aggregated for the entire roadway.

Weather data for the tollway in 1978 were obtained from six recording stations operated by the National Oceanographic and Atmospheric Administration (NOAA). The stations were dispersed along the length of the tollway and recorded for each hour of the day the amount of rainfall and snowfall. These spatially and temporally disaggregate weather data were used in two ways: (a) to classify days as clear, snowy, or rainy and (b) to construct, for regression analysis, variables called "hours of rain" (HRSRAIN) and "hours of snow" (HRSNOW). The regression variables were constructed by using the following procedure:

1. Any precipitation entry beyond a trace for an hour at a station was called one hour of rain or snow at that station.
2. The total hours of rain (or snow) at all stations for a day were summed and divided by the number of reporting stations to obtain the hours of rain and snow for the entire tollway for that day. Lack of segment-specific VMT data dictated this aggregation procedure.

Data on hours of daylight and darkness for 1978 were obtained from the Old Farmer's Almanac for South Bend, Indiana--approximately the midpoint of the tollway. The 24-h VMT data used in an earlier University of Michigan study of the Indiana Tollway (14) were then entered to determine an estimate of the proportion of daily truck and automobile VMT driven during daylight and darkness. The estimate was obtained by picking the hours of the day for sunrise and sunset and taking the area under the curve.

Complete accident records were available for 1978, chosen as the year of the study. Nearly 1000 accidents that occurred on the tollway were reviewed. Accidents at tollbooths, on access roadways, in service areas, and on entrance-exit ramps were excluded from the data set in order to arrive at data that could be considered typical of Interstate highway conditions. Whereas entrance-exit ramp accidents are common to all Interstates, it was often not clear in the tollway data set whether proximity to a toll collection facility influenced the ramp accident. The more than 600 accidents that remained in the data set consisted primarily of main-line and merge accidents. In transcribing vehicle information from accident reports, care was taken to classify all vehicle involvements in one of the nine tollway VMT classifications. Each vehicle involved in an accident was thus described to allow the computation of vehicle accident involvement rates (i.e., involvements per million VMT). As discussed by Scott and O'Day (13), the use of vehicle involvement rates rather than accident rates corrects the rates for different amounts of travel by vehicle class.

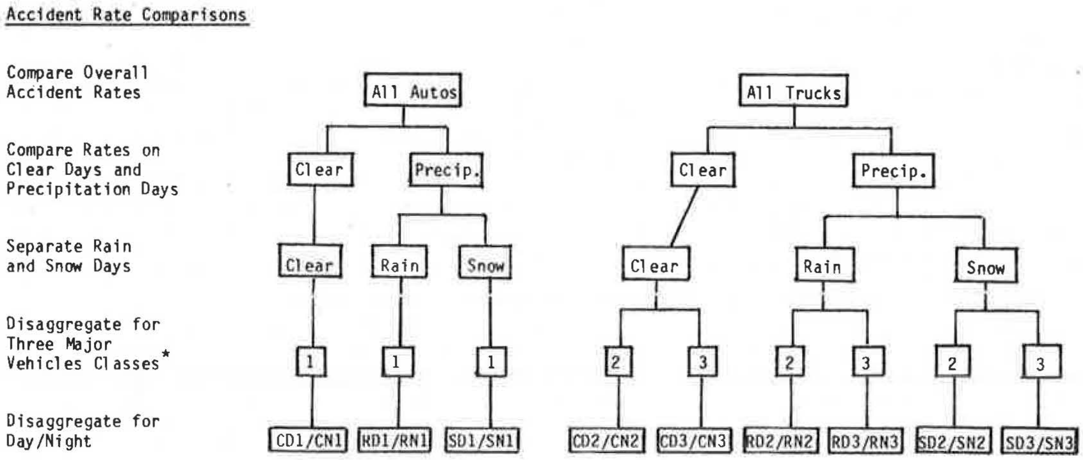
EXPERIMENTAL DESIGN

The data analysis sought to identify statistically significant differences in automobile and truck accident experience. To achieve this goal, a two-phase experiment was conducted. Initially, vehicle accident involvement rates were compared at increasing levels of disaggregation (see Figure 1). Overall accident involvement rates of automobiles and trucks were compared first; next, days with precipitation (rain or snow) were separated from clear days and separate accident rates were computed; precipitation days were further segregated into days with rain and days with snow; truck accident rates were segregated into those for class 3 (small trucks) and those for class 6 (five-axle semitrailers and doubles); finally, separate day and night rates were computed based on when each accident actually occurred.

Conceptually, more than three vehicle classes could have been included in the study, but small sample sizes of accidents in the remaining six vehicle classes precluded their separate analysis. Because an involvement rate is computed for each day (our fundamental data analysis unit), the mean and variance of the daily accident involvement rate can be computed for each cell and used to test statistical hypotheses concerning equality of means. These comparisons provided broad indications of the accident experiences of different vehicles in different travel conditions.

The second phase of the experiment was the development of regression models to predict the mean daily accident involvement rate as a function of several explanatory variables. Regression allowed the examination of rain and snow as continuous rather than dichotomous variables; the models provided an understanding of the effect of the amount of rain or snow as well as its occurrence. The effect of traffic mix was also examined; i.e., are

Figure 1. Design of hypothesis tests.



*1 = Autos and other 2 axle, 4 tire vehicles (Class 1)

2 = Two axle, 6 tire vehicles (Class 3)

3 = Five axle vehicles; both semi's and double bottom (Class 6)

automobile accident rates higher on days with high truck VMT?

Preliminary examination of the data revealed the presence of two winter days on which the tollway was closed for part of each day due to extremely heavy snows and icy conditions. The poor weather contributed to a high number of accidents and, combined with very low VMT, very high accident rates. The conditions of travel on these two days were so extreme as to be considered very unlikely to occur with any frequency. Therefore, these two days were removed from the data set, which left 363 days of usable data.

DATA ANALYSIS

Accident Rate Comparisons

The mean and variance of the daily accident involvement rate for each cell in Figure 1 are summarized in Figure 2. A series of paired comparisons of accident rates were conducted by using the following test statistic:

$$t = (m_1 - m_2)/[(S_1^2/n_1) + (S_2^2/n_2)]^{1/2} \qquad (1)$$

where m_1, S_1^2, and n_1 are the sample mean, sample variance, and sample size of the variable in one group and m_2, S_2^2, and n_2 are comparable measures for variables in the second group. The test statistic is asymptotically t-distributed with degrees of freedom,

$$V = [(S_1^2/n_1) + (S_2^2/n_2)]^2 / \left\{(S_1^2/n_1)^2 [1/(n_1 - 1)] + (S_2^2/n_2)^2 [1/(n_2 - 1)]\right\} \qquad (2)$$

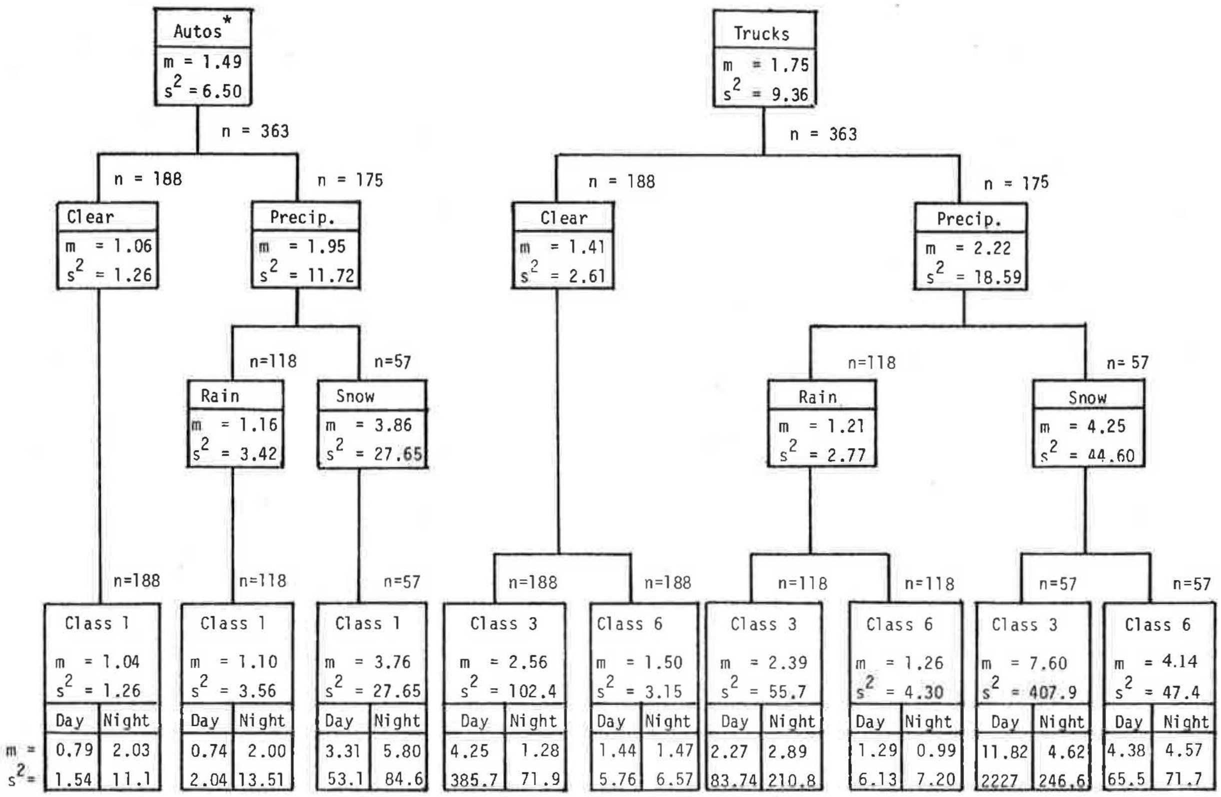
The null hypothesis is that the sample means are equal, and the alternative hypothesis is that they are not equal. The test statistic is used because initial comparisons of the variances in Figure 2 resulted in rejection of the null hypothesis of equal variances in all cases.

Table 1 presents t-statistics and significance probabilities for the null hypothesis that the mean clear-weather accident rate of different vehicle types is equal to the accident rate for days with rain or snow. Compared with rates during clear days ($m_A = 1.06$ accidents/million vehicle miles), automobiles experienced significantly higher accident rates during snow ($p < 0.0001$) and insignificantly higher rates during rain ($p = 0.30$). All trucks have a similar accident experience that shows significant increases during snow but a marginal decrease during rain.

The comparisons for the three separate vehicle classes indicate that results for class 1 closely match results for all automobiles (hardly surprising since class 1 contains 97 percent of automobile VMT). Very different results are obtained when comparisons are conducted separately for small trucks (class 3) and large trucks (class 6). The large trucks continue to show large increases in accident rates during snow and marginal, nearly significant decreases during rain. Small trucks, however, show a small but significant increase during snow and no significant difference during rain.

These results suggest that rainy conditions have less influence on the accident rates of large trucks than on those of automobiles and small trucks. Perhaps drivers of large trucks are more alerted to danger during these conditions and their driving experience and training provide them with better

Figure 2. Summary of accident involvement rates.



*m = mean daily accident involvement rate in involvements/million VMT.

Table 1. Comparison of accident involvement rates in clear weather with rates during snowy and rainy days.

	Rain		Snow	
Vehicle Type	t	p	t	p
All automobiles	0.520	0.30	3.99	<0.0001
All trucks	-0.81	0.79	2.84	0.002
Vehicle class				
1	0.340	0.37	3.88	<0.0002
3	0.175	0.44	1.81	0.035
6	-1.02	0.15	2.87	0.003

Table 2. Summary of statistical tests comparing accident involvement rates for different vehicle types.

Vehicle Type Comparison	Clear		Rain		Snow	
	t	p	t	p	t	p
All automobiles versus all trucks	2.64	0.004	0.499	0.31	0.004	0.5
Class 1 versus class 3	2.06	0.02	1.82	0.035	1.39	0.08
Class 1 versus class 6	2.98	0.001	0.611	0.27	0.329	0.63
Class 3 versus class 6	1.43	0.08	1.59	0.055	1.22	0.12

Table 3. Comparison of day and night accident involvment rates.

Vehicle Class	Clear		Rain		Snow	
	t	p	t	p	t	p
1	-4.79	<0.0001	-3.47	<0.0002	-1.63	0.10
3	1.90	0.06	-0.39	0.70	1.09	0.28
6	-0.12	0.90	0.89	0.37	-0.12	0.90

judgment on how to safely operate the vehicle. Automobile and small-truck drivers are likely to have less experience and training and may not be able to make judgments of the same quality. Vehicle technology in terms of tires, steering, and braking may also be sufficiently advanced to allow the more experienced large-truck driver to take corrective action to avoid danger.

Comparisons of all vehicle types indicate that accident rates increase significantly on snowy days.

A comparison of vehicle performance in the same weather conditions is summarized in Table 2. The null hypothesis is that the automobile (or vehicle class 1) accident rate for the given weather condition is equal to the truck accident rate for the same weather condition. The results indicate that automobile accident rates are lower than truck accident rates only in clear weather. In snow, rates are very similar; in rain, approximately similar. Rate comparisons by vehicle class yield a somewhat different picture. Compared with rates for two-axle, six-tired trucks, automobile rates are significantly lower for all weather conditions. Although the results for snow days are only marginally different ($p = 0.08$), the results are very different from those of comparisons in which all truck classes were aggregated. The findings for large trucks are consistent with previous results: Clear-weather accident rates are significantly higher for large trucks (class 6) than for 'automobiles. Accident rates are not significantly different on rain and snow days: Comparisons of rates for the two truck classes indicate that rates are marginally higher for small trucks than for large trucks.

The most disaggregate comparison of mean accident involvement rates included a breakdown of day and night accidents and accident rates. Table 3 summarizes the results. The null hypothesis is that the daytime accident rate is equal to the nighttime accident rate for each vehicle class in each weather condition, and the alternative hypothesis is that the rates are unequal. It is interesting that automobile accident rates increased significantly at night for both clear and rainy days. Both small and large trucks had generally the same accident rate during the day and night except for two instances in which the rate was marginally lower at night. These results provide further evidence of different safety performance for different vehicle types; in fact, the automobile nighttime accident rate during clear weather was marginally higher than the large-truck accident rates during both clear and rainy days.

It is clear, and somewhat surprising, that the accident rates for small trucks are consistently higher in all weather conditions than the rates for large trucks. Furthermore, large trucks have higher accident rates than automobiles only during clear weather and exhibit marginally lower accident rates than automobiles during rain. Large trucks have generally similar (or lower) accident rates at night. Automobiles are exactly the opposite, having significantly higher rates at night. In general, the comparison of means revealed very different accident characteristics for automobiles and trucks: Automobiles were much more sensitive to travel conditions than either truck type.

Regression Analysis

Regression models were constructed to further study variable interrelations, particularly the influence of one mode's VMT on the other's accident rate (e.g., truck VMT on automobile accident rate) and the effect of the amount of snow, rain, and nighttime travel on accident experience. The variables used in the models can be defined as follows:

AUTODAY = percentage of daily automobile VMT driven during daylight hours;
HRSNOW = average snowfall for a day, estimated as described earlier in this paper;
HRSRAIN = average rainfall for a day, estimated as described earlier in this paper;
TRUCDAY = percentage of daily truck VMT driven during daylight hours;
VMTCL1 = daily VMT for vehicle class 1;
VMTCL16 = term measuring the interaction of the VMTs of classes 1 and 6, computed as the product of VMTCL1 and VMTCL6;
VMTCL6 = daily VMT for vehicle class 6;
VMTA = daily VMT for automobiles, obtained by summing VMTs for classes 1 and 2;
VMTAT = term measuring the interaction of the VMTs for automobiles and trucks, computed as the product of VMTA and VMTT; and
VMTT = daily VMT for trucks, obtained by summing the VMTs for vehicle classes 3-9.

The models were developed by using a linear additive specification:

$$\text{Daily accident involvement rate} = b_0 + b_1\text{HRSNOW} + b_2\text{HRSRAIN} + b_3\text{VMTAT} + \ldots \quad (3)$$

Models were developed separately for automobile, truck, and large-truck (class 6) daily involvement rate. Predictor variables were screened to remove those that were strongly intercorrelated. Model estimates are discussed below, including coefficient values, coefficient t-statistics, and equation R^2

Table 4. Summary of automobile accident rate regressions.

Variable	All Data		Weekday		Weekend	
	B	t	B	t	B	t
HRSNOW	0.52	6.33	0.85	7.33	0.29	2.29
HRSRAIN	0.23×10^{-1}	0.31	-0.06	-0.69	0.24	1.79
VMTAT	-0.83×10^{-12}	-2.25	-0.65×10^{-12}	-1.63	-0.15×10^{-11}	-1.73
AUTODAY	-0.34×10^{-1}	-0.02	0.27	0.14	0.42	0.12
VMTT	0.61×10^{-6}	0.98	0.37×10^{-6}	0.40	0.31×10^{-5}	0.97
Constant	1.56	1.19	1.29	0.82	0.59	0.20
R^2	0.16		0.23		0.13	

values. For each equation, t-statistics in excess of 1.96 in absolute value indicate parameters that are statistically significantly different from zero ($\alpha = 0.05$).

Automobile Accident Rates

A summary of the automobile regression models is given in Table 4. The R^2 value of 0.16 for the linear model with all automobiles indicates that a substantial portion (84 percent) of the variance in the data is unexplained. Although this is not completely satisfying, it is not very different from R^2 values obtained in disaggregate regressions in other transportation planning applications. The low R^2 can be explained by the presence of a number of days with no automobile accidents and significant levels of VMT. Thus, a model is being fit through these points as well as points with similar VMT and some number of accident involvements. The R^2 could be increased by aggregating involvements over several days, but one would then lose resolution on the variables that describe conditions of travel. It is believed that the low R^2 values are characteristic of the data disaggregation and that the model coefficients can still illustrate significant data association.

Only two variables are significant in the linear model. HRSNOW is very significant and positive in sign, which indicates increased automobile accident rates on days with increasing snowfall. The coefficients for the remaining weather variable (HRSRAIN) and the variable that denotes the percentage of automobile VMT during daylight (AUTODAY) are not statistically different from zero. The results for snow were certainly to be expected, given the comparisons of the accident rates in the preceding section. Daylight automobile VMT was expected to be more significant and was expected to be negative in sign.

The coefficient of the truck VMT variable (VMTT) is nearly significant and positive, which indicates that there may be higher automobile accident rates on days with higher truck volumes. The association of higher automobile accident rates with high truck VMT supports the general concern for mixing high levels of truck traffic with automobiles.

The interaction term of automobile and truck VMT (VMTAT) was significant and negative in sign, indicating lower daily accident rates when the product of automobile and truck VMT is high. The interpretation is that automobile accident rates are lower on days with high automobile and truck VMT, a surprising finding. The expectation was that automobile accident rates would increase as VMTAT increased because increased levels of automobile and truck mileage are a surrogate for high flows and possible congestion. The tollway is a rural highway throughout nearly all of its length, but congestion occurs only near the western end of the facility.

It would also be interesting to differentiate all involvements into single-vehicle/multiple-vehicle crashes and thereby determine the influence of automobile-truck VMT interaction. Other authors (17) have suggested that single-vehicle accidents increase with traffic volume to a point and then decrease as multiple-vehicle crashes predominate. Further insight could also be obtained by the spatial disaggregation of the data, although Indiana Tollway traffic data were unavailable in this form.

Examination of tollway VMT data indicated two trends:

1. Automobile volumes tend to be slightly higher and truck volumes lower on weekends during the year, which results in higher values for VMTAT during weekdays. Furthermore, weekday drivers are likely to be more regular travelers of the tollway than weekend travelers who drive for recreation purposes.
2. Automobile VMT increases (by a factor of 2) starting in the late spring and building into summer due to recreational travel; truck VMT remains nearly constant throughout the year.

To determine which of these trends is significant, separate regressions were estimated for weekday and weekend conditions (Table 4). These separate models seek to describe accident rates when conditions of travel are more uniform--i.e., when the truck-automobile vehicle mix is more nearly constant and the type of automobile driver is consistent.

The segmentation of the analysis into separate models for weekdays and weekends yielded very interesting results. HRSNOW was significant in both segmented models but was more significant on weekdays and had a substantially larger magnitude. The results can be explained by the lower VMT (and thus higher accident rates) during winter compared with other seasons. Furthermore, much of the weekday travel is done by commuters, for whom the work trip is mandatory. Weekend travelers can plan their discretionary trips in winter to keep their trips shorter and be ready to handle adverse weather; those who do travel during snow may be better able to handle the adverse travel conditions.

A significant change is observed in the sign and the statistical significance of the rainfall variable. For weekdays HRSRAIN has a negative and insignificant sign, whereas for weekends the coefficient is positive and marginally significant ($t = 1.79$, $p \simeq 0.07$). This result may again reflect the inexperience of weekend vacationers or leisure drivers in dealing with rainy weather. This may be particularly true of summer vacationers who are not familiar with the tollway and who are traveling when the most severe rainfall of the year is likely to occur.

It is interesting that the VMT interaction term (VMTAT) remains negative and marginally significant for both weekdays and weekends. The interpretation is that this variable is capturing the seasonal travel trend of substantially increased automobile VMT during summer. The sign of the coefficient indicates that automobile accident rates are lower during these heavy travel days, a rather surprising result.

Table 5. Summary of truck accident rate regressions.

	All Data		Weekday		Weekend	
Variable	B	t	B	t	B	t
HRSNOW	0.69	7.16	0.66	5.50	0.68	3.68
HRSRAIN	-0.02	-0.25	-0.07	-0.79	0.07	0.33
VMTA	$-0.26x10^{-6}$	-0.74	$-0.87x10^{-6}$	-1.53	$0.49x10^{-6}$	0.35
TRUCDAY	$0.62x10^{-2}$	0.00	0.47	0.22	-2.13	-0.38
VMTAT	$-0.14x10^{-12}$	-0.26	$0.47x10^{-12}$	0.65	$-0.12x10^{-11}$	-0.48
Constant	1.89	2.05	1.81	1.97	2.53	1.05
R^2	0.16		0.15		0.18	

Table 6. Summary of accident rate regressions for large trucks: vehicle class 6.

	All Data		Weekday		Weekend	
Variable	B	t	B	t	B	t
HRSRAIN	$-0.67x10^{-2}$	-0.07	-0.05	-0.53	0.09	0.39
VMTCL1	-0.21	-0.55	$-0.66x10^{-6}$	-1.09	$0.10x10^{-6}$	0.07
HRSNOW	0.77	7.30	0.76	5.72	0.75	3.79
TRUCDAY	0.85	0.37	1.32	0.57	-0.90	-0.15
VMTCL16	$-0.36x10^{-6}$	-0.48	$0.27x10^{-6}$	0.27	$-0.89x10^{-6}$	-0.26
Constant	1.52	1.52	1.35	1.33	2.21	0.86
R^2	0.16		0.15		0.18	

Truck Accident Rates

The model of daily truck accident rates is summarized in Table 5. The model reveals a strong association of higher truck accident rates with days on which there are greater hours of snowfall. Surprisingly, none of the other variables in the linear specification were found to be significantly different from zero. Only VMTA, the daily automobile VMT, has a t-statistic that suggests significance; the sign of its coefficient suggests lower truck accident rates on days when automobile VMT is highest, such as on weekends and during the summer. Segmentation into weekends and weekdays resulted in VMTA being much more significant ($p = 0.12$) than in the pooled model. The sign of VMTA was still negative, which indicates decreased truck accident rates on days with high automobile VMT. Occurrence in the weekday segment implied lower truck accident rates during weekdays throughout the year.

It is interesting that none of the variables in the weekend model have significant coefficients other than the hours of snow.

To obtain a better idea of the influence of conditions of travel on large trucks, an additional set of regression analyses was conducted for vehicle class 6 (see Table 6). Results generally paralleled those for the all-truck model. Hours of snow was consistently significant and the only significant variable in the pooled model. Automobile VMT was again negatively associated with truck accident rate but not as strongly as in the models for all trucks. As before, the weekend segment contained hours of snowfall as the only significant predictor.

Summary

The findings for the large-truck and total-truck regression analyses are very similar: Hours of snowfall is the strongest predictor of truck accident rates, and high automobile VMT is associated with lower truck accident rates. in general, the truck accident analyses yielded models with slightly poorer goodness of fit than the automobile regression analyses. One may infer that the truck accidents were more likely due to factors not included in the models, whereas automobile accident rates were more heavily dependent on conditions of travel.

DISCUSSION OF RESULTS

In order to place this study's findings in the proper perspective, it is useful to compare them with previous studies. Research published by Vallette and others (2), Khasnabis and Atabak (8), and Scott and O'Day (13) presents findings useful for comparison.

In their study of accident experience in the State of Michigan, Khasnabis and Atabak (8) found that straight trucks had higher accident rates overall compared with tractor-semitrailers and panels, pickups, and vans. Compared with all other vehicles, tractor-semitrailers had a higher fatality rate but a lower overall accident rate. Although our truck classification does not identify straight trucks as such, vehicle class 3 would certainly include a large proportion of these vehicles and other small trucks. Our findings are similar to those of Khasnabis in that small trucks had a higher overall accident rate than large trucks. Our results further show that this is true for all comparable conditions for automobiles and large trucks. Our results differ from those of Khasnabis and Atabak in that large trucks in our data have higher overall accident rates than automobiles, primarily due to their higher accident rate in clear weather.

Scott and O'Day (13), using a large sample of main-line tollway accidents, found that the involvement rates for trucks and automobiles were not significantly different. These results are not the same as our findings, which are based on a smaller sample size. Scott also found that trucks were less affected by weather as a causative factor in accidents than were passenger cars. Comparison of means for our data generally supports this finding: The increase in accident involvement rate in snowy weather over that in clear weather is less for trucks than for automobiles; in addition, accident rates for large trucks are lower in rainy weather than in clear weather and change little or decrease at night.

Looking at a much broader class of roadway types, Vallette and others (2) found no significant difference in the accident involvement rate for trucks and automobiles. For urban and rural freeways, they found higher accident rates for tractor-semitrailers than for straight trucks, a finding opposite to ours for the most similar vehicle types. Whereas our "large" trucks include both singles and doubles, the accident rates we found for straight trucks (vehicle class 3) are directly opposite to those of Vallette and others and more closely related to the results of Khasnabis and Atabak.

None of the three previous research studies was able to make a statistical comparison of the accident rates of automobiles and trucks at this level of detail, describing conditions of travel.

CONCLUSIONS

The inclusion of conditions of travel can substantially aid in the understanding of the accident performance of different types of vehicles. Automobiles were consistently the most sensitive to travel conditions: Automobile involvement rates increased significantly at night during clear and rainy days; they also increased marginally during snow. Large and small trucks, however, had similar or lower accident rates at night.

Snowy weather was the single most important predictor of high accident rates for both trucks and automobiles for all the models tested. Weather conditions also appeared to affect different vehicle types in different ways: Large-truck accident rates actually were lower during rainy days than during clear days whereas automobile and small-truck accident rates remained approximately the same.

Although regression models of automobile and truck daily accident rates yielded low R^2 values (0.12 to 0.23), they frequently yielded significant and consistent results. As expected, snow was the most significant weather condition contributing to both automobile and truck accidents. Higher automobile accident rates were associated with high levels of truck VMT, which raises concerns about mixing high levels of these two vehicle groups in traffic.

A strong seasonal trend was apparent for automobiles: Lower accident rates were associated with days of high automobile and truck volumes, which occur mainly during summer months. These results somewhat contradict the findings regarding truck VMT but appear to reflect a different phenomenon--the twofold to threefold increase in automobile VMT during summer vacation months.

In summary, the study found important and significant changes in motor carrier and automobile accident rates when the concept of exposure was expanded to include weather conditions, daytime-nighttime travel, and, to a limited extent, vehicle mix.

The study illustrated the usefulness of combining data from divergent sources to conduct a detailed exposure analysis. The study also revealed important characteristics of motor vehicle performance as travel conditions change: Automobiles are much more sensitive to adverse weather and nighttime travel than trucks.

ACKNOWLEDGMENT

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REFERENCES

1. An Investigation of Truck Size and Weight Limits: Final Report. Office of the Secretary, U.S. Department of Transportation, Aug. 1981.
2. G.R. Vallette and others. The Effect of Truck Size and Weight on Accident Experience and Traffic Operations: Volume III--Accident Experience of Large Trucks. FHWA, 1981.
3. J. Parker. Study Faulting Twins Safety Challenged by C.F. in Court. Transport Topics, Washington, DC, July 5, 1982.
4. K. Perchonok and T.A. Ranney. Analysis of Truck, Tractor/Trailer Accident Data. Calspan Corp., Buffalo, NY, June 1976.
5. T.H. Herzog. Injury Rate as a Function of Truck Weights in Car-Truck Accidents. NHTSA, Tech. Note N43-31-7, 1976.
6. L.S. de Savornin Lohman and P.F. Waller. Trucks: An Analysis of Accident Characteristics by Vehicle Weight. Highway Safety Research Center, Univ. of North Carolina, Chapel Hill, Sept. 1975.
7. M.S. Kubacki. Collisions of Cars with Tractor-Semitrailers. HSRI Research Review, Vol. 10, No. 3, 1979.
8. S. Khasnabis and A. Atabak. Comparison of Accident Data for Trucks and All Other Motorized Vehicles in Michigan. TRB, Transportation Research Record 753, 1980, pp. 9-14.
9. L.L. Philipson, P. Rashti, and G.A. Fleischer. Statistical Analysis of Commercial Vehicle Accident Factors: Volume 1, Part 1. Traffic Safety Center, Univ. of Southern California, Los Angeles, Feb. 1978.
10. H.R. de Silva. Why We Have Automobile Accidents. Wiley, New York, 1942.
11. P.S. Carroll. The Meaning of Driving Exposure. Highway Safety Research Institute, Univ. of Michigan, Ann Arbor, HIT Lab Repts., April 1971.
12. R. Chapman. The Concept of Exposure. Accident Analysis and Prevention, Vol. 5, 1973, pp. 95-110.
13. R.E. Scott and J. O'Day. Statistical Analysis of Truck Accident Involvements. Highway Safety Research Institute, Univ. of Michigan, Ann Arbor, Dec. 1971.
14. K. Campbell, R. Scott, and S. Tolkin. Highway Safety Effects of the Energy Crisis on U.S. Toll Roads. Highway Safety Research Institute, Univ. of Michigan, Ann Arbor, June 1976.
15. W.S. Meyers. Comparison of Truck and Passenger-Car Accident Rates on Limited-Access Facilities. TRB, Transportation Research Record 808, 1981, pp. 48-53.
16. D.D. van der Zwagg. A Determination of the Relative Collision Involvement of Trucks and Other Vehicles. Highway Safety Research Institute, Univ. of Michigan, Ann Arbor, HIT Lab Repts., July 1971.
17. A.D. Ceder and M. Livneh. Further Evaluation of the Relationships Between Road Accidents and Average Daily Traffic. Accident Analysis and Prevention, June 1978.

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Variability in Rural Accident Reporting

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A research project was conducted for the Alabama Highway Department to assess the accident-reporting consistency of jurisdictions across the state. During the first phase of the research, a literature review was conducted, variables were selected for regression analysis, preliminary regression studies were begun, and a manual evaluation was conducted on the five-year accident pattern. Statistical investigations revealed strong relations between the number of accidents and several predictor variables for rural data and countywide data. The strongest single-variable model used population as the independent term and had an R^2 greater than 0.93. The strongest multiple-variable model used eight independent terms and had an R^2 greater than 0.99. Evaluation of the five-year accident pattern for individual Alabama cities and counties disclosed that 28 percent of them had erratic reporting trends. Significantly, county irregularities were not as severe as those for cities. Almost one-seventh of all cities had major discrepancies in the number of accidents reported over a five-year period. Traffic engineers and others performing safety studies must exercise care to ensure that study data reflect the character and quantity of accidents that actually occurred in the study area. Overall, the initial phase of the project was successful in documenting the existence of discrepancies in Alabama traffic accident data and in establishing strong regression relations between the number of accidents and predictor variables. Future phases of the project will address regression of city data, define reasons for discrepancies, and recommend improvements.

Historical accident data are a significant source of information used by engineers to establish safety programs and to implement safety countermeasures. These data are becoming increasingly important as safety programs receive more emphasis. This paper outlines a portion of a research project undertaken for the Alabama Highway Department to determine the consistency of the traffic accident data base.

PROBLEM STATEMENT AND RESEARCH PLAN

Reliability in the reporting of traffic accident data is obviously desirable but is not always present. In Alabama, individual jurisdictions are charged with investigating and reporting collisions. Both the quantity and quality of data appear to vary from location to location. This research was undertaken to assess the consistency of reporting, to devise a technique for predicting the number of accidents in a given location, and to identify jurisdictions where the number of accidents reported did not conform to the expected number.

The primary research technique was a regression analysis of the number of reported accidents for each Alabama city, followed by a confidence band analysis to isolate jurisdictions that did not do an adequate job of reporting. The initial portion of the project was directed toward determining the adequacy of the contemplated regression techniques.

This paper deals with the specific work steps in the first phase of the project--analysis of rural area reporting and of year-to-year consistency.

LITERATURE REVIEW

A literature review was conducted for several purposes:

1. To document the nature of the existing problem,
2. To identify previous research of a similar nature, and
3. To identify and designate variables for the statistical analysis.

The literature review is described in detail in a paper by Willis and others elsewhere in this Record. Three main reasons for consistency problems in accident data reporting were identified:

1. Variations in threshold accident reporting values (as Table 1 indicates, Alabama's threshold property-damage value of $50 or more is low in comparison with the criteria of other states),
2. Failure to investigate accidents properly, and
3. The secondary importance given to accident reporting in comparison with the many other duties of law enforcement personnel.

Table 1. Accident reporting thresholds by state.

State	Amount of Property Damage ($)	Other Criterion	State	Amount of Property Damage ($)	Other Criterion
Alabama	50		Montana	100	
Alaska	500		Nebraska	250	
Arizona	300		Nevada	250	
Arkansas	100		New Hampshire	300	
California		Injury	New Jersey	200	
Colorado		All	New Mexico	100	
Connecticut	250		New York		Injury
Delaware	250		North Carolina	200	
Florida	100		North Dakota	300	
Georgia	100		Ohio		All
Idaho	100		Oklahoma	100	
Illinois		All	Pennsylvania		Towaways
Indiana	200		South Carolina	100	
Iowa	250		South Dakota	250	
Kansas	200		Tennessee	200	
Kentucky		On request	Texas		Inoperable vehicle
Louisiana	100		Utah	200	
Maine	200		Vermont		All
Maryland		All	Virginia	100	
Massachusetts	200		Washington	300	
Michigan	200		West Virginia		All
Minnesota	100		Wisconsin	200	
Mississippi	50		Wyoming	250	
Missouri		Fatality			

Note: Data obtained from the International Association of Chiefs of Police. No information was available for the District of Columbia, Hawaii, Oregon, and Rhode Island.

SELECTION OF REGRESSION VARIABLES

During the initial portion of the investigation, a conference was conducted to select variables for the regression analysis. Representatives from the Accident Investigation and Surveillance Branch of the Alabama Highway Department and members of the project research staff prepared the list of items given in Table 2.

One of the primary considerations was the availability of the various data items. Specific variables were dismissed from further consideration if they were not readily available from conventional sources. The reason for dismissal was that, even if a variable was an excellent predictor, traffic engineers would refrain from using the prediction equation if it were not convenient to obtain data values for the variables.

It became apparent that many of the most desirable data items were not available for individual cities. However, these variables were applicable to counties and were found to be readily available. At this point, the data were placed in three categories: county, city, and rural. The county classification was used for variables applicable on a countywide basis, including both urban and rural areas. Examples include the number of vehicle registrations and the number of driver licenses.

The city classification was restricted to data applicable to incorporated cities in the state. One example is the census data used to establish the population. The final classification, rural, was used to handle data items that were only applicable to areas outside incorporated cities. For example, the rural population of a specific county would be the county population minus the population of all incorporated areas. Variables in each file are given in Table 3.

Table 2. Desirable data items for regression analysis.

Data Item	Description
Population	Census data
Paved highway	Miles of paved highway by classification
Land area	Square miles in city limits
Population density	Persons per square mile
Land use	Square miles by land use (urban, agricultural, etc.)
Employment activity	Number of jobs by category (manufacturing, etc.)
Gasoline tax	Allocation of state gasoline tax to cities and counties
Law enforcement	Number of law enforcement officers
Vehicle travel	Vehicle miles for each city
Vehicle registrations	Automobiles in a city
Driver licenses	Drivers in a city
Accidents	Number of traffic accidents

Data Strengths and Weaknesses

The obvious shortcoming of the city and rural data was the limited number of independent variables for use in the prediction equation. It is fortunate, however, that the population variable was in both sets. This was the single most desirable variable for use as a predictor because it was the easiest variable to obtain on a widespread basis.

The accident data associated with the rural data file had possessed a greater degree of reliability than the other two files. Most of these data were gathered by troopers from the Alabama Department of Public Safety, which has statewide programs for officer training and traffic accident investigation that should create a high degree of accuracy and uniformity in the reporting of accident data. On the other hand, the cities are subject to local policies and emphasis, so the quantity and quality of accident data can vary considerably from jurisdiction to jurisdiction within the state.

The county data set contained the greatest number of variables and thus offered the greatest opportunity to identify any accident prediction relations. A majority of the desirable variables, as given in Table 2, were found to be available in the county data file.

Variables Used in Analysis

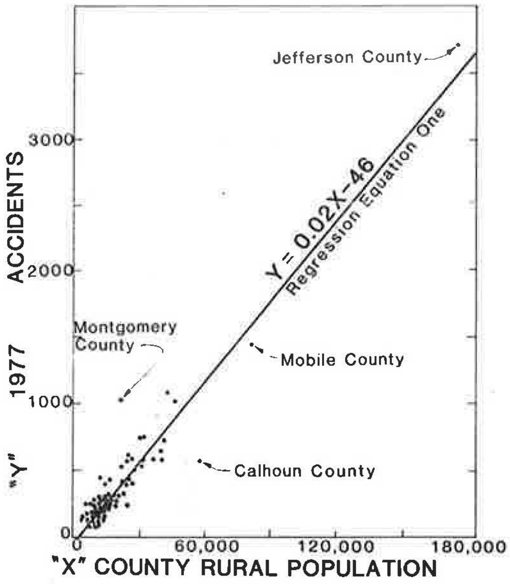
The final objective for the regression was to identify cities with irregular accident reporting characteristics. Unfortunately, the city data file was not as large or as versatile as desired for a rigorous statistical analysis. To overcome this, a procedure was formulated to use the strengths of all three data sets. The procedure consisted of the following steps:

1. The strongest accident data (the rural file) would be used in the initial investigation of the relation between accidents and population.
2. The most complete data set (county file) would be used to investigate a wide range of variables to determine the strongest possible prediction technique and to determine whether population alone was sufficient to use for prediction purposes.
3. A prediction method would be developed for

Table 3. Variables used in regression analysis.

	Data File			
Data Item	County	City	Rural	Source
Population				
1970-1977	X		X	Alabama Municipal Data Book, 1980 (12) and Information Bulletin, Directory of Mayors and Commissioners in Alabama (13)
1980	X	X		Alabama Municipal Journal (14)
Law enforcement officers				
Uniformed		X		Crime in Alabama: 1979 (15)
Civilian		X		Crime in Alabama: 1979 (15)
Traffic accidents, 1975-1979	X	X	X	Urban and Rural Accident Statistics (16)
Total miles of paved highway	X			Alabama County Data Book, 1980 (17)
Miles of state and federal route	X			Alabama County Data Book, 1980 (17)
Miles of Interstate highway	X			Alabama County Data Book, 1980 (17)
Miles of county road	X			Alabama County Data Book, 1980 (17)
Square miles of land area	X			Alabama County Data Book, 1980 (17)
Urban and rural land	X			Alabama County Data Book, 1980 (17)
Urban, agricultural, and other land	X			Alabama County Data Book, 1980 (17)
Automobile registrations, 1978	X			Alabama County Data Book, 1980 (17)
Driver licenses, 1978	X			Total licenses issued (renewals and new applications), 1977, 1978, 1979, and 1980, Alabama Department of Public Safety
Gasoline tax allocation, 1979	X			Gasoline tax distribution spread: Oct. 1, 1978-Sept. 30, 1979, Alabama Treasurer's Office

Figure 1. Rural data with regression equation.



the city data file. Population would be used as the independent variable if warranted by the findings of the first two steps. Should the initial step reveal that population was not a strong predictor, efforts would have to be renewed to find suitable variables.

The aim of the three-step investigative process was to determine whether the population variable was sufficient to use for predicting accidents, or if further variables would have to be added to the data set before proceeding with the research.

REGRESSION OF RURAL DATA

An objective of regression analysis is to fit an equation to the data that best explains the functional relation between the dependent variable and some set of regressor variables. The criterion for determining the appropriate equation is to minimize the sum of the squared differences between the actual observed value and the predicted value of the dependent variable. By observing the patterns of the individual differences for one or more models, it is possible to determine the transformations needed in order to better meet the necessary assumptions and to determine the appropriate model.

Regression Work Steps

The analysis of the data consisted of several steps. Initially, the data were edited in order to identify erratic or inconsistent observations. The second step consisted of determining the most complete model that best explained the functional relation between the number of accidents and various regressor variables that characterize the rural area. Finally a reduced model was sought that was less complex (or contained fewer regressor variables) than the complete model but did not excessively sacrifice predictive ability.

Step One

Erratic data points, called outliers, may occur for several reasons. Clerical errors could exist, a value of a variable may have been recorded or keypunched incorrectly, or the data source may have been in error. It is also possible that the area might have been atypical when compared to other areas of similar characteristics. During the regression analysis, outliers were identified by using various plots of residuals, such as the residual versus each regressor variable, the predicted Y-values, and the "deleted residuals" (18). In addition, statistics such as "Cook's distance measure," the "deleted residual t-statistic," and leverage factors were used for spotting outliers (19-21).

Step Two

The data were analyzed for variations of fundamental assumptions for regression analysis. These assumptions were that the residuals were normally and independently distributed, with a constant variance for each set of values of the regressor variables. In addition, if the regressor variable was multicollinear, alternative estimation procedures were examined.

Step Three

After the identification and correction of clerical errors, successive analyses were performed to determine the "best" equation to fit the data. A few unusual localities were removed to determine their effect on the remainder of the locations; then variables were systematically added, removed, or combined. During this entire phase of the analysis, several measures of effectiveness were examined and tabulated to identify the equation that best fit the data.

Step Four

The last phase of the analysis consisted of simplifying the equation that had previously been identified as best fitting the data. This involved removing those variables that made only marginal contributions to the success of the regression equation. The multiple work steps just described were not applicable in all cases. There were times when simpler methods were quite appropriate and the detailed analysis described here was not necessary.

Population as a Predictor

The initial step was to plot the variables to determine the presence or absence of patterns and to locate erroneous data points. The data were found to lie in a linear band with only a small amount of scatter, as shown in Figure 1. Four counties were identified as falling away from the rest of the data. Montgomery County had a higher than average number of accidents, and Calhoun had a lower than average number. Two locations, Mobile and Jefferson, fit the linear pattern but were displaced from the remainder of the data due to large rural populations. All four of the outlier points have been identified in the figure.

Because no errors were apparent and the data formed a linear pattern, a computer-assisted analysis was performed to determine the best linear equation. The least-squares regression technique was used to produce the following formula:

$$Y = 0.020X - 46 \qquad (1)$$

where Y is the number of accidents and X is the population. The generalized formula has been superimposed on Figure 1 as regression Equation 1.

The two values used to indicate how effectively the regression equation fit the data were definitely quite strong. The value for R^2 was 0.92, which is exceptional for accident data, and the standard error was 138.6. Part of the strength of these measures was due to the displacement of Jefferson County. A single remote data point significantly influences the curve fit for a scattered group of points. Jefferson is the only data point on the right end of the curve, and its high numerical value exerted a large influence on the measures of effectiveness.

To determine the effects of the Jefferson County rural area, this data point was removed and the analysis was repeated. The resulting formula was similar to the initial regression results:

$$Y = 0.016X + 7 \qquad (2)$$

where Y and X retain their former definitions. For regression Equation 2, the R^2 was 0.78 and the standard error was 117.5. Even though the R^2 was lower than the initial regression, it is still considered strong and could be used for predictive purposes. This was particularly true in this case because the standard error was even smaller.

The examination of rural population as an accident predictor was fruitful. Equations were developed that positively linked the two variables. Equation 2 was the most appropriate analysis tool and proved strong enough to be used for predictive purposes.

REGRESSION OF COUNTY DATA

Computer Runs

The second regression study was thorough, encompassing all of the variables given in Table 3. Other variables were formed by combining or factoring existing variables. The same regression techniques previously discussed were used for the county data. Many computer analyses were conducted, with variables added or deleted between runs, with and without outlier points. The results of each run guided the scope of the following run. A series of more than 25 refinements was conducted, and each refinement had multiple steps. The most prominent of the runs are discussed in the following paragraphs.

Results of the Analysis

Variables in the initial computer run included the calculated value of population density (population/land area) and its square to account for curvature. The fit was very good, and the predictor could be considered to be accurate. The R^2 was 0.9955 and the standard error was 285.

Even though the initial run was strong, attempts were made to improve the predictive equation. Several subsets of the variables were examined. The R^2 values did well for these runs, but the standard error tended to increase as variables were deleted. When population alone was used, the standard error increased to 459.

It became apparent that the largest counties were not being fit well. Several runs were made to determine the most effective method of handling the five counties with large populations. One county was not fit well for any run, whereas another dominated any equation in which it was included due to its large size. As a result, runs were made omitting the five largest counties. The resulting R^2 was 0.93 and the standard error was 209.

During additional runs, subsets of other variables were examined. Several cases were noted in which variables were interchangeable. For example, driver licenses and gasoline tax allocations provided the same explanatory power for the number of accidents; either could be used when coupled with roadway mileage and county area.

The R^2 values for the 25 runs were closely grouped from 0.9955 to 0.9257. The standard error ranged from 459 to 203, the smaller values being associated with the less complex models. All of these measures of effectiveness were quite strong.

The best single-variable predictor model was based on population, and the measures of effectiveness ($R^2 = 0.9257$ and standard error = 203) were quite strong. In the following equation, Y is the number of accidents and X is the county population:

$$Y = 0.033\,69X - 337.42 \qquad (3)$$

In summary, it was shown that the number of accidents in a county could be estimated by using the characteristics of the county. In particular, population was found to be the best single-variable predictor available. The other variables helped the model, but the equation did well even without them.

EVALUATION OF FIVE-YEAR RECORD

During preparation of the data, several cases of erratic year-to-year reporting were noted. To evaluate data consistency, accident histories for each city and county rural area in the state were evaluated. The research technique involved a manual screening of accident records for the five most recent years. An analysis of coefficients of variation was conducted to verify the screening process. The objective was to identify those jurisdictions with erratic accident reporting patterns.

Classification Criteria

To quantify any discrepancies noted during the review of accident data, subjective criteria were formulated and placed in three categories. The various criteria for each category are as follows:

1. Category 1--(a) One unusual year in a five-year period, (b) a major change in the number of accidents, and (c) a minor change in the number of accidents;
2. Category 2--(a) A highly abnormal year in a five-year period, (b) two or more unusual years in a five-year period, (c) major changes in the number of accidents, (d) an accelerated decrease in the number of accidents, and (e) a city with few previous accidents suddenly reporting a significant number; and
3. Category 3--(a) A highly erratic accident pattern, (b) severe changes in the number of accidents, and (c) an obvious and drastic error in the reporting of the number of accidents.

Category 1 was reserved for the mildest types of erratic accident histories. In general, a city with some unusual occurrence in accident reporting would be placed in this category whether the city had any control over the erratic reporting or not. A city could receive a category 1 accident history rating due to one year with an unusually large number of accidents even though random chance rather than the city's reporting procedures caused the erratic pattern. Not all of the cities on the category 1 list could be termed deficient in reporting practices.

Category 2 applied to cities with more erratic accident histories than cities in the first category. Although it was possible that such deviations were the result of random chance, it was much more likely that improper reporting caused the problem. The criteria for category 2 in the list above indi-

Table 4. Summary of Alabama locations with erratic accident histories.

	Category 1		Category 2		Category 3		All Categories	
Location	No.	Percent	No.	Percent	No.	Percent	No.	Percent
Cities	64	15.0	36	8.5	21	5.0	121	28.6
Rural areas	18	26.9	1	1.5	0	0.0	19	28.4

Table 5. Examples of erratic year-to-year accident reporting (category 3).

	No. of Accidents				
City	1975	1976	1977	1978	1979
A	1150	78	3	1481	1595
B	285	51	78	173	6
C	36	6	1	61	55
D	4	5	68	476	341
E	1	1	213	132	227

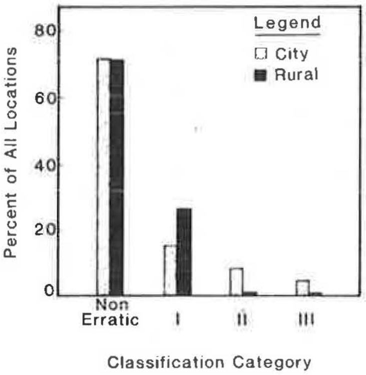


Figure 2. Percentage of Alabama cities with erratic accident histories.

cate more severe abnormalities than the criteria for category 1.

Category 3 cities experienced the most severe deviations and the most erratic patterns of accident reporting. The patterns were so unusual and pronounced that they were almost certainly due to variances in reporting practices. This type of pattern is obvious from the number of accidents occurring in consecutive years.

Results of the Evaluation

The 67 county rural areas and all 423 cities were subjected to manual review based on the criteria outlined above. Because the criteria were subjective, two independent reviews were conducted to offset any bias on the part of the reviewer. A summary of the findings is presented in Table 4, and a sample of highly erratic year-to-year reporting by some cities (category 3) is given in Table 5.

In Table 4, note that the city and rural data files had almost exactly the same percentage of erratic locations (28.6 percent for city and 28.4 percent for rural). This would seem to indicate that a certain amount of error may be associated with both files. It could also be interpreted to mean that the random nature of traffic accident occurrence exerted a powerful influence on all data. Further examination tends to discredit the second conclusion.

The erratic pattern for rural areas was concentrated in category 1. Only one location was rated as high as category 2. Thus, the deviations from uniform accident reporting could be considered mild for the rural data. City ratings were much different from those observed for rural locations (see Figure 2). A significant percentage received ratings worse than category 1. One out of every 20 cities exhibited the most severe variations and was placed in category 3. This indicates a very serious problem. Apparently, reported data for these cities do not realistically represent the number or the character of accidents that actually occurred. Safety studies that use such data could produce misleading results.

A significant conclusion can be drawn from the preceding analysis. Traffic engineers must exercise care when using Alabama accident data. Several years worth of accident data should be examined to ascertain the true accident pattern before performing a study on data for a single year at a specific location.

Locations of Erratic Data

The cities that were found to report data erratically are shown in Figure 3. The category 3 (most severe) locations are denoted by large, dark circles. There is not a clear overall pattern to the spots.

Category 2 cities are denoted by triangles and category 1 cities are shown by small squares. In several locations, these symbols are clustered or are spaced along a particular route; however, no pattern could be discerned. Several attempts were directed toward isolating a relation between location and severity of erratic reporting. These attempts were not successful.

The major conclusion that can be drawn from Figure 3 is that erratic reporting of accidents appears to be widespread in all categories. Further investigation would be necessary to determine whether the deviation at specific locations is due to fluctuations in traffic volume or local law enforcement policies.

Effect of City Size

A brief investigation was conducted to determine whether city size contributed to deficient reporting practices. The majority of Alabama cities are small: one-third have populations under 500; one-half have less than 1000. It would seem that the large number of small cities would contribute to erratic reporting.

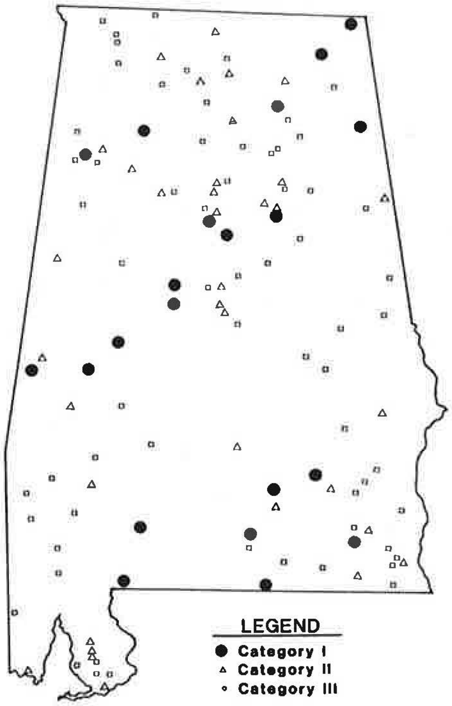
Cities with erratic accident reporting and cities with nonerratic reporting were compared as to size. The two were virtually the same, which indicates that the cities with erratic reporting were a representative sample of all Alabama cities. No relation between accident reporting and city size could be established from the data gathered for this project.

CONCLUSIONS DRAWN FROM YEAR-TO-YEAR REPORTING

Accident data for a five-year period were compiled for each Alabama city. Each city's record was examined for signs of irregular reporting by using a subjective scale to establish the degree of erratic behavior. The following conclusions were reached:

1. Approximately one-fourth of all Alabama cities displayed erratic patterns in the number of reported traffic accidents during the period 1975-1979. Five percent of all Alabama cities showed serious discrepancies in the number of accidents reported over the five-year period.
2. During the 1975-1979 period, 8.5 percent of

Figure 3. Locations of Alabama cities with erratic accident histories.



all Alabama cities showed serious accident reporting discrepancies.

3. Approximately one-fourth of Alabama county rural areas displayed erratic accident reporting patterns during the period.

4. Rural area accident reporting was less erratic than city accident reporting. Although the percentage of jurisdictions with erratic patterns was the same for both groups (28 percent), there were no severe discrepancies in the rural area classification.

5. Traffic engineers and others performing safety studies must be very careful in using accident data for a specific location because one-seventh (5 percent + 8.5 percent) of all Alabama cities have seriously erratic accident histories. It is recommended that several years of data be checked to ensure that data were reported uniformly and that they accurately represent a specific location.

6. Erratic reporting of traffic accidents does not seem to be strongly linked to the size or location of Alabama cities.

SUMMARY

The literature review indicated that many researchers have found bias and inconsistency in traffic accident data. None of the previous studies documented the consistency of reporting from location to location or from year to year.

Desirable variables were identified for use in the regression analysis. The majority of these variables were not readily available for Alabama cities, so three data files were developed: county, rural, and city. Because there were few variables in the city data set, the other two files were subjected to extensive analysis techniques. Strong relations were detected for both data files. Population was shown to be the best single-variable predictor model, giving excellent values for the measures of effectiveness.

Five years of accident data were screened to evaluate consistency in year-to-year reporting of accidents. About one-fourth of all Alabama cities and one-fourth of the rural areas were found to report erratically. The inconsistency in rural reporting was mild, but the reporting of at least one-seventh of all cities was seriously erratic. The reporting in these cities was so inconsistent that it might seriously bias the results of any safety studies in which it was used.

At the close of the initial phase of the project, there were two significant findings. Strong regression relations had been identified between population and traffic accidents. This indicated that statistical methods might be successful in identifying jurisdictions that do not do an adequate job of accident reporting. The second finding was conclusive proof of erratic year-to-year reporting. For the first time, the magnitude of the inconsistencies was documented.

Succeeding portions of the research project are to be directed toward regression of city data, identification of reasons for deficiencies, and recommendations for improving future reporting of accident data.

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The contents of this paper reflect our views, and we are responsible for the facts and the accuracy of the data presented. The contents do not necessarily reflect the official view or policies of the Alabama Highway Department or the Office of Highway and Traffic Safety. The paper does not constitute a standard, specification, or regulation.

REFERENCES

1. F.M. Council and others. Accident Research Manual. Highway Safety Research Center, Univ. of North Carolina, Chapel Hill, Rept. DOT-FH-11-9424, Feb. 1980.
2. K. Pfundt. Three Difficulties in Comparison of Accident Rates. Accident Analysis and Prevention, Vol. 1, No. 3, 1969.
3. E.G. House and others. How Complete Are Driver Records? An Analysis Based on Insurance Claim Crashes. Highway Safety Research Center, Univ. of North Carolina, Chapel Hill, 1974.
4. Helmets Cut Crash Odds for North Dakota Cyclists. Highway Loss Reduction Status Report, 1979.
5. J.K. Kihlberg and K.J. Tharp. Accident Rates as Related to Design of Rural Highways. NCHRP, Rept. 47, 1968.
6. J.P. Bull and B.J. Roberts. Road Accident Statistics: A Comparison of Police and Hospital Information. Accident Analysis and Prevention, Vol. 5, No. 1, 1973.
7. D. Mitchell and C. Lynn. Use of the Fatal Accident Reporting System (FARS) in Evaluating Characteristics of Virginia Traffic Fatalities. Proc., Human Factors Society, Santa Monica, CA, Oct. 1978.
8. J.P. Gerrard and W.W. Mosher. Analysis of Reliability of Accident Information Obtained from Off-Scene Sources: Part 1. Institute of

Transportation and Traffic Engineering, Univ. of California, Los Angeles, Rept. Rr-68-63, 1968.
9. R. Henson, C. Cannell, and S. Lawson. Effects of Interviewer's Style and Question Form on the Validity of Reporting Automobile Accident Information. Highway Safety Research Institute, Univ. of Michigan, Ann Arbor, HIT Lab Reports, Vol. 3, No. 12, Aug. 1973.
10. P.J. Cooper. Effects of Increased Enforcement at Urban Intersections on Driver Behavior and Safety. TRB, Transportation Research Record 540, 1975, pp. 13-22.
11. J. Byun, W.R. McShane, and E.J. Cantilli. Changing Baseline in Transportation Safety: An Assessment of Some Key Factors. TRB, Transportation Research Record 709, 1979, pp. 6-10.
12. Alabama Municipal Data Book, 1980. Alabama Office of State Planning and Federal Programs, Montgomery, 1981.
13. Information Bulletin, Director of Mayors and Commissioners in Alabama. Alabama League of Municipalities, Montgomery, Aug. 1980.
14. The Alabama Municipal Journal. Alabama League of Municipalities, Montgomery, Vol. 38, No. 8, Feb. 1981, pp. 14-18.
15. Crime in Alabama: 1979. Uniform Crime Reports Division, Alabama Criminal Justice Information Center, Montgomery, 1980.
16. Urban and Rural Accident Statistics. Accident Identification and Surveillance Section, Alabama Highway Department, Montgomery, 1975-1979 Computer Summaries.
17. Alabama County Data Book, 1980. Alabama Office of State Planning and Federal Programs, Montgomery, 1981.
18. R.F. Gunst and R.L. Mason. Regression Analysis and Its Applications. Marcel-Dekker, Inc., New York, 1980.
19. O.F. Dunn and V.A. Clark. Applied Statistics: Analysis of Variance and Regression. Wiley, New York, 1974.
20. S. Chatterjee and B. Price. Regression Analysis by Example. Wiley, New York, 1977.
21. E.R. Mansfield, R.F. Gunst, and J.W. Wester. An Analytic Variable Selection Technique for Principal Component Regression. Journal of the Royal Statistical Society, Series C, Vol. 26, 1977, pp. 34-40.

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Application of Microcomputer Technology to Local Accident Problem Identification

DAVID B. BROWN AND CECIL W. COLSON

The potential for implementing a microcomputer-based problem identification system in small to medium-sized cities is explored in terms of the City Accidents RAPID Evaluation (CARE) system. The benefits of such a system are examined. One primary benefit is overall data improvement for all applications. The capabilities of CARE are explained in terms of a user-oriented menu-driven operating system. Example outputs are presented along with the methodology for their generation. Finally, some technical specifications are provided to illustrate considerations required for actual installation.

Problem identification is an essential part of the design of an optimal safety system at all levels (1). NHTSA has recognized the criticality of performing systematic problem identification and has incorporated this as a requirement for each state highway safety plan (HSP) (2,3). But problem identification is also essential at the local level for local countermeasure implementation. In fact, the closer to the source of the problem the process of problem identification and evaluation is performed, the more effective it will be. For example, if local law-enforcement officers knew the locations in their city where accident rates are high as well as the times and types of accidents at those locations, they would then be in a position to implement selective enforcement countermeasures.

The benefits of having a local problem identification capability are obvious. Being able to obtain information for specific problem subject areas (such as accidents involving alcohol or pedestrians) or specific locations gives the local decisionmaker the information needed to develop an optimal allocation of resources. A few years ago, it was not economically feasible to provide direct on-line query capability to a small town. Now, however, with the advances made in microtechnology, every city and town of any reasonable size can take advantage of the tools that have been developed. One of the major benefits of distributed problem identification will be the tremendous increase in accuracy of the records themselves as local police realize the important role that accident records can play in countermeasure development.

City Accidents RAPID Evaluation (CARE) (4) is a microcomputer-based system that enables city officials to quickly retrieve information stored in their accident records. The users of CARE need no formal training in computer hardware or software since no knowledge of computers is required. The various options of CARE are incorporated into menus that thoroughly guide the user in obtaining the desired output. By following the directions given on these menus, all output required can be readily obtained at the terminal and/or on a printer.

CARE is patterned after Records Analysis for Problem Identification and Definition (RAPID) (5), a system developed for statewide accident problem identification that has been installed in Alabama, Kentucky, South Carolina, Tennessee, and Delaware. The differences between CARE and RAPID are as follows:

1. CARE is designed to operate on its own dedicated hardware, a microcomputer in the $10 000-$15 000 price range, whereas RAPID requires a large system because of the large subsets necessary for statewide application.

2. CARE is designed to provide problem identification for a moderate-sized city, whereas RAPID is generally applied statewide.
3. CARE will generally be based on the most recent three years of accident data, whereas RAPID problem identification generally uses one year of data. (Informal studies in Alabama have shown that three years provides an optimal balance between data completeness and timeliness.)
4. Because of the local application, variables used for statewide research will generally be excluded from CARE. The CARE variables are only those that have application to local decisionmaking.

CARE provides the following capabilities directly to the user:

1. The user can create a subset of the city's accident records according to any logical specification, such as all pedestrian accidents, alcohol-related fatal accidents, motorcycle accidents at a given intersection, etc.
2. The user can obtain labeled frequency distributions for the accident subset chosen. Note that the production of total citywide frequency distributions (for all variables) falls within this capability. Any or all variables (such as time of day, day of the week, weather, etc.) can be selected by the user on-line.
3. Labeled histograms (graphs) of any frequency distribution produced by capability 2 can be obtained.
4. Fully labeled cross tabulations for any of the variables for subsets produced by capability 1 can be obtained.
5. The user can find high accident locations according to user-specified criteria [a "location" is specified by road code(s) and/or mileposts]. The interactive nature of this task enables the user to try any number of alternative criteria in order to obtain the number and the type of high accident locations desired.
6. The user can obtain frequency distributions for any variable for locations found by capability 5 to be high accident locations or for any other location specified by the user.
7. The user can obtain the accident report numbers for any subset of the accident records so that the hard copy for particular types or locations of accidents can be retrieved.

Although the capabilities of CARE are quite sophisticated, they can be obtained by anyone by merely selecting an option on a menu. To understand the capabilities of CARE, it helps to follow the flow of data from the origin to the final CARE output report. Suppose that a pedestrian accident occurs in a specific city, injuring a child on his or her way to school. This accident is recorded on a standardized form by an officer of the local police department. This hard-copy form is sent to a central point in the state for data entry. It, along with thousands of other records, becomes part of the state's accident records data base, which is generally stored on tape.

The accident records data base described above is generally not constructed with problem identification in mind. In fact, it contains virtually all of the codeable elements from the accident records. Many of these are not required for problem identification work, and generally they are not in a form that is compatible with problem identification. For example, the pedestrian's actual age will probably be coded on the tape whereas age intervals (e.g., 0-4, 5-7, 8-9, 10-15, 16-21, etc.) would be much more useful for problem identification and cross tabulation. In addition, certain calculations and other data manipulation might be required for problem identification. For this reason, it is essential to reformat and modify this data base before trying to use it for problem identification.

To resume the trace of the data, a program is now run to create a new tape which is totally compatible with CARE formats and objectives. (The original tape remains unaffected and may be used for other purposes.) It is important to note here that CARE can work on any properly formatted data base. The arrangement, number, or type of variables is totally flexible and may be specified by the user during the development of the BASE program. At this point, the records for the particular city to be considered are selected from the reformatted tape and downloaded onto the microprocessor hard disk. This new subset of data that resides on the hard disk is called the CARE Master Data Base. For cities in the 20 000 to 40 000 population grouping, this will produce from 3000 to 7500 records for a three-year time period. For larger cities, fewer years of data will be sufficient for problem identification purposes.

Residing in a small subset on the microprocessor hard disk, the data are now ready for quick processing through any of the CARE processing options: frequencies, histograms, or cross tabulations. They can also be processed through high accident location determination and reporting modules.

For example, suppose that the pedestrian accident above has caused considerable pressure in a given city for an increase in the number of school crossing guards. In order that these additional guards be placed where and when they can be most effective, a report consisting of the age distribution of the pedestrian accidents in that city over the past three years by severity, day of the week, pedestrian sex, and pedestrian action is required. Further, the specific locations at which the 7- to 9-year-old age group had accidents and the times at which these accidents occurred will be useful in making tactical decisions. With CARE this information is readily available, and it can be printed out for a report in a matter of a few seconds after the request is made. Similarly, any other classification of accidents can be studied in detail by using CARE.

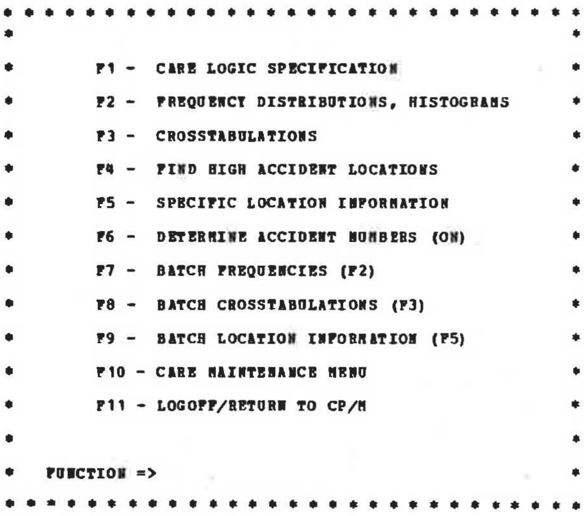
CARE OPERATIONS

An overview of the CARE functions can easily be obtained because CARE is totally menu driven. This means that option lists appear on the terminal that thoroughly guide the user in obtaining every CARE output. No supplementary documentation is required to use the system, and no knowledge of computers or data processing is required. To illustrate this concept, consider the CARE supervisory menu (SM) shown in Figure 1, which will appear on the terminal screen when the system is turned on. The top row of keys on the terminal are function keys labeled F1, F2, ... F11. The user merely pushes the key that corresponds to the desired function on the menu. The following summary illustrates the CARE capabilities.

SM-F1 - CARE Logic Specification

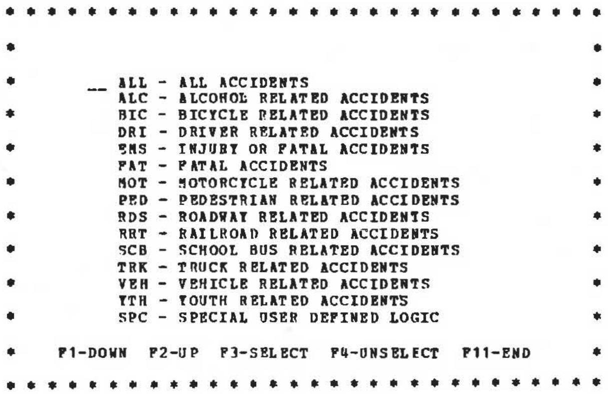
The SM-F1 option enables the user to specify any subset of records. Standard subsets such as pedestrian, speed, or alcohol will appear immediately as on the menu shown in Figure 2. The user can subdivide the data into any combination of these standard subsets--for example, speed and fatal accidents involving alcohol. The menu also gives the user the ability to combine subsets. For example, all accidents that are either bicycle or pedestrian related

Figure 1. CARE supervisory menu.



```
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                             *
*         F1 - CARE LOGIC SPECIFICATION                       *
*         F2 - FREQUENCY DISTRIBUTIONS, HISTOGRAMS            *
*         F3 - CROSSTABULATIONS                               *
*         F4 - FIND HIGH ACCIDENT LOCATIONS                   *
*         F5 - SPECIFIC LOCATION INFORMATION                  *
*         F6 - DETERMINE ACCIDENT NUMBERS (ON)                *
*         F7 - BATCH FREQUENCIES (F2)                         *
*         F8 - BATCH CROSSTABULATIONS (F3)                    *
*         F9 - BATCH LOCATION INFORMATION (F5)                *
*         F10 - CARE MAINTENANCE MENU                         *
*         F11 - LOGOFF/RETURN TO CP/M                         *
*                                                             *
*    FUNCTION =>                                              *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

Figure 2. CARE logic menu.



```
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

*                                                             *

*       __ ALL - ALL ACCIDENTS                                *
           ALC - ALCOHOL RELATED ACCIDENTS
*          BIC - BICYCLE RELATED ACCIDENTS                    *
           DRI - DRIVER RELATED ACCIDENTS
*          EMS - INJURY OR FATAL ACCIDENTS                    *
           FAT - FATAL ACCIDENTS
*          MOT - MOTORCYCLE RELATED ACCIDENTS                 *
           PED - PEDESTRIAN RELATED ACCIDENTS
*          RDS - ROADWAY RELATED ACCIDENTS                    *
           RRT - RAILROAD RELATED ACCIDENTS
*          SCB - SCHOOL BUS RELATED ACCIDENTS                 *
           TRK - TRUCK RELATED ACCIDENTS
*          VEH - VEHICLE RELATED ACCIDENTS                    *
           YTH - YOUTH RELATED ACCIDENTS
*          SPC - SPECIAL USER DEFINED LOGIC                   *

*    F1-DOWN  F2-UP  F3-SELECT  F4-UNSELECT  F11-END          *

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

can be examined concurrently. All of this is performed by entering options specified at the bottom of the menu. Once the given subset of the records is determined, the user is queried for a title. This title will appear at the top of every page of output generated on the printer. After these specifications, the system returns control to the supervisory menu. The logic and the title specified will remain in effect until F1 is entered once again from the supervisory menu.

SM-F2 - Frequency Distributions, Histograms

Once the user specifies the subsets to be processed, the next step is to designate the processing desired. This option enables tabular summaries of any of the variables in the CARE master data base to be returned to the screen or printer in the form of frequency distributions. There is also the option to generate a graphical picture of any of these frequency distributions. If a hard copy of the variable list (the choice of variables and their numbers) is not available, the user can obtain a quick listing of these on the screen or the printer merely by pressing the appropriate function button given on the menu.

SM-F3 - Cross Tabulations

The SM-F3 option is another processing option that can be applied to any subset specified by SM-F1. When the cross-tabulation option is selected, the user will be queried for a pair of variables. The system will then print out the cross tabulation on the line printer, after which another pair of variables may be entered.

SM-F4 - Find High Accident Locations

The SM-F4 function is used to find high accident locations that may be hazardous or might need attention because of the volume of traffic. The objective of SM-F4 is to find locations that either have a high total frequency of all accidents or have a high frequency of a given type of accident (e.g., pedestrian, injury, or any other of the logical qualifications specified in SM-F1). The user is queried for the minimum number of accidents needed to qualify a location for this category. An entry of 1 will generate all locations. Once specific locations are found, frequency distributions and/or accident numbers for any of the locations can be generated by following the instructions given.

SM-F5 - Specific Location Information

The SM-F5 function is used to obtain detailed information on a location-by-location basis. It complements SM-F4, which finds the high accident locations. Once specific locations are found, the next logical step is to determine the details, such as weather, roadway condition, lighting, and time of day, at that location. When SM-F5 is selected, the user will be queried for the location to be processed. A selection may then be made of any of the variables in the data base. Abbreviated frequency distributions (i.e., without percentages) will be listed for these variables. This printout can then be used for an on-site investigation. Accident numbers can also be obtained within this option.

SM-F6 - Determine Accident Numbers

Accident numbers are required to obtain the hard-copy original of the accident report. These are of obvious value in investigating high accident locations. However, quite often specific information that has not been entered into the computer system will be required from the hard copy for a subset of accidents. For example, a recent request was made for the names of all children between the ages of 6 and 10 who were injured in pedestrian accidents in a given local area. CARE can be used to obtain the subset through logic specification (SM-F1). Once this has been specified, SM-F6 will return the accident report numbers for all accidents in the subset. Accident numbers can also be obtained by location within SM-F4.

SM-F7 - Batch Frequencies (F2)

The SM-F7 function enables frequency distributions and histograms to be generated on a production basis rather than on-line. The system will query for as many variables as the user desires to input. Variable ranges may be input as well as individual variables to save time in data entry. Once all variables are entered, the system will produce all frequency distributions and/or histograms requested.

SM-F8 - Batch Cross Tabulations (F3)

Cross tabulations can also be obtained in a batch mode to save user time. In this case, the user will be queried for all variables for which cross tabulations are required.

SM-F9 - Batch Location Information (F5)

In cases where several variables for a large number of locations are to be output, this batch option for specific location information will be used.

SM-F10 - Care Maintenance Menu

A number of "housekeeping" chores must be performed to keep the CARE system operating properly. For example, adding a new road code requires an addition to the road name file. Similarly, each year (or more frequently) new data will be added to the system and this requires the execution of certain utility programs. SM-F10 presents the user with an entire menu of these maintenance items.

SM-F11 - Logoff/Return to CP/M

The SM-F11 function makes possible a systematic shutdown of the system, which is necessary to protect data on the hard disk. It also makes possible a convenient exit to CP/M so that the hardware can be used for systems other than CARE.

EXAMPLE CARE OUTPUTS

Frequency Distributions, Histograms

When function F2 is entered from the supervisory menu, the CARE frequency menu will appear immediately. To specify a variable, the user merely inputs the variable number for which a frequency distribution is desired. The frequency distribution will appear on the screen in a matter of seconds. The listing on the screen is similar to that shown in Figure 3. (The example shown is for the city of East Greenford for the 1979-1981 period. The title input during SM-F1 was "Alcohol Injury Accidents Study," and the logic is for ALC and EMS--i.e., alcohol-related accidents that resulted in one or more injuries.) A message at the bottom of the screen tells the user to press any key to generate the histogram. When this is done, a histogram similar to that shown in Figure 4 will appear on the

Figure 3. CARE frequency analysis.

```
ALCOHOL INJURY ACCIDENTS STUDY                 02-02-82
EAST GREENFORD: 1979-81
LOGIC SELECTION:  ALC and EMS

C002        MONTH
                                RELATIVE     ADJUSTED   CUMULATIVE
CATEGORY             ABSOLUTE   FREQUENCY    FREQUENCY    ADJ FREQ
LABEL      CODE     FREQUENCY   (PERCENT)    (PERCENT)   (PERCENT)

January       1         2           4.4          4.4         4.4
March         3         4           8.9          8.9        13.3
April         4         6          13.3         13.3        26.7
May           5         2           4.4          4.4        31.1
June          6         9          20.0         20.0        51.1
July          7         2           4.4          4.4        55.6
August        8         1           2.2          2.2        57.8
October      10         3           6.7          6.7        64.4
November     11        11          24.4         24.4        88.9
December     12         5          11.1         11.1       100.0
                     ------       -------      -------
            TOTAL      45         100.0        100.0

Subset size: 45 Records (16.014% of 281 Record CARE Database)
```

Figure 4. CARE frequency histograms.

```
ALCOHOL INJURY ACCIDENTS STUDY                 02-08-82
EAST GREENFORD: 1979-81
LOGIC SELECTION:  ALC and EMS

C002      MONTH

CODE
       I
     1 ****** ( 2 )
       I  January
       I
     3 *********** ( 4 )
       I  March
       I
     4 **************** ( 6 )
       I  April
       I
     5 ****** ( 2 )
       I May
       I
     6 *********************** ( 9 )
       I June
       I
     7 ****** ( 2 )
       I  July
       I
     8 **** ( 1 )
       I  August
       I
    10 ******** ( 3 )
       I  October
       I
    11 ***************************** ( 11 )
       I  November
       I
    12 ************* ( 5 )
       I  December
       I.........I.........I.........I.........I.........I
       0         4         8        12        16        20
       Frequency

Subset Size:  45 Records  (16.014%  of 281 Record CARE Database).
```

Figure 5. CARE cross-tabulation analysis.

```
1981 SEVERITY ANALYSIS                               02-25-82
EAST GREENFORD
LOGIC SELECTION: ALL

C006    ACCIDENT SEVERITY    BY    C040    LIGHT

                   C040
          COUNT   I
          ROW PCT IPROPERTY NONFATAL FATALITY   ROW
          COL PCT I DAMAGE   INJURY            TOTAL
          TOT PCT I      1 I      2 I      3 I
C040      ------------------------------------I
                1 I    435 I     77 I      2 I   514
DAYLIGHT          I   84.6 I   15.0 I    0.4 I  63.9
                  I   65.9 I   55.0 I   50.0 I
                  I   54.1 I    9.6 I    0.2 I
                  ----------------------------I
                2 I      2 I      0 I      0 I     2
DAWN              I  100.0 I    0.0 I    0.0 I   0.2
                  I    0.3 I    0.0 I    0.0 I
                  I    0.2 I    0.0 I    0.0 I
                  ----------------------------I
                3 I     19 I      4 I      0 I    23
DUSK              I   82.6 I   17.4 I    0.0 I   2.9
                  I    2.9 I    2.9 I    0.0 I
                  I    2.4 I    0.5 I    0.0 I
                  ----------------------------I
                4 I    125 I     32 I      1 I   158
DARKNESS          I   79.1 I   20.3 I    0.6 I  19.7
                  I   18.9 I   22.9 I   25.0 I
                  I   15.5 I    4.0 I    0.1 I
                  ----------------------------I
                5 I     79 I     27 I      1 I   107
DARKNESS,         I   73.8 I   25.2 I    0.9 I  13.3
RD. LIGHTS        I   12.0 I   19.3 I   25.0 I
                  I    9.8 I    3.4 I    0.1 I
                  ----------------------------I
           COLUMN      660      140        4     804
            TOTAL     82.1     17.4      0.5   100.0

SUBSET SIZE: 804 RECORDS(100.000% OF 804 RECORD CARE DATABASE).
```

Figure 6. CARE high accident locations.

```
BICYCLE ACCIDENT LOCATIONS
EAST GREENFORD 1979-1981          MINIMUM ACCIDENTS: 1
LOGIC SELECTION:  BIC

ACCIDENTS                        LOCATION-INTERSECTION
                                 ON                  AT
  2                     0030-DEAN RD.      0035-AVONDALE ST.
  1                     0036-CLANTON AVE.  0047-BRUTON ST.
  1                     0043-COLSON LA.    0051-CLARK AVE.
  1                     0043-COLSON LA.    0067-CHURCH ST.

ACCIDENTS                        LOCATION-NONINTERSECTION
                     ON                BETWEEN               AND
  1     0036-CLANTON AVE.    0047-BURTON ST.    0058-COOK ST.
  2     0044-COX ST.         0018-BINFORD RD.   0019-BROWN ST.
  1     0072-DELWOOD DR.     0021-BOWDEN AVE.   0038-CARTER ST.

TOTAL ACCIDENTS: 9
```

screen. The user is given the option to print none, one, or both of these outputs to the printer. Regardless of which of these options is chosen, the system then returns to the variable query and will follow through this same procedure with the next variable specified.

Cross Tabulations

When the cross-tabulation function is selected, the system immediately queries the user for the pair of variables for which cross tabulations are required. It then calculates the cross tabulation for the subset as defined in the logic specified in SM-F1. An example of cross tabulations is shown in Figure 5. Every attempt has been made to keep the CARE outputs to report-sized documents. The system will flip-flop variables and use compressed print when necessary to accomplish this end.

Find High Accident Locations

The SM-F4 function provides the mechanism by which high accident locations can be found. Whatever logic was specified within SM-F1 will form the basis for determining the type of location under consideration. After specifying whether intersection or nonintersection accidents are of concern, the user is immediately queried for the number of accidents that will determine a high accident location. This is followed by a query for printed or screen output. The system will then respond by listing all locations that meet all of the criteria specified.

Figure 6 shows the output generated from a typical high accident location run.

By following the directions given below the listing, the user can put the system into a "frequency" mode. In this mode, frequency distributions can be obtained for any of the locations on the screen. These are obtained by moving the cursor to the line listing the desired location and pressing the proper function key. The user will then be queried for the variable desired. Thus, any item of information for a specific location is at the fingertips of the user.

TECHNICAL SPECIFICATIONS

CARE can be applied in any political subdivision that has from a few hundred to tens of thousands of accidents per year. Hardware should be chosen to provide the degree of service desired. This will depend heavily on the number of records to be stored and processed. A minimal configuration consists of a 5-megabyte (5 million bytes) hard disk and a 64K central processing unit with terminal and printer. This will support a city that has approximately 2500 accidents/year, assuming three years of accident data are to be maintained on-line. The cost of such hardware is about $10 000. For a larger number of accidents and faster service, microcomputers of the 16-bit word length variety, which range in cost up to $30 000, can be configured.

Implementation of CARE for a political subdivision will require more than just the purchase of hardware and the installation of the CARE software. In addition, an interface program is required to establish the data base for the political subdivision under consideration. This is no great problem for those states that perform data entry of all recordable accidents. First, a program would be written to pick off and convert the appropriate records and variables from the state master tapes to the format required by CARE. This would be performed on a mainframe to minimize cost and save time. The second step would involve a downloading of the data from the mainframe to the micro. Standard programs for this are available and quite reliable.

In the case where the state data entry is not sufficient for the needs of the city, a program would be developed to perform the data entry locally. The expense of such a program is nominal compared with the cost of the ongoing data entry effort. However, many cities may opt for continual local data entry to ensure the integrity of their data.

CONCLUSION

Space does not permit all of the CARE features to be explained here. Rather, the objective is to demonstrate the reality of microcomputer-based systems for local problem identification. At the inception of the CARE system design and development project, the objective was to develop software on state-of-the-art hardware, looking some four or five years into the future when hardware development would produce a machine that was both fast enough and in the price range to make local problem identification feasible. When the software was developed and tested, it was found that there was no need for localities to wait: Hardware and software technology is now more than adequate for the task. This is not to say that there is no room for further innovation. Every attempt will be made to keep CARE current with the most recent advances in microtechnology.

ACKNOWLEDGMENT

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REFERENCES

1. D.B. Brown. Systems Analysis and Design for Safety. Prentice-Hall, Englewood Cliffs, NJ, 1976.
2. D.B. Brown. Highway Safety Problem Identification. In Implementing Highway Safety Improvements, ASCE, New York, 1980.
3. Problem Identification Course: Data Analysis Requirements. NHTSA, April 1977.
4. RAPID: System Overview. Alabama Office of Highway and Traffic Safety, Montgomery, Rept. 300-78-002-401-095, 1978.
5. CARE: System Overview and User Guide. Alabama Office of Highway and Traffic Safety. Montgomery, Rept. 300-82-002-401-11, 1982.

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Evaluation of Accident Reporting Histories

C.O. WILLIS, JR., DANIEL S. TURNER, AND CECIL W. COLSON, JR.

Research was undertaken to identify jurisdictions in Alabama whose accident reporting histories do not match the anticipated trends of the community and to suggest reasons for deficiencies in accident reporting. Correction of these deficiencies is expected to result in improved data analysis for all future safety investigations and evaluations. The sequence of research actions included a literature review, selection of variables for detailed study, statistical analyses, and site studies of several cities found to deviate from the expected accident pattern. The field studies (along with an examination of accident records) served as the basis for the recommendation of guidelines and policies to improve the quality of Alabama traffic accident data. Thirteen specific recommendations were developed to alleviate existing problems in reporting accidents and to guard against the recurrence of these problems. Implementation of these recommendations will result in a more reliable accident data base for use in safety studies. This in turn will result in more efficient use of safety funds.

Historical accident data are a significant source of information used by engineers to establish safety programs and implement safety countermeasures. Local governments, through their law enforcement agencies, gather these data during accident investigations. The State of Alabama has adopted a standard accident reporting device and has mandated accident investigation training for all enforcement officials. In spite of these uniformity measures, differences exist in accident report data due to differences in the policies and procedures of local enforcement agencies.

Reliability in both the quality and the quantity of accident reports expected from any jurisdiction greatly increases the value of the data base used for safety studies. On the other hand, data discrepancies or deficiencies reduce the credibility of such studies and hinder the effort to make the best use of safety funds. This paper and the paper by Turner and Mansfield in this Record discuss research undertaken to identify jurisdictions in Alabama whose accident reporting histories do not match the anticipated trends of the community and in turn to suggest reasons for deficiencies in accident reporting. Correcting these deficiencies is expected to result in improved data analysis for all future safety investigations and evaluations.

The sequence of research actions included a literature review, selection of variables for detailed study, statistical analyses, and site studies of several cities found to deviate from the expected accident pattern. The field studies (along with an examination of accident records) served as the basis for the recommendation of guidelines and policies to improve the quality of Alabama traffic accident data.

LITERATURE REVIEW

A literature review was an ongoing, continuous element of the research project. The preliminary portion of the literature review had three purposes:

1. To document the nature of the existing problem,
2. To identify previous research of a similar nature, and
3. To identify and designate variables to be considered in the statistical analysis.

The reasons for conducting a literature review are obvious. Such a process can eliminate the duplication of effort and can also be used to guide the research in that previous research efforts can be used to identify those procedures that should be developed further and those that should not be considered further.

This review was concentrated at two levels: First, contacts were made with government agencies such as the U.S. Department of Transportation (DOT) and the Alabama Highway Department and within various agencies in the State of Florida (due to the location of the available project staff). The second level involved an intensive screening of current technical literature and periodicals applicable to the transportation field.

Nature of the Existing Problem

There are inherent weaknesses in traffic accident data. Council and others (1) cite examples including collection practices, reporting methods, data bias, and the nature of accidents. The collection and reporting problems are of interest to this research effort. The first specific example focuses on inconsistent reporting due to reporting threshold variation. The 1961 Alabama law that governs accident reporting is as follows:

> Section 7. WRITTEN REPORTS OF ACCIDENTS. Every law enforcement officer, who in the regular course of duty, investigates a motor vehicle accident, either at the time of and at the scene of the accident or thereafter by interviewing participants or witnesses shall, within 24 hours after completing such investigation, forward the necessary completed written report or copy thereof of such accident to the Director on the uniform accident report form supplied by the Director.
>
> Section 8. ACCIDENT REPORT FORMS. (a) The Director shall prepare and upon request supply to police departments, coroners, sheriffs, garages, and other suitable agencies or individuals, uniform accident report forms required hereunder. The required written accident report to be made by persons involved in accidents and by investigating officers shall call for sufficiently detailed information, to disclose with reference to a traffic accident, including but not limited to location of accident, probable cause, injuries to persons, property damage, deaths of persons, registration of vehicles involved including license numbers, name, address and driver's license number of operator, highway design and maintenance (including lighting, markings, and road surface), and names and addresses of witnesses. (b) Every accident report required to be made in writing shall be made on the uniform accident form approved and supplied by the Director and shall contain all available information required therein.
>
> Section 12. DIRECTOR TO TABULATE AND ANALYZE ACCIDENT REPORTS. The Director shall tabulate and analyze all accident reports, and shall publish annually or at more frequent intervals statistical information based thereon as to the number and circumstances of traffic accidents. The Director shall make available to the State Highway Director all accident reports so that he may obtain sufficient detailed information so as to provide data for surveillances of traffic for detection and correction of high or potentially high accident locations.

The law establishes criteria for reporting and processing but does not establish a quantitative value that mandates reporting. According to information from the International Association of Chiefs of Police, in Alabama all accidents resulting in $50 or more in property damage are usually reported. The $50 value is a generally accepted rule-of-thumb based on insurance reporting requirements.

This is a very low value in comparison with those of other states. The low threshold calls for reporting of practically all accidents and can lead to the flooding of accident files with data on minor (often insignificant) collisions. At the same time, the very low threshold can lead to abuse and disregard for the reporting level. Repair values are often estimated at the accident scene by investigating officers, and it is not unusual for the cost to be underestimated to spare the driver the trouble of filing a report if no injuries are encountered. This leads to a consistency problem in that scores of low-cost incidents are reported at one location and very few at another.

A second consistency problem in reporting arises from a failure to investigate accidents properly. Researchers know that only a portion of the accidents that actually happen are reported (2). Only 89 percent of insurance-reported accidents were reported by police in one case and only 47 percent of motorcycle accidents in another (3,4).

This compares with other researchers' estimates that as many as three out of four accidents go unreported (5). An investigation of accidents in Sweden raised serious doubts about the accuracy of road accident statistics in the reporting of fatalities and injuries (6). A study in Virginia (7) found that accident data were not suitable for a detailed study due to (a) problems in format, (b) insufficient information, and (c) inconsistencies in coding.

A prominent reason for lack of proper reporting is the secondary importance of accident investigation in comparison with the multitude of other law enforcement duties. At least one study has been conducted to determine whether off-the-scene sources could supply accident data and thus reduce the officer's time at the site (8). A number of reliable off-scene data items were identified; however, the technique was not shown to be cost effective and has not been widely adopted. Accident investigation must still compete for the officer's time and attention.

There are several other common reporting difficulties, including (a) cross-jurisdictional differences in investigation or processing due to varying criteria and (b) management that may place minimal emphasis on accident reporting. Another important factor may be lack of proper training of enforcement officers. There is evidence that simple items such as the interviewing style of the investigating officer have a pronounced effect on the accuracy of the data (9).

To summarize the nature of the existing problem, there are a number of documented reasons for discrepancies in highway accident data. There are reasons to suspect that some of these deficiencies exist in Alabama accident records. Routine safety studies have uncovered cases in which Alabama data did not seem to represent accurately the situation under investigation. In several cases, consultants have called discrepancies to the attention of the Alabama Highway Department.

Similar Previous Research

At the federal level, the literature review first concentrated on FHWA and, within that agency, on the Office of Research. This office was identified as one that would have current information on similar research efforts, published and unpublished, that have received federal funding.

The contacts resulted in the identification of very few previous research projects similar to this effort. Some work was found in the same broad area. A number of research efforts were identified in which causal effects of accidents have been isolated. In general, however, these efforts were designed to relate particular types of accidents at a specific location to their causal effects.

One study that was conducted by the University of Maryland was typical of the type of previous research efforts that were uncovered in this phase of the literature review. In that study, the objective was to determine in a number of corridors in Maryland whether differences in accident rate could be related to changes in the speed limit on Maryland highways or whether other causal effects could be identified. The result of the research was that the noted decline in accidents was related primarily to an increase in overtime work by safety officials and secondly to the reduced speed limit. Neither of these items appears to be directly applicable to the current study.

The objective of the research effort discussed in this paper is to relate historical accident trends to some characteristics of the jurisdiction that reports the accidents. This would imply that gross measures of socioeconomic activity that could be identified at a county or city level should be related to the accident experience. The results of the contacts at the federal level were that at this time no similar research could be identified that would assist this effort. Contacts within the Alabama Highway Department and the Florida DOT did not disclose any evidence of pertinent research efforts.

Personnel within FHWA pointed out that automobile insurance companies apply different rate structures in different cities. With this in mind, contacts were made at the Office of Research of the Insurance Institute for Highway Safety. These contacts did not produce records of any research efforts that could be directly related to the stated objectives of this project.

Contacts were then made with a number of insurance companies and insurance regulation agencies in both Alabama and Florida to discover whether data available from the insurance companies in Alabama could be used to satisfy the objectives of this research. The contacts in the insurance industry led to the conclusion that in Alabama insurance rates are determined within geographic boundaries based on the experiences and dollar losses resulting from the accidents in that area. The larger companies in the state determine these rates based on the records of their own customers, whereas the smaller companies depend on independent rating offices to provide sufficient data to make the ratings. Typically, the rates are determined based on dollar losses per customer. The Farm Bureau firm, for example, uses five different ratings within the state.

Although the rating system used by the insurance industry does not directly relate to the objectives of this research, it does provide an alternative means of analysis. Specifically, some relation should be expected between a high accident rate for a city and the insurance rating that the city might be assigned. In other words, in those cities where either unusually high or low accident reporting trends have been noted, the insurance rating should indicate the same trend. The rating could be reviewed to determine whether there is a correlation between the reported accident history and the data used in determining the insurance rating.

To summarize this portion of the literature review, no suitable work of a similar nature could be located. Neither the literature review nor contacts with various government agencies identified previous research that could be used for specific guidance in the current study.

Accident Prediction Variables

The bulk of previous research into accident-related factors has been oriented toward isolating the effect of specific items at specific roadway locations. Geometric features, traffic control devices, and other items were studied extensively. Some of these studies suggest pertinent techniques for investigation of areawide accident rates, however. One variable that could be used is the volume of traffic. Kihlberg and Tharp (5) pointed out that average daily traffic (ADT) is one of the best indicators of accident potential for the various categories of highways. Other researchers echo their findings and have been able to establish very specific relations between ADT and accidents, especially for intersections (10-12).

Other areawide variables were harder to locate. Cooper (13) suggested that the level of law enforcement activity could be a major factor in reducing accidents, but the Alabama Office of Highway and Traffic Safety has found that there are not enough enforcement officers in the state to continuously monitor the known hazardous locations (14, p. 10). Thus, reductions in accidents achieved by assigning officers to specific locations are probably temporary and could disappear when the officer moves to a new location.

Byun, McShane, and Cantilli (15) suggest that societal and other forces exert influence on the number of accidents in a given area. They indicate that the current trend of population aging will increase accidents. They also see the urban-rural split as important and point out that a significant change in the mode of travel can alter accident patterns and rates.

In summary, only a few variables have been shown to be applicable to accident prediction on an areawide basis. These are traffic volume, population characteristics, rural-urban split, and transportation mode. This does not mean that other variables are not related to areawide accident rates but that such related factors have not been identified to date.

Table 1. Variables used in regression analysis.

Data Item	Source
Population	
1970-1977	Alabama Municipal Data Book (21)
1980	Alabama Municipal Journal (22)
Law enforcement officers[a]	
Uniformed	Crime in Alabama (23)
Civilian	Crime in Alabama (23)
Traffic accidents, 1975-1979	Alabama Highway Department (24)
Total miles of paved highway	Alabama County Data Book (25)
Miles of state and federal route	Alabama County Data Book (25)
Miles of Interstate highway	Alabama County Data Book (25)
Miles of county road	Alabama County Data Book (25)
Square miles of land area	Alabama County Data Book (25)
Urban and rural land	Alabama County Data Book (25)
Urban, agricultural, and other land	Alabama County Data Book (25)
Automobile registrations, 1978	Alabama County Data Book (25)
Driver licenses, 1978	Total licenses issued (renewals and new applications), 1977, 1978, 1979, and 1980, Alabama Department of Public Safety
Gasoline tax allocation, 1979	Gasoline tax distribution spread: Oct. 1, 1978-Sept. 30, 1979, Alabama Treasurer's Office

[a] Sheriff's office employees and city police department employees were separated and placed in the appropriate data sets.

RESEARCH PROCEDURES FOR THE STUDY

The statistical procedures used in this investigation were regression and confidence band analyses. Both techniques are accepted and commonly used by the traffic engineer. Regression techniques are presented in many engineering textbooks, and computer-assistance packages have been developed to make application easier (16-18). For example, Belmont (19) developed a regression equation to predict the accident rate based on ADT and roadway median width. Turner, Fambro, and Rogness (20) developed regression equations in Texas to warrant addition of paved shoulders to two-lane roads based on accident rate. Regression equations were developed in a similar manner during this research to predict the number of accidents associated with Alabama cities.

The second statistical technique used was the confidence level analysis. This technique was used to identify cities whose accident levels fell outside of expected limits. High-rate and low-rate accident cities could be identified during the research by denoting data points that fell outside of specified confidence bands.

SELECTION OF REGRESSION VARIABLES

A list of desirable data items to be used in a regression analysis was prepared. These data items include variables that are associated with accident histories and are related to population characteristics, driver characteristics, and roadway characteristics. It became apparent that some of the most desirable data items were not available for the individual cities. However, many of these variables were applicable to counties and were found to be readily available.

At this point, the data were placed in three categories: county, city, and rural. The county classification was used for variables applicable on a countywide basis, including both urban and rural areas. Examples include the number of vehicle registrations and the number of driver licenses. The city classification was restricted to data applicable to incorporated cities in the state. One example is the census data used to establish the population. The final classification, rural, was used to handle data items that were only applicable to areas outside incorporated cities. For example, the rural population for a specific county would be the county population minus the population of all incorporated areas.

After the data analysis was finished, the city data classification contained only three data items (see Table 1). These were population, the number of law enforcement officials, and the number of traffic accidents for each year from 1975 through 1979. The number of law enforcement officers was for 1979, and was subclassified as uniformed or civilian members. The population figures for 1977 were estimates prepared by the Bureau of the Census, based upon extension of 1970 census data (21). These figures were compared with more recent estimates (26) and with 1980 census figures (22) when they became available later in the investigation. Where necessary, the original 1977 population estimates were adjusted to reflect the growth trend shown by the most recent data. It would have been convenient to use 1980 population; but 1980 accident data were not available at this stage of the study. The 1977 population figure was used because accident data were available for that year and because there were several sources of population data that could be used to cross check and verify the estimates.

The rural data file was similar to the city file in that very few variables were available. The only two items included in the final data set were 1977 population and the number of traffic accidents for the same year.

The most comprehensive data set was for entire counties. There were at least seven variables with strong potential for use as accident predictors. Several of these variables included excellent subclassifications, such as the breakdown of highway mileage.

EVALUATION OF FIVE-YEAR RECORD

After the data were gathered, the consistency of year-to-year accident reporting was investigated for various jurisdictions. The initial research technique involved a manual screening of accident records for the five most recent years. The objective was to identify those jurisdictions with erratic accident reporting patterns.

Classification Criteria

To quantify any discrepancies noted during the review of accident data, subjective criteria were formulated and placed in the three categories described below.

Category 1

Category 1 was reserved for the mildest types of erratic accident histories. In general, a city with some unusual occurrence in accident reporting would be placed in this category whether the city had any control over the erratic reporting or not.

It is important to remember that accidents are random events governed by the laws of probability and that unusual patterns are possible and normal under the laws of probability. Therefore, a city could receive a category 1 accident history rating due to one year with an unusually large number of accidents even though random chance rather than the city's reporting procedures caused the erratic pattern. Not all of the cities on the category 1 list could be termed deficient in reporting practices.

Category 2

The next classification applied to cities with more erratic accident reporting than the first category. Although there was the possibility that such deviations were the result of random chance, it was much more likely that improper reporting caused the problem.

Category 3

Cities that experienced the most severe deviations and the most erratic patterns of accident reporting were placed in category 3. The patterns are so unusual and pronounced that they are almost certainly due to variances in reporting practices. This type of pattern is obvious from the number of accidents occurring in consecutive years.

Results of the Manual Evaluation

The 67 county rural areas and all 423 cities were subjected to manual review based on the criteria outlined above. Since the criteria were subjective, two independent reviews were conducted to offset any bias on the part of the reviewer. A summary of the findings is presented in Tables 4 and 5 and shown in Figure 2 in the paper by Turner and Mansfield in this Record. These findings are summarized as follows:

1. Approximately one-fourth of all Alabama cities displayed erratic patterns in the number of reported traffic accidents during the period 1975-1979.
2. Five percent of all Alabama cities had very serious discrepancies in the number of accidents reported over the five-year period.
3. During the 1975-1979 period, 8.5 percent of all Alabama cities had serious accident reporting discrepancies.
4. Approximately one-fourth of Alabama county rural areas displayed erratic accident reporting patterns during the period.
5. County rural accident reporting was less erratic than city accident reporting. Although the percentage of jurisdictions with erratic patterns was the same for both groups (28 percent), there were no severe discrepancies in the county rural classification.
6. Traffic engineers and others performing safety studies must be very careful in using accident data for a specific location since one-seventh (5 percent + 8.5 percent) of all Alabama cities have seriously erratic accident histories. It is recommended that several years of data be checked to ensure that data were reported uniformly and that they accurately represent a specific location.
7. Erratic reporting of traffic accidents does not seem to be strongly linked to the size of Alabama cities.

In addition to the manual review, a statistical technique (coefficient of variation) was used to identify cities with erratic year-to-year reporting patterns. The analysis confirmed the presence of many jurisdictions with substantial variation in reporting. Although most of these cities were small, at least four of them were large enough to report more than 100 collisions/year.

REGRESSION OF 1977 COUNTY AND RURAL DATA

A comprehensive research procedure was developed and applied to the data in the county and rural files. Various combinations of variables were tested to determine the strongest possible model. Outliers (locations whose data values behaved unusually) were removed from the analysis to isolate their exact effects. The regression of county and rural data is discussed in detail in the paper by Turner and Mansfield in this Record.

REGRESSION OF CITY DATA

1977 Data

One of the primary objectives of the project was to identify a relation between accidents in Alabama cities and some predictor variable. Toward that end, a regression analysis was performed on the city data set by using the same comprehensive techniques that had been applied to rural and county data previously. Pertinent findings include the following:

1. Most Alabama cities are small; more than 80 percent of them have less than 5000 people. The few large Alabama cities dominate the numerous small cities during a normal regression analysis.
2. Prediction equations for small cities were improved by using disjoint population groupings rather than the entire population of Alabama cities. Five population groups were established: 0-1000, 1000-5000, 5000-10 000, 10 000-50 000, and > 50 000.
3. Population was used as the independent variable based on the findings of previous regression of rural and county data sets.

Table 2. Designated regression results by population group for cities.

Population Group	Regression Equation
0-1000	Accidents = 0.010 47 x population + 0.5134
1000-5000	Accidents = 0.035 82 x population - 39.234
5000-10 000	Accidents = 0.041 33 x population - 66.834
10 000-50 000	Accidents = 0.053 18 x population - 212.284
>50 000	Accidents = 0.058 52 x population - 540.770

Table 3. Regression summary for 1980 accident data.

Population Group	No. of Cities	R^2	SE	Intercept	Slope	t-Statistic
All cities	424	0.989 52	110.589	−65.490	0.051 27	199.616
1–1000	211	0.060 29	11.441	+0.666	0.011 48	3.662
1000–5000	133	0.310 82	43.581	−21.365	0.027 24	7.687
5000–10 000	42	0.223 12	119.560	−107.046	0.047 48	3.389
10 000–50 000	33	0.848 13	217.618	−144.609	0.046 36	13.157
⩾50 000	5	0.994 67	359.220	−712.208	0.055 43	23.653

4. Because several cities were known to report accidents in an erratic manner, regression studies were performed on average five-year reporting levels in addition to 1977 reported levels.

5. Outlier cities were removed from the data set to improve the regression and were not included in the final regression formulas.

6. After a comprehensive analysis, predictive formulas were developed for each of the population groups (see Table 2). The independent variable was population, the dependent variable was average five-year accidents, and outliers were omitted to produce the best-fit equations.

1980 City Accident Data

At the point in the research project when 1980 data became available, the scatterplot and regression analysis was repeated for each of the five population groups by using the 1980 accident reports and 1980 census population data. The 1980 data were not greatly different from the 1977 data.

The regression of 1980 data is summarized in Table 3. The regression equations are comparable to those specified previously in Table 2. The five-year-average equations in Table 2 are preferable to the single-year formulas in Table 3.

CONFIDENCE BAND INVESTIGATION

Once the regression models were adequately fit, a second statistical technique was used to construct the equation of the surface that describes the mean number of accidents for a city of selected characteristics. For linear regression, this surface approximates symmetrical lines straddling the designated regression curve. It is possible to associate a designated level of confidence with given values above or below the regression curve by determining whether the values fall within the confidence bands. Confidence bands were constructed for the various population groups by using the following equation:

$$\hat{Y} \pm [t(df, \alpha/2)(SE)\sqrt{(1/N) + [X_o - \bar{X})^2/dx^2]} \qquad (1)$$

where t(df, α/2) is taken from the appropriate t-table and

$\hat{Y}$ = predicted mean value at point X_o,
df = degrees of freedom = N - 2,
α = 1 - confidence interval,
SE = standard error from the regression,
N = number of cities in the sample,
X_o = population at the point in question,
$\bar{X}$ = mean of the population values in the sample,
dx^2 = (N - 1) Sx^2, and
Sx = standard deviation of population values in the sample.

A computer-assisted confidence interval analysis was performed on each of the five population groups. Confidence intervals of 80, 90, and 95 percent were applied during these analyses. Data for 1977, 1975-1979 (five-year average), and 1980 were scrutinized by using the equations developed for five-year-average data, as summarized in Table 2. In addition, 1980 data were subjected to a study based on 1980 regression equations. In summary, the five population groups were subjected to four separate analyses of three confidence levels each. This three-way tabulation resulted in 60 separate applications of the computer program.

The extremely thorough study was undertaken for several reasons:

1. It was necessary to examine each of the population groups because grouped data yielded the best regression results.

2. Multiple confidence levels were used to rank Alabama cities in relation to accident overreporting or underreporting. The cities that lay outside of the highest confidence levels exhibited the most severe reporting problems. Those at the next level were not quite as severe, and so forth. The ranking of cities allowed the project staff a great deal of leeway in identifying trends and selecting cities for further study.

3. Regression equations developed for various years were compared with several years of data to remove the overriding influence of one bad year and to identify those jurisdictions that exhibited poor reporting practices year after year.

The results of the multilevel approach indicated that 65 cities fell outside of 90th percentile confidence bands during one or more applications of the computerized procedure.

DETERMINING REASONS FOR DEFICIENCIES

After the designation of certain Alabama cities as chronically underreporting or overreporting accidents, attempts were made to categorize and isolate the reasons for the reporting abnormalities. These efforts included a telephone questionnaire administered to a select group of police chiefs, a comparative analysis of accident records, and site visits.

Telephone Survey

The telephone survey was conducted prior to the field visits to identify problem areas common to underreporting (or overreporting) jurisdictions. The problem areas could then be subjected to intensive scrutiny at each field site rather than being identified after the study had closed. The telephone survey would provide insight into the type and amount of data to gather during field studies in order to maximize the project results.

A questionnaire was prepared to allow an examination of items that were likely to influence the number of reported accidents. Items such as changes in the city's administration or policies, traffic volumes, training of the police chief or police force, the chief's perception of the accident situation, the city's investigating and reporting practices, handling of private-property collisions, and identification and correction of high accident locations were addressed by the survey.

Sites were selected from outlier cities by using the confidence band analysis. Where possible, four overreporting cities and four underreporting cities were selected from each of the population groups used in the regression analysis. No cities with more than 50 000 people fell outside the confidence bands, so the largest population group was excluded from the study. Four outlier sites were not available in all cases, so only 25 cities were selected instead of the desired 32. Another group of 25 cities were selected as control sites. These sites fell along or near the regression curves. For each population class, the number of control sites was balanced against the number of outlier sites.

The police chief for each city in the study was contacted via telephone. The objectives of the project were explained and the interviewer posed questions to the chief. In the larger police forces with well-defined functional divisions, the head of the traffic division was also interviewed. The respondent was allowed a great deal of freedom in answering because of the variety of city sizes and police department organizational structures. As the interview progressed, additional topics were introduced as necessary to expand the material contained in the original questionnaire or to explore situations unique to the city being studied. Where pertinent, the chief's comments were recorded for amplification. The results of these contacts are summarized below:

1. A great number of cities have changed mayors or police chiefs in the last five years, as evidenced by a 70 percent turnover rate for small cities. The change of administrators undoubtedly caused some changes in policies, which contributed to irregularities in accident reporting patterns.
2. Control cities had the most stable administrators. There were fewer changes and consequently fewer irregularities in reporting.
3. The majority of police chiefs had received some form of accident training, and approximately 90 percent of their police forces had received accident investigation training within the past five years. Law enforcement personnel would appear to be sufficiently trained to handle accident reporting adequately.
4. The unknown factor in accident training is the scope and intensity of the curricula offered by Alabama law enforcement academies. An investigation of the material offered by the academies may be in order.
5. The police chiefs in cities that underreported accidents appeared to be less knowledgeable of the local accident situation than their counterparts in overreporting cities.
6. The police chiefs in overreporting cities had the strongest grasp of the local accident situation.
7. Many small cities tend to depend on neighboring cities or the local Department of Public Safety (DPS) for assistance in investigating and reporting accidents.
8. Forty percent of the underreporting cities responded that they withhold some or all of their accident reports instead of forwarding them to the DPS.
9. A large number of cities, of all sizes and in all three reporting groups, fail to mail completed accident reports to the DPS within 24 hours after completing the investigation.
10. Almost all cities in the study maintain their own files of completed accident reports.
11. Very few private-property accidents are reported to the DPS.
12. There are many different policies for investigating private-property accidents and much concern on the part of police chiefs. Many progressive departments have developed their own form for such investigations. Usually, this form is provided for drivers to swap information.
13. Standardization of private-property accident policies would appear to be highly desirable. For example, "semipublic" areas such as shopping center entrances could be treated by use of a standard form for drivers to use in swapping information at the scene.
14. Comments compiled during the survey indicated a high degree of group uniformity within each of the three separate reporting levels used in the study (underreporting, overreporting, and control).
15. Common factors for control cities seemed to be (a) good cooperation with neighboring jurisdictions; (b) a knowledgeable, well-trained staff and an interested, aggressive police chief; and (c) a well-defined system for handling private-property accidents.
16. Common factors for underreporting cities seemed to be failure to mail all reports to the DPS and a lack of emphasis on the part of police chiefs.
17. Common factors for the overreporting cities included (a) high traffic volumes, (b) a system for private-property accidents, and (c) an aggressive program to abate the accident situation.

Field Studies

After certain cities had been identified as chronically overreporting or underreporting accidents and after the telephone survey had provided some insight into reasons for atypical reporting, a program of site visits was conducted to identify specific deficiencies.

A questionnaire was devised to standardize the questions asked during field visits and to provide consistency in the manner in which the questions were asked. The questionnaire was designed to provide a comprehensive picture of the total accident reporting operation at each of the field visit locations. Three general areas of interest were addressed by the interview form:

1. Questions asked of the police chief--Questions that expanded on the telephone interview were asked to assess the police chief's knowledge of the causes of local accidents (high traffic volumes, new developments, commuting patterns, etc.) to determine investigative policies and to examine accident record processing.
2. Alabama Uniform Traffic Accident Report (AUTAR) processing system--The interviewer observed actual processing of accident records at the field study sites. Questions were directed to the police dispatcher and file clerk, who are heavily involved in overseeing accident investigation and processing of AUTARs.
3. Questions asked of an investigating officer--Questions asked of an investigating officer were designed to supplement the responses of the police chief and to provide another view of departmental policies.

Candidate cities for field visits were designated in a meeting of the project principal investigator and the Alabama Highway Department project monitor. A classification matrix was created with four population groups (0-1000, 1000-5000, 5000-10 000, and

10 000-50 000) and three accident reporting classes (underreporting, control, and overreporting). One city was selected for each cell of the matrix. Because one of these cells was empty (underreporting with a population of 5000-10 000), only 11 cities were designated to receive visits. Cities were notified in advance of the proposed visit of the general nature of the interview and of the personnel who should be made available for the interview. Each of the 11 cities selected for field visits was in the sample previously used for the telephone survey.

The field visits were accomplished between October 14 and October 30, 1981. In general, the procedure consisted of an interview with the police chief in which the 36 questions were asked from the questionnaire. The interviewer then met with the dispatcher and the file clerk to ask the questions specified for these personnel. An important part of this portion of the interview consisted of observing the procedures used in recording and filing accident records. The final phase of the field visit involved interviewing an officer actually involved in investigating accidents.

The responses obtained during the field visits were compiled by both reporting characteristic (underreporting, overreporting, or control) and by city size grouping. The relatively small number of cities in the sample limits the degree of confidence that may be placed in any statistical inferences drawn from the data. Because of the small sample sizes, it is not possible to arbitrarily ascribe observed characteristics to the entire population of Alabama cities. Care should also be taken in ascribing results to the city population for various reporting characteristics or population groups.

In spite of the limitation imposed by the small sample sizes, the field survey performed a valid function by documenting various details of accident investigation and reporting for a wide range of conditions. A number of interesting trends and results were observed. The responses received during the interview can be summarized as follows.

1. The high turnover rate among administrative personnel was documented. The field visits indicated a higher rate of change for overreporting cities than had been disclosed by the telephone survey.
2. Police chiefs were found to have less accident training than street officers. A high percentage of all policemen have received accident training, but the quality of this training is unknown.
3. Street officers were generally unaware of how accident data are used for engineering purposes and did not gather data with such uses in mind.
4. Many police chiefs were not aware that accident summary reports are prepared by the Alabama Highway Department. The majority of the chiefs did not know how to use such reports to alleviate hazardous roadway situations.
5. Chiefs in overreporting cities seemed to have a clearer knowledge of the accident situation than chiefs in underreporting cities.
6. Reporting thresholds were discovered in several cities. Although departments may not have formal thresholds, some officers report that they decide at the accident scene whether or not the collision is worth reporting.
7. Not all cities were in compliance with requirements to mail all AUTARs to DPS within 24 hours of completing an investigation. Some cities simply do not mail in the reports, whereas other cities delay their mailings.
8. Police chiefs and other departmental employees were not always in agreement regarding departmental policies. Conflicting responses were given concerning the presence of written instructions at the site, investigating private-property accidents, threshold values, and how rapidly AUTARs were forwarded to DPS.
9. Instances were documented in which population was not an appropriate factor to use in predicting accidents. Three of the overreporting cities were found to have accident problems based on other factors.
10. Little contact was observed between DPS and local police departments. It appears that a feedback mechanism is necessary to edit and control the quantity and quality of local accident reports.

RECOMMENDATIONS

An extensive research effort was conducted to identify jurisdictions that reported accidents in an abnormal manner. At the conclusion of the study, such locations had been identified. The following list of recommendations has been prepared to alleviate existing problems and guard against their reoccurrence:

1. Those cities designated by this research as chronic atypical reporters should receive individual visits in the near future to identify specific causes for overreporting or underreporting.
2. The regression/confidence band analysis should be repeated at regular intervals as reliable population data become available. This study has proved that regression based on population is a good way to identify cities that need to improve their reporting.
3. A follow-up study should be conducted on those cities with erratic five-year reporting histories. The reason for variability should be identified in each case, and countermeasures should be suggested.
4. A program should be developed to evaluate the quantity of annual accident data submitted by the various jurisdictions. The mechanism should identify year-to-year variance. For example, a simple computer program could edit each year's accident reports and flag cities that show a large change in the number of reported accidents.
5. A mechanism should be developed to evaluate the quality of each item of accident data submitted by the various jurisdictions. For example, a simple computer program could edit reporting characteristics (such as percentage of injuries and wet or dry pavement) and flag those jurisdictions with abnormal patterns.
6. Before accident data are used for future safety studies, the number of accidents reported by any jurisdiction should be compared with tabulated values to determine the validity of the data.
7. An abnormally large number of cities report no accidents or very few accidents. These jurisdictions fall within the confidence band and are statistically satisfactory; however, they should be examined to determine whether they are properly reporting all accidents that actually occur.
8. Law enforcement academy curricula should be reviewed in the area of accident investigation and reporting. Officers should be aware of how data are used in engineering work and of the necessity for data to be of uniform quality.
9. Police chiefs are not totally aware of the accident situation or of the summary reports and other devices available to assist them in identifying and alleviating hazardous situations. A training program should be instituted to improve their knowledge of the overall accident situation, high accident locations, summary reports, and abatement of the accident problem.

10. Almost all cities expressed concern about private-property accidents. A full-scale study should be conducted to establish a statewide policy to provide uniformity. Perhaps a "driver swap" form might be provided for use by all cities.

11. Reporting of accidents in the police jurisdiction should be standardized. All law enforcement officials should be aware that rural street codes and location codes should be used for accidents within the police jurisdiction.

12. Reporting thresholds, both official and implied, were found to exist. A uniform treatment is necessary if accident data are to be meaningful. Law enforcement officials should be made aware that such thresholds are not condoned under existing statutes.

13. Lines of communication should be developed and maintained between the DPS and local jurisdictions. The high turnover among administrators causes constant change at the local level. The DPS must continually emphasize reporting requirements and the reasons for them to ensure that accident data are consistent and of high quality.

Implementation of these recommendations will result in rapid improvement in the quality and quantity of accident data. Safety studies based on a more reliable data base will result in better use of safety funds. In turn, the citizens of Alabama will benefit from an enhanced roadway environment.

REFERENCES

1. F.M. Council and others. Accident Research Manual. Highway Safety Research Center, Univ. of North Carolina, Chapel Hill, Rept. DOT-FH-11-9424, Feb. 1980.
2. K. Pfundt. Three Difficulties in Comparison of Accident Rates. Accident Analysis and Prevention, Vol. 1, No. 3, 1969.
3. E.G. House and others. How Complete Are Driver Records? An Analysis Based on Insurance Claim Crashes. Highway Safety Research Center, Univ. of North Carolina, Chapel Hill, 1974.
4. Helmets Cut Crash Odds for North Dakota Cyclists. Highway Loss Reduction Status Report, 1979.
5. J.K. Kihlberg and K.J. Tharp. Accident Rates as Related to Design of Rural Highways. NCHRP, Rept. 47, 1968.
6. J.P. Bull and B.J. Roberts. Road Accident Statistics: A Comparison of Police and Hospital Information. Accident Analysis and Prevention, Vol. 5, No. 1, 1973.
7. D. Mitchell and C. Lynn. Use of the Fatal Accident Reporting System (FARS) in Evaluating Characteristics of Virginia Traffic Fatalities. Proc., Human Factors Society, Santa Monica, CA, Oct. 1978.
8. J.P. Gerrard and W.W. Mosher. Analysis of Reliability of Accident Information Obtained from Off-Scene Sources: Part 1. Institute of Transportation and Traffic Engineering, Univ. of California, Los Angeles, Rept. Rr-68-63, 1968.
9. R. Henson, C. Cannell, and S. Lawson. Effects of Interviewer's Style and Question Form on the Validity of Reporting Automobile Accident Information. Highway Safety Research Institute, Univ. of Michigan, Ann Arbor, HIT Lab Reports, Vol. 3, No. 12, Aug. 1973.
10. R.F. Del Mistro. Accidents at Urban Intersections. National Institute for Road Research, Council for Scientific and Industrial Research, Pretoria, South Africa, Tech. Rept. RF/3/79, Sept. 1979.
11. A.S. Hakkert and D. Mahelel. Estimating the Number of Accidents at Intersections from a Knowledge of the Traffic Flow on the Approaches. Accident Analysis and Prevention, Vol. 10, 1978.
12. J.W. McDonald. Relationship Between the Number of Accidents and Traffic Volumes at Divided Highway Intersections. HRB, Bull. 74, 1953.
13. P.J. Cooper. Effects of Increased Enforcement at Urban Intersections on Driver Behavior and Safety. TRB, Transportation Research Record 540, 1975, pp. 13-22.
14. OHTS Traffic Safety Newsletter. Alabama Office of Highway and Traffic Safety, Montgomery, Vol. 9, No. 1 and 2, Oct.-Nov. 1980.
15. J. Byun, W.R. McShane, and E.F. Cantilli. Changing Baseline in Transportation Safety: An Assessment of Some Key Factors. TRB, Transportation Research Record 709, 1979, pp. 6-10.
16. G.W. Snedecor and W.G. Cochran. Statistical Methods. Iowa State Univ. Press, Ames, 1967.
17. I. Miller and J.E. Freund. Probability and Statistics for Engineers. Prentice-Hall, Inc., Englewood Cliffs, NJ, 1965.
18. N.H. Nie and others. SPSS: Statistical Package for the Social Sciences. McGraw-Hill, New York, 1970.
19. D.M. Belmont. Accidents Versus Width of Paved Shoulders on California Two-Lane Tangents: 1951 and 1952. HRB, Bull. 117, 1956, pp. 1-5.
20. D.S. Turner, D.B. Fambro, and R.O. Rogness. Effects of Paved Shoulders on Accident Rates for Rural Texas Highways. TRB, Transportation Research Record 819, 1981, pp. 30-37.
21. Alabama Municipal Data Book, 1980. Alabama Office of State Planning and Federal Programs, Montgomery, 1981.
22. The Alabama Municipal Journal. Alabama League of Municipalities, Montgomery, Vol. 38, No. 8, Feb. 1981.
23. Crime in Alabama: 1979. Uniform Crime Reports Division, Alabama Criminal Justice Information Center, Montgomery, 1980.
24. Urban and Rural Accident Statistics. Accident Identification and Surveillance Section, Alabama Highway Department, Montgomery, 1975-1979 Computer Summaries.
25. Alabama County Data Book, 1980. Alabama Office of State Planning and Federal Programs, Montgomery, 1981.
26. Information Bulletin, Directory of Mayors and Commissioners in Alabama. Alabama League of Municipalities, Montgomery, Aug. 1980.

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Accident Model of the Traffic Mix: Use of Vehicle Miles to Predict Accidents

THIPATAI CHIRACHAVALA AND JAMES O'DAY

Information on vehicle miles of travel for any two classes of vehicles (e.g., cars versus trucks or vehicles with drunk drivers versus vehicles with nondrunk drivers) can be used together with accident frequency to develop an accident prediction model based on the mix of traffic on roadways. As an illustration, a model was developed to predict the proportion of many possible accident configurations involving cars and trucks (single-car accidents, car-truck accidents, etc.), taking into account the effect of environmental factors such as road class and time of day. Extension of this model to include any number of factors other than road class and time of day is possible. Useful applications of the model include assessment of the relative highway safety of any two vehicle classes that may possess different accident characteristics, assessment of environmental factors that affect the highway safety of these vehicles, and quick input for evaluating policy options concerning of the use of certain types of vehicles.

An accident is considered a single event even when it involves more than one vehicle. Vehicle involvements in accidents, on the other hand, are counts of the number of vehicles involved in accidents. Vehicle involvements in accidents are usually specified by type of vehicle--i.e., car involvements, truck involvements, etc. Therefore, "accidents" and "vehicle involvements" are different concepts and should not be used interchangeably. For example, the number of accidents in 10 collisions, each involving 2 cars, is 10 whereas the number of car involvements in those accidents is 20.

Vehicle miles of travel is a common measure of exposure. The rates (involvements per vehicle mile of travel) provide a more useful comparison of the accident experience of the vehicles than the number of involvements alone. The use of exposure information is not, however, restricted only to the rates comparison. It can be used together with accident information to develop an accident model that permits some inference regarding the nature of accidents. This paper presents a method for achieving such a goal by using an example of cars versus trucks.

Highway accidents can be categorized as single-vehicle, two-vehicle, or more-than-two-vehicle crashes. For traffic consisting of passenger cars and trucks only, the possible accident configurations are (a) single-car (SC), (b) single-truck (ST), (c) car-car (CC), (d) car-truck (CT), (e) truck-truck (TT), and (f) multivehicle (CCC, CCT, TTT, CCTT, CCCC, etc.).

Accidents involving more than two vehicles are relatively rare: They typically account for 5 percent or less of total accidents. They were, therefore, neglected in developing the model.

LITERATURE REVIEW

Scott and O'Day (1) showed that, if involvements in accidents of both cars and trucks were assumed to be proportional to their respective miles of travel, the probability that an accident-involved vehicle (V) was a truck would be equal to the proportion of vehicle miles accumulated by all trucks and the same for cars. Thus, for a population consisting only of cars and trucks,

$$P(V = \text{truck} | \text{an accident}) = T \quad (1)$$

and

$$P(V = \text{car} | \text{an accident}) = (1 - T) \quad (2)$$

where T is the proportion of truck mileage and (1 - T) is the proportion of car mileage.

If the proportion of single-vehicle accidents is represented by S and therefore the proportion of two-vehicle accidents by (1 - S), then the proportions of oneand two-vehicle accident configurations are given by

$$\text{Proportion of SC accidents} = S(1 - T) \quad (3)$$

$$\text{Proportion of ST accidents} = ST \quad (4)$$

$$\text{Proportion of CC accidents} = (1 - S)(1 - T)^2 \quad (5)$$

$$\text{Proportion of CT accidents} = 2(1 - S)T(1 - T) \quad (6)$$

$$\text{Proportion of TT accidents} = (1 - S)T^2 \quad (7)$$

These five proportions sum to 1.0 (crashes involving more than two vehicles are neglected).

The limitation of the above model arises from its assumption that the chance of involvement in an accident is the same for a car and a truck. That is, if the car mileage were equal to the truck mileage, the frequencies of their involvements would also be equal. The model does not allow for the fact that trucks and cars might have different potential for being involved in an accident due to different vehicle and/or driver characteristics. In the situation where this assumption is not justified, the model will no longer be valid. This has led to the development of a more general model that does not require such a stringent assumption. This general model will be referred to as the accident model of the traffic mix.

MODEL DEVELOPMENT

Accidents can be viewed as the result of "failures" in a system comprising the vehicles, the drivers, and the environment. To be useful, an accident model ought to reflect such a relation.

The accident model of the traffic mix is a mathematical representation of the probabilities of the occurrence of various possible accident configurations. In considering an example of cars versus trucks, the rationale for such a model is that accident involvements of cars and trucks are some function of their individual characteristics (which collectively reflect the vehicle and/or the driver characteristics), mileage, and environmental factors. That is, P(V = car | an accident) = f(characteristics of cars, car miles, environment); and P(V = truck | an accident) = f(characteristics of trucks, truck miles, environment).

In developing an accident model based on the above assumption, a two-stage modeling procedure was introduced. The first stage derives an accident model of the traffic mix, assuming that the car and truck involvements are some function of their individual characteristics and their respective mileage. The second stage incorporates the environmental factors into the model externally. The two stages are discussed below.

Stage 1

It is assumed that

$$P(V = \text{car}|\text{an accident}) = W_1 (1 - T) \quad (8)$$

and

$$P(V = \text{truck}|\text{an accident}) = W_2 T \quad (9)$$

where W_1 and W_2 are constants representing the involvement propensity of cars and trucks, respectively.

If S represents the proportion of single-vehicle accidents and (1 - S) the proportion of two-vehicle accidents, then the proportions of the five accident configurations involving cars and trucks are given by

$$\text{Proportion of SC accidents} = S(1 - T)/(1 + aT) \quad (10)$$

$$\text{Proportion of ST accidents} = S(1 + a)T/(1 + aT) \quad (11)$$

$$\text{Proportion of CC accidents} = (1 - S)(1 - T)^2/(1 + bT)^2 \quad (12)$$

$$\text{Proportion of CT accidents} = 2(1 - S)(1 + b)T(1 - T)/(1 + bT)^2 \quad (13)$$

$$\text{Proportion of TT accidents} = (1 - S)(1 + b)^2T^2/(1 + bT)^2 \quad (14)$$

The sum of the proportions is 1.0.

The constant a is the difference between the truck involvement rate (per mile of truck travel) and the car involvement rate (per mile of car travel) for single-vehicle accidents, expressed as a percentage of the car involvement rate, or

$$a = (\text{truck involvement rate} - \text{car involvement rate})/\text{car involvement rate} \quad (15)$$

and the constant b is the difference between the truck involvement rate and the car involvement rate for two-vehicle accidents, expressed as a percentage of the car involvement rate, or

$$b = (\text{truck involvement rate} - \text{car involvement rate})/\text{car involvement rate} \quad (16)$$

In this model, the proportionality constant, W_1 in Equation 8, is equal to 1. W_2 in Equation 9 is equal to (1 + a) and (1 + b) for single- and two-vehicle accidents, respectively, which allows the truck involvement rate relative to the car involvement rate to be different for single-vehicle and two-vehicle accident configurations. In the circumstance where a and b are equal, the model as represented by Equations 10-14 still holds. When the accident involvement rates of both cars and trucks are equal, both a and b will be zero and Equations 10-14 simplify to Equations 3-7. Therefore, the model proposed earlier by Scott and O'Day (1) is a special case of the general accident model of the traffic mix.

Stage 2

The model as represented by Equations 10-14 is then applied to each of the cells (or subsets) created by the cross classification of the environmental factors. There may be any number of such variables. For each cell, two independent estimates of a are obtained from Equations 10 and 11 and three independent estimates of b from Equations 12-14. Unique cell estimates of a and b are then determined as a function of the environmental factors. The following model estimation illustrates this point.

MODEL ESTIMATION

The following model estimation is based on a population of vehicles consisting of cars and trucks. The environmental factors considered were road class and time of day. These two factors have been cited in a number of past studies as having an important effect on accident rates. For example, Herd and others (2) reported that on rural roads the overall accident rate (accidents per vehicle mile of travel) was higher at night than during the day. His reported ratio of the night-to-day accident rates was greatest for rural expressways (1.98) and smallest for four-lane roads (1.47). The accident rate at dusk was reported to be higher than that at dawn. The rate for fatal accidents was also reported to be higher at night.

The model estimation involves the following steps:

1. The accident and exposure data are cross-classified by road class and time of day. Let the rows represent the various time-of-day periods and the columns the various categories of road class.
2. The model as represented by Equations 10-14 is applied to the data. For each cell, the estimated values of a can be obtained by solving Equations 10 and 11 and the estimated values of b by Equations 12, 13, and 14. Because all of the factors that affect the occurrences of different accident configurations can never be accounted for in modeling, the two estimated values of a from Equations 10 and 11 may not be exactly identical, though they will be close; the same applies to the three estimated values of b from Equations 12-14. As a result, each combination of road class and time of day will have two independently estimated values of a and three independently estimated values of b.
3. The unique cell estimates of a and b as well as the effects of road class and time of day can be determined as follows. Define

$$a_{+++} = \{\Sigma_i \Sigma_j \Sigma_k a_{ijk}\}/IJK$$
$$a_{i++} = \{\Sigma_j \Sigma_k a_{ijk}\}/JK$$
$$a_{+j+} = \{\Sigma_i \Sigma_k a_{ijk}\}/IK$$

where

I = number of rows,
J = number of columns, and
D = number of a in each cell (i,j), which is 2.

We have

$$\alpha_i^a = a_{i++} - a_{+++} \quad (17)$$

$$\beta_j^a = a_{+j+} - a_{+++} \quad (18)$$

$$\gamma_{ij}^a = a_{ij+} - a_{i++} - a_{+j+} + a_{+++} \quad (19)$$

where a_{ij+} is the average value of a for cell (i,j). Therefore,

$$a_{ij} = a_{+++} + \alpha_i^a + \beta_j^a + \gamma_{ij}^a \quad (20)$$

Similarly, for b with I rows, J columns, and K = 3,

$$\alpha_i^b = b_{i++} - b_{+++} \quad (21)$$

$$\beta_j^b = b_{+j+} - b_{+++} \quad (22)$$

$$\gamma_{ij}^b = b_{ij+} - b_{i++} - b_{+j+} + b_{+++} \quad (23)$$

where b_{ij+} is the average b for cell (i,j). Therefore,

$$b_{ij} = b_{+++} + \alpha_i^b + \beta_j^b + \gamma_{ij}^b \quad (24)$$

The results of the model estimation are represented by Equations 17-24. The values of a_{ij}

and b_{ij} are therefore the unique cell estimates of the model parameters a and b, road class and time of day having been accounted for. α_i^a, β_j^a, γ_{ij}^a, α_i^b, β_j^b, and γ_{ij}^b estimate the main effect of time of day, the main effect of road class, and their interactions on a and b, respectively.

APPLICATION OF THE MODEL

Possible applications of the accident model of the traffic mix include the following:

1. The model can be used to assess the relative involvement rates of any two different classes of vehicles that have different characteristics, taking into account the effect of any number of environmental factors. This will help minimize the undesirable "Simpson's Paradox" caused by confounding factors not otherwise considered.
2. The model can be used to predict the reduction (or the increase) in the number of accidents that results from altering the travel pattern (or the amount of travel) of some vehicles on certain roads and at certain times of day. These results can then be used as input for evaluating various highway-safety policy options concerning the use of certain types of vehicles.

CONCLUSIONS

The accident model of the traffic mix as developed might be expected to predict well when applied to a traffic situation in which the mix of any two different vehicle classes and the overall traffic volume are relatively uniform. The model can potentially be extended to include any number of environmental factors without altering the basic model presented in Equations 10-14. These factors are incorporated into the model in such a way that they partition the accident and exposure data into cells with relatively uniform traffic mix and overall traffic volume. The factors that can be included in the model, of course, depend on the level of detail of the available exposure and accident data. The stability of the estimated model for prediction depends on the ability to search for environmental factors that strongly influence the accident rates of the vehicle classes being investigated. The reliability of the estimated model is a function of the accuracy in measuring exposure. Future research efforts should therefore also be directed to acquiring reliable exposure data with a greater level of detail than is generally available now. Furthermore, there is a need for compatible definitions of the variables in both the accident and exposure data sets.

Computer programs to perform model estimation and prediction are available at the University of Michigan Transportation Research Institute in Ann Arbor.

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REFERENCES

1. R.E. Scott and J. O'Day. Statistical Analysis of Truck Accident Involvements. NHTSA, FH-11-7614, Dec. 1971.
2. D.R. Herd, K.R. Agent, and R.L. Rizenbergs. Traffic Accidents: Day Versus Night. TRB, Transportation Research Record 753, 1980, pp. 25-30.

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Microcomputer-Based Traffic Records System for Small Police Agencies

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In Virginia, there are many small cities, towns, and counties that maintain manual traffic records systems to meet their traffic safety data needs. Of these, the larger localities have a sufficiently high number of motor vehicle crashes and traffic violations to justify the need for automated record-keeping systems. However, the high cost of computer hardware and required technical expertise have discouraged these localities from acquiring the record management capability they need. The advent of the microcomputer has now brought sophisticated record-keeping technology within reach of even the smallest budgets. Still, lacking the staff support and the required applications software, most localities are unable to take advantage of the benefits of the new technology. In an effort to solve the problem, the Virginia Highway and Transportation Research Council, with funding support from the Virginia Department of Transportation Safety, has developed a model user-oriented local traffic records software system for small localities. The system accepts, stores, and recalls data for accidents and traffic offenses rapidly, accurately, and inexpensively. With further development, it will have the capability to be run on most currently marketed microcomputers.

An effective local program for reducing traffic accidents requires the capability to (a) identify traffic safety problems, (b) develop and implement appropriate countermeasures, and (c) evaluate the results of the chosen strategies. To achieve this capability, localities must keep records on the incidence of motor vehicle crashes and violations of traffic ordinances. Further, these records must be organized so they can be easily accessed and analyzed.

Localities also need to keep traffic records for the efficient management and operation of safety programs. Clearly, the key to maximizing the use of limited resources is information about the nature and scope of the traffic safety problem to be addressed. With this information, traffic safety administrators presumably can direct their resources toward the most serious problems or toward those problems that have the highest potential for payoff.

Finally, during these times of economic hardship for local governments, it is important for traffic safety officials to be able to justify traffic safety programs that compete for a share of the local budget or to obtain grant money from other sources. Again, traffic records are essential because they are the source of the information needed to support the requests for funds.

Many localities lack the capability to store, recall, and analyze traffic records for application to safety programs. This is particularly true of the smaller communities that lack the wherewithal to develop sophisticated and often expensive record-keeping systems. It would appear that this is an activity for which federal and state agencies could render assistance. However, such federal and state involvement has been and continues to be extremely limited. Direct federal involvement has been principally confined to improving state record-keeping systems through the NHTSA state and community highway safety grant program. The federal government has indirectly assisted some of the larger localities by providing grant money to pay for development of systems; however, many of the smaller localities cannot take advantage of this aid because the amount of money available for grants is limited and a grant requires a substantial local matching contribution.

In Virginia, the state provides no direct financial assistance to localities for traffic records but does provide some traffic safety statistics based on data reported to the Department of State Police. This information is of limited use, however, because (a) the data are not location specific, (b) they are up to 18 months out of date by the time they are received, (c) the reports do not cover accidents that are not legally reportable, (d) the report formats are too highly aggregated to be useful for detailed analysis, and (e) the quality of the data is suspect because state quality control is somewhat lax. Finally, neither the federal nor the state government keeps comprehensive statistical data on traffic violations.

The problems facing the smaller localities that desire to enhance their record-keeping capabilities are twofold: they lack the technical expertise to develop a system, and they lack the money to purchase the required equipment and services. It would appear that an appropriate solution to their problems would be the development of a model microcomputer-based system for traffic records that would be both productive and inexpensive to procure and maintain. Because little attention has been given to meeting this need of small localities, the development and implementation of such a system would be a novel and significant solution.

Thus, the goal of the project reported here was to design, develop, and implement a model microcomputer-based traffic records system (MTRS) for small localities. It was planned that the MTRS should provide the capability to enter, edit, store, and recall data on traffic accidents and violations on demand in a variety of formats. The system should be user-friendly and reasonably efficient with respect to response time and storage of information, require little or no maintenance, and above all be conceptually simple and practical to use. In addition, because the intent was to develop a model system, it should be designed so that any appropriately qualified and needy locality could implement it with minimal effort.

MTRS PROJECT DESCRIPTION

The project began in April 1981 with a review of available microcomputer technology. This was followed by selection of a pilot implementation site in June 1981 and the hardware purchase in October 1981. The MTRS was implemented in the Staunton, Virginia, Police Department (SPD) in March 1982. The project is now in the testing and evaluation phase.

Pilot Implementation Site

It was clear that, if the major goal of ensuring practicality for the system was to be attained, the MTRS should be implemented in a suitable locality on a pilot basis. The SPD agreed to participate in the project. It is believed that the operational setting of the pilot MTRS is typical of that of most small localities in Virginia. The SPD has a staff of 46 full-time uniformed personnel and a civilian support staff of 10. The 1978-1981 accident and traffic arrest patterns for the city, which has a population of 25 000, are indicated below (the data were obtained from the SPD manual record-keeping system):

Year	No. of Traffic Summons Issued	No. of Motor Vehicle Crash Investigations
1978	NA	803
1979	NA	840
1980	NA	691
1981	1939	696

Before the introduction of the MTRS, the SPD had no automated system for processing accident or traffic summons statistics nor any imminent prospects of obtaining this capability. It did, however, maintain a manual record-keeping system for both traffic accidents and arrests. This function was the responsibility of one full-time clerk. A limited range of reports, including monthly and annual accident and traffic arrest summaries, were produced from the manual statistical tallies. The hard copies of all accident reports and traffic citations were also kept on file for reference and distribution to appropriate interested parties.

Limitations of SPD System

The basic deficiency of the SPD's manual system was that a great deal of information was retained on file but little was used. In addition, the periodic reports issued were too highly aggregated and too limited in scope to be of use in the planning and allocation of police resources. Another deficiency was that the manual system was labor-intensive and prone to error. Finally, the record-keeping system, although fairly current, was unresponsive to ad hoc information needs. The preparation of nonstandard reports was extremely time-consuming because all work had to be done by hand. Thus, all but the most urgent requests for data were discouraged. It was clear that a more productive, accurate, and efficient means for gathering and analyzing traffic safety statistics was desirable.

Data Elements Captured by MTRS

The MTRS captures and reports on data from two forms: the Virginia uniform traffic summons and the Virginia FR-300P police accident report form. After negotiation with the SPD, certain data elements were selected from these forms for inclusion in the MTRS data files. The following accident data base elements were selected:

1. FR-300P report number;
2. Date of accident (month, day, and year);
3. Day of the week;
4. Hour of the day;
5. Weather conditions;
6. Investigating officer badge number;
7. Location and/or patrol zone;

8. Number of vehicles involved;
9. Vehicle type(s), each vehicle;
10. Vehicle speed(s), each vehicle;
11. Vehicle maneuver(s), each vehicle;
12. Type of collision;
13. Number of pedestrian(s) and bicyclist(s) injured or killed;
14. Age of pedestrian(s) and bicyclist(s) injured or killed, each pedestrian;
15. Sex of pedestrian(s) and bicyclist(s) injured or killed, each pedestrian;
16. Pedestrian actions, each pedestrian;
17. Pedestrian drinking, each pedestrian;
18. Number of vehicle occupants killed or injured, each vehicle;
19. Safety equipment used, each occupant;
20. Age and sex of occupants injured or killed, each occupant;
21. Driver age, each driver;
22. Driver sex, each driver;
23. Driver action, each driver; and
24. Driver drinking, each driver.

The traffic summons data base elements selected were as follows:

1. Traffic summons report number,
2. Date of offense (month, day, and year),
3. Day of the week,
4. Hour of the day,
5. Whether an accident was involved,
6. Court to which referred,
7. Number of violations,
8. Violation type(s),
9. Violator's age,
10. Violator's sex,
11. Officer badge number,
12. Weather conditions, and
13. Location and/or patrol zone.

These elements were selected to meet the following information needs:

1. For accidents--(a) Date, time, and location, (b) severity, (c) contributing factors, and (d) police investigation activity; and
2. For traffic violations--(a) Date, time, and location, (b) selected characteristics of violations, (c) selected characteristics of violators, and (d) police arrest activity.

MTRS Hardware

The MTRS was implemented on an Ohio Scientific Industries (OSI) C-3 OEM microcomputer, which featured 48K Static RAM, 6502A CPU, 2.2-MHz clock, dual 8-in floppy disks (single-sided), a total of 500K bytes of secondary storage, a 9600-baud Microterm ACT-5A CRT terminal, and an 80-cycle/s Epson MX-80 printer. The C-3 OEM comes standard with the manufacturer's OS-65U Ver. 1.3 operating system, which features microsoft interpreted BASIC. Because of the overhead associated with the operating system and the language interpreter, only 24K of main memory is available for user programs. The total purchase price for this unit, including related supplies, was $7300.

Overview of MTRS Functions

The MTRS provides the capability to enter, edit, and store encoded descriptions of each traffic accident and arrest. It features the capability to link traffic incidents (accidents or violations) to street locations and to individual officers. It can also produce a variety of fixed-format reports based on key file variables.

The MTRS is a menu-driven, interactive software system designed to permit even the novice to add and extract traffic safety information with minimal effort. After insertion of either volume 1 or volume 2 (software diskettes) in the computer's A drive, followed by a reset, a system master menu is displayed on the CRT console. After the display, the system prompts for a selection. Depending on the choice, the system either displays another menu, informs the user of a required disk change or insertion, or begins to prompt the user for specific information. This continues until all the parameters necessary to perform a task are identified. After completion of each task, the system returns to the menu last displayed. Each menu is back-linked to its parent menu and ultimately to the master menu.

By using this menu scheme, the user may move around among any of the subsystems. For most functions the user never has to issue an operating system command. The user does, however, have to contend with the operating system in three situations: (a) the initial creation of data disks for MTRS files, (b) preparation of backup copies of MTRS files, and (c) dumps of MTRS files. However, OS-65U system functions are also implemented in a menu-driven scheme similar to that of the MTRS; thus, little user knowledge of system details is required for any task.

The MTRS is divided into three subsystems: the accident subsystem, the traffic summons subsystem, and the auxiliary file subsystem. Each subsystem consists of a data file, file maintenance software module(s), and one or more report-producing programs. The software is physically divided among two diskettes, volumes 1 and 2. Volume 1 contains all auxiliary file subsystem data and programs in addition to all accident subsystem and traffic summons subsystem software that requires access to any of the auxiliary files. Volume 2 contains only accident subsystem and traffic summons subsystem software. Because of their size, the accident records and the traffic summons data files reside on separate diskettes; thus, the entire system resides on a total of four 8-in diskettes.

MTRS File Descriptions

The MTRS software system revolves around creating, maintaining, and accessing data in the files listed below:

File	Length (K bytes)
Accident records	230
Traffic summons	230
Officer badge	7
Street index	32

The file sizes given are those of the Staunton files. There are no software restrictions on the length of these files.

The accident records file (ARF) contains encoded values for each of the elements contained in the listing of accident data base elements given previously, organized in hierarchical, sequential records. Each accident case is represented by one master record, up to 10 vehicle/driver records, up to 10 injured occupant records per vehicle, and up to 3 injured pedestrian or bicyclist records. Table 1 gives the layouts for each of the various record types. Up to approximately 1000 accident cases may be accommodated in the ARF.

The traffic summons file (TSF) contains encoded values for each of the elements contained in the listing of traffic summons data base elements given earlier, organized into sequential records. Each TSF record may accommodate as many as 3 violations per arrest incident (multiple summonses may be issued by the arresting officer). The record layout for the TSF is given in Table 2. As many as 3000 traffic summons records may be accommodated in the TSF.

The officer badge file (OBF) contains the badge number and name of each police officer in the SPD, organized as an indexed sequential (ISAM) file. Badge numbers and names of as many as 150 police officers can be accommodated. This file is used to check the validity of badge numbers entered in the ARF or the TSF and to provide alphabetic counterparts for the badge numbers for certain outputs. The record layout for the OBF is also given in Table 2.

The SIF contains the street name and a three-digit code (index) in the range 100-998 for each of the 450 streets in Staunton, organized as an ISAM file. As many as 899 street names and indices can be accommodated. Like the OBF, the SIF is used to check the validity of encoded accident locations in the TSF or the ARF and to provide alphabetic counterparts to the street codes for certain outputs. The record layout for the SIF is given in Table 2.

Table 1. ARF record layout.

Element	No. of Positions	Data Type	Possible Values[a]
Master record			
Record type	2	Alpha	A = master
Report number	5	Numeric actual	1-9999
Location type	2	Alpha	I = intersection, S = segment
Street index			
#1	4	Numeric code	100-999
#2	4	Numeric code	100-999
#3	4	Numeric code	100-999
Month of accident	3	Numeric actual	1-12
Day of accident	3	Numeric actual	1-31
Year of accident (last two digits)	3	Numeric actual	1-99
Day of week	2	Numeric code	1-7
Hour of occurrence	3	Numeric actual	1-12
Minute of occurrence	3	Numeric actual	00-59
AM or PM	2	Numeric code	1 = AM, 0 = PM
Zone of occurrence	3	Numeric code	1-28
Weather conditions	2	Numeric code	1-7
Badge number	4	Numeric actual	1-150
Number of vehicles	3	Numeric actual	1-10
Number of pedestrians	2	Numeric actual	1-3
Driver/vehicle record layout			
Record type	2	Alpha	V = vehicle
Vehicle type	2	Numeric code	1-7
Vehicle speed	2	Numeric code	1-5
Vehicle collision type	3	Numeric code	1-13
Vehicle maneuver	3	Numeric code	1-15
Age of driver	3	Numeric actual	1-99
Sex of driver	2	Alpha	M = male, F = female
Driver alcohol involvement	2	Numeric code	1-4
Driver action	3	Numeric code	1-18
Driver injury	2	Numeric code	1 = killed, 2 = injured, 3 = not injured
Driver restraint use	2	Numeric code	1-6
Number of vehicle occupants killed or injured	3	Numeric actual	1-10
Occupant record layout			
Record type	2	Alpha	O = occupant
Occupant age	3	Numeric actual	1-99
Occupant sex	2	Alpha	M = male, F = female
Occupant injury	2	Numeric code	1 = killed, 2 = injured
Occupant restraint use	2	Numeric code	1-6
Pedestrian record layout			
Pedestrian type	2	Alpha	P or B = pedestrian or bicyclist
Pedestrian age	3	Numeric actual	1-99
Pedestrian sex	2	Alpha	M = male, F = female
Pedestrian alcohol involvement	2	Numeric code	1-4
Pedestrian injury	2	Numeric code	1 = killed, 2 = injured
Pedestrian action	2	Numeric code	1-7
Vehicle hit by	3	Numeric actual	1-10 (vehicle number)

[a] For numeric-type elements, 0 = unknown/not stated/missing, deleted/not applicable; for alpha-type elements, U = unknown/not stated/missing/not applicable.

Table 2. Record layouts for TSF, OBF, and SIF.

File	Element	No. of Positions	Data Type	Possible Values[a]
TSF	Report number	5	Numeric actual	1-9999
	Location type	2	Alpha	I = intersection; S = segment
	Street index			
	#1	4	Numeric code	100-999
	#2	4	Numeric code	100-999
	#3	4	Numeric code	100-999
	Court of record	2	Alpha	G = general district, J = juvenile
	Violation			
	#1	3	Numeric code	1-18
	#2	3	Numeric code	1-18
	#3	3	Numeric code	1-18
	Total violations	2	Numeric actual	1-3
	Badge number	4	Numeric actual	1-150
	Violator			
	Sex	2	Alpha	M = male, F = female
	Month of birth	3	Numeric actual	1-12
	Day of birth	3	Numeric actual	1-31
	Year of birth (last two digits)	3	Numeric actual	1-99
	Violation			
	Zone	3	Numeric actual	1-28
	Month	3	Numeric actual	1-12
	Day	3	Numeric actual	1-31
	Year (last two digits)	3	Numeric actual	1-99
	Day of week	2	Numeric code	1-7
	Hour of occurrence	3	Numeric actual	1-12
	Minute of occurrence	3	Numeric actual	00-59
	AM or PM	2	Numeric code	1 = AM, 0 = PM
	Weather conditions	2	Numeric code	1-7
	Whether accident related	2	Alpha	Y = yes, N = no
OBF	Badge number	4	Numeric actual	1-150
	Officer name	21	Alpha	Any string
SIF	Street index	4	Numeric code	100-999
	Street name	21	Alpha	Any string

[a] For numeric-type elements, 0 = unknown/not stated/missing, deleted/not applicable; for alpha-type elements, U = unknown/not stated/missing/not applicable.

Overview of Major MTRS Functions

MTRS programs can be categorized broadly as file maintenance software or report-generating software. File maintenance programs and their basic functions are summarized in Table 3 and the report-generating programs and their basic functions in Table 4. To better illustrate how the MTRS works, several example functions are discussed in detail below.

Traffic Summons and Accident File Maintenance

ACENTR and TSENTR are the ARF and TSF maintenance modules. Each program has three major components: (a) a data element input and edit component, (b) an element verification feature, and (c) a record deletion facility. The data element entry and editing portion prompts the user with a series of questions regarding each of the elements to be entered in the file. The order of the questions occurs in direct correspondence with the locations of the data elements on the source report forms. Each element is edited at the time of entry for validity and, in some cases, for consistency with other elements. To speed the entry process, system prompts are brief, usually 5-6 words in length. If the user is at a loss as to what is a legal response, he simply hits <CR> in response to any system prompt to produce a brief description of the response options. The original prompt is then reissued by the system. In this way, the user can teach himself how to enter data simply by responding to all system prompts with a <CR>.

Table 3. MTRS file maintenance and supervisory software.

Program Name	Description
ACENTR	ARF editing routine: add/verify/delete accident case data
TSENTR	TSF editing routine: add/verify/delete traffic summons data
EDOBF	OBF editing routine: adds, deletes, modifies, lists OBF records
EDSIF	SIF editing routine: adds, deletes, modifies, lists SIF records
UTIL	General file maintenance utility: initializes ARF, TSF, OBF, and SIF prior to first use; copies ARF and TSF; physically deletes "deleted" records
BEXEC	Simulates menu scheme; initializes system; sets up printer and console; toggles certain system features; calls required programs

The element verification portions of ACENTR and TSENTR permit modification of any element entered during the session for each incident before its entry in the file. After the last system prompt for data, the program displays all of the elements entered for this case and asks whether they are correct. If not, the user may specify the element(s) he wishes to change (one at a time); the system reissues the prompt for each element, edits the response as before, and returns to the verification mode with the now modified element displayed as prescribed. This procedure may be repeated as often as necessary. Eventually, the data will be made correct and the user may release the case to be written to the disk file or reject the case. In the latter situation, no data are written to the file and the program returns to its parent function menu.

ACENTR and TSENTR also permit deletion of a record (by report number only). When the record is found, its report number field is set to zero, which signifies that the record is no longer valid. (Report-generating programs skip over all deleted records.) The rest of the data in the now deleted record remain intact. The result of this procedure is that, over time, garbage records will accumulate in the files as deletions are made. The garbage accumulation problem is handled by execution of the program UTIL, which copies an accident or traffic summons file from one disk to another while eliminating deleted records as it proceeds. The frequency of use is left to the user and depends on the frequency of record deletions.

Auxiliary File Maintenance

The programs EDOBF and EDSIF provide for the addition, deletion, or modification of records in the OBF and SIF, respectively. In addition, these programs can produce a listing of the contents of these files in a directory format. All file transactions result in physical changes on the disk; thus, no garbage records accumulate in these files as in the ARF or the TSF. Records in both files consist of a numeric element (badge numbers or street index) followed by an alpha element (officer name or street

Table 4. MTRS report-producing software.

Program Name	Description of Program
ACACTV	Produces report of accident investigation frequencies by month of year, time of day, day of week, accident severity, and total investigations for given officer
TSACTV	Produces traffic arrest frequencies by month of year, time of day, day of week, court of record, violation type, and total arrests for given officer
HILOC	Identifies streets with more than mean number of traffic incidents
HILST	Produces report of details for locations of incidents occurring on high-incident streets
ACLOC	Produces report of accident frequencies by month, time of day, day of week, driver action, severity, weather conditions, collision type, vehicle maneuver, and total crashes at given location
TSLOC	Produces report of traffic arrest frequencies by month, time of day, day of week, court of record, violation type, and total violations at given location
ACGEN	Produces report of accident frequencies by month, time of day, day of week, severity, driver action, weather conditions, collision type, location type, and total crashes
TSGEN	Produces report of traffic arrest frequencies by month, time of day, day of week, court of record, total violations, violations by type, and weather conditions
ACAGSX	Produces report of frequencies of accidents involving at least one driver with age and sex characteristics specified by the user by month, time of day, day of week, severity, driver action, location type, collision type, weather conditions, and total crashes
TSAGSX	Produces report of traffic arrest frequencies of drivers with age and sex characteristics specified by the user by month, time of day, day of week, court of record, violation type, weather conditions, and total violations
ACALSP	Produces report of frequencies of accidents involving at least one driver with user-specified alcohol involvement characteristics and/or at least one vehicle traveling at user-specified speed by month, time of day, day of week, severity, driver age, driver sex, collision type, weather conditions, and total crashes
TSVIOL	Produces report of traffic arrest frequencies for user-specified violation type by month, time of day, day of week, court of record, driver age, driver sex, weather conditions, and total violations
ACPED	Produces report of frequencies of pedestrian-involved accidents by month; time of day; day of week; severity; pedestrian action, age, sex, and alcohol involvement; vehicle maneuver, vehicle type, and total crashes
ACREST	Produces report of occupant restraint use in injury and fatal crashes by occupant type, age, sex, and type of restraint used

name). Thorough edit checking is provided at the time of entry on the numeric element; however, the alpha element is checked only for length (fewer than 20 characters). Thus, it is up to the user to spell names properly, include punctuation, etc. It is also left to the user to make sure that there are no duplicate names in these files.

Traffic Summons Subsystem Report Generation

Six types of traffic summons reports can be produced by the MTRS:

1. General traffic arrest statistics,
2. Officer activity statistics,
3. Statistics by age and sex of violator,
4. Statistics by type of violation,
5. High-incidence locations, and
6. Traffic arrests at particular locations.

Each report-producing program permits the user to restrict the report content based on the value of certain key variables in the file. All reports can be restricted to any of Staunton's 28 patrol areas, restricted to any block of contiguous months of the year, and routed to the CRT console or Epson printer. The printer output is formatted slightly differently from CRT output in that relative percentages are computed in addition to the frequencies for each variable. A sample traffic summons subsystem report is shown in Figure 1.

Accident Records Subsystem Reports Generation

Eight types of accident reports can be produced by the MTRS:

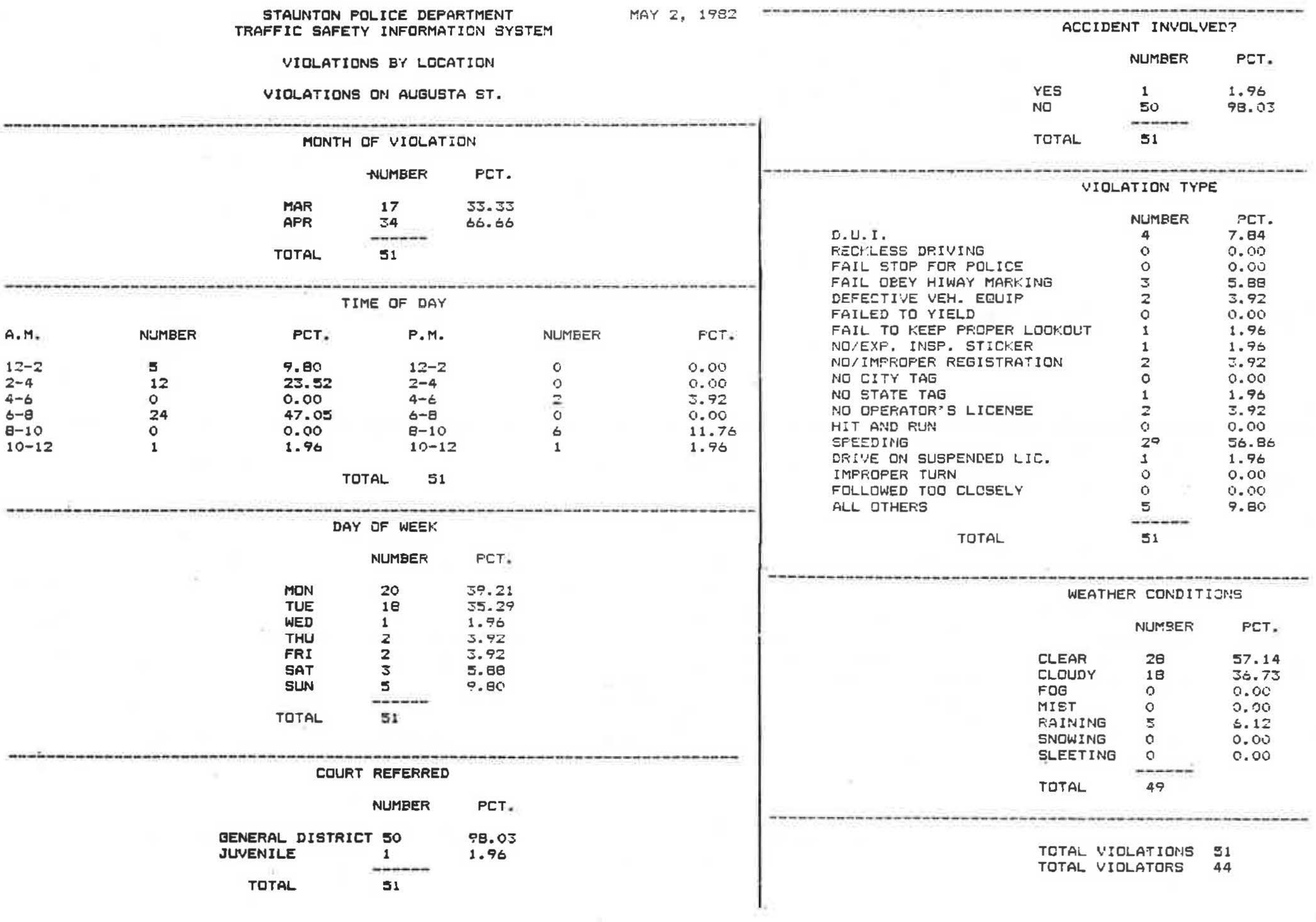
1. General accident statistics,
2. Officer activity statistics,
3. Statistics by driver age and sex,
4. Statistics by alcohol and speed involvement,
5. Pedestrian and bicyclist accident statistics,
6. Occupant restraint use in accidents,
7. High-accident locations, and
8. Accident statistics at particular locations.

As in the traffic summons subsystem, the report content may be restricted based on the value of key file variables. In addition, reports may be restricted to patrol areas or blocks of contiguous months and may be routed to the CRT console or printer. A sample accident records subsystem report is shown in Figure 2.

FUTURE DIRECTIONS FOR MTRS

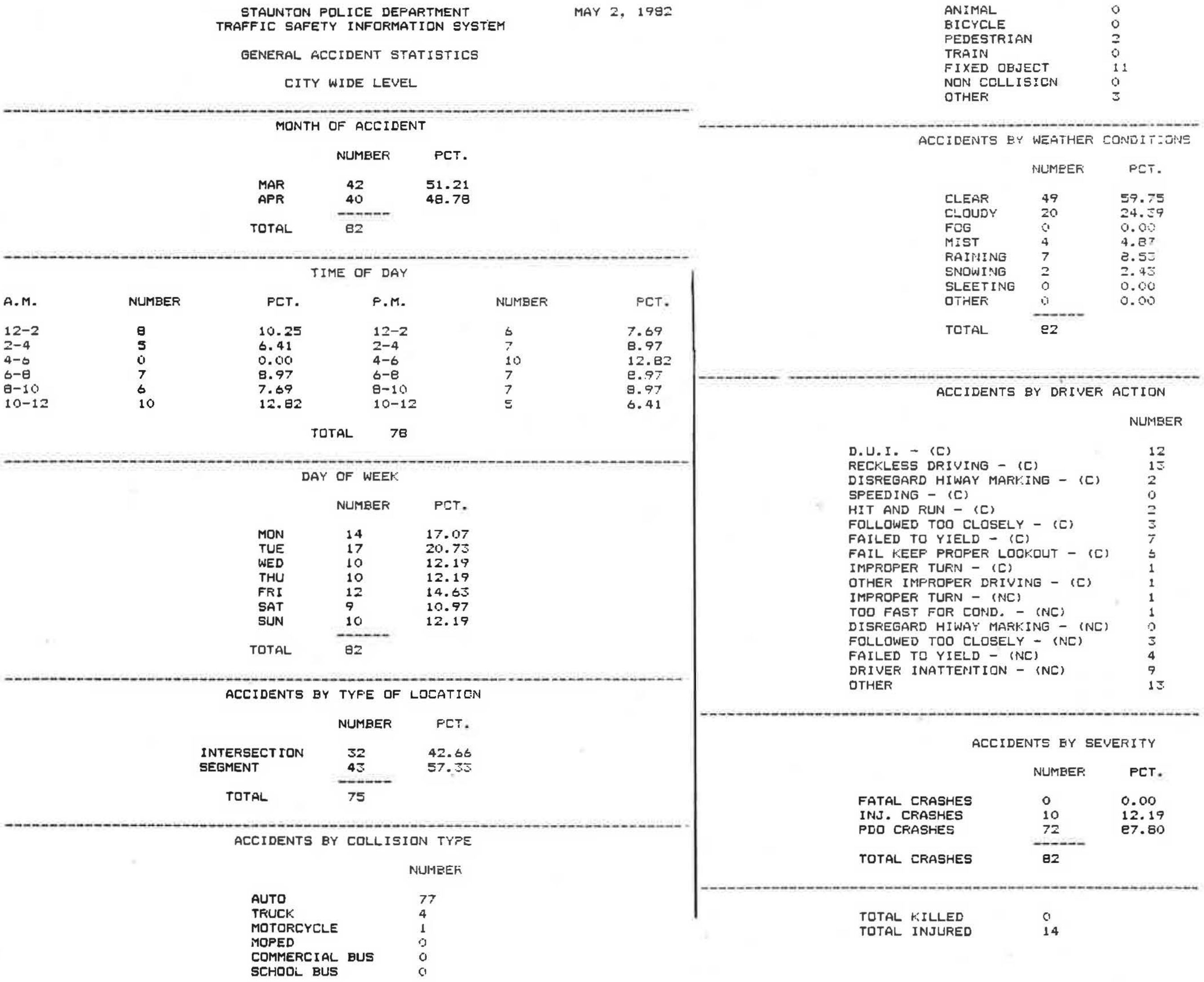
Because of funding limitations, full development of the MTRS concept was not achieved in the first-generation model. An application for the funding of a second-generation development effort is pending approval by the Virginia Department of Transportation Safety. The most important area in need of attention is system transportability. Because the system was initially developed for the OSI hardware and operating system, its diskettes cannot be read by non-OSI hardware. This means that any locality that desires to obtain the system will have to either purchase OSI equipment or convert and enter the source code from hard copy. The latter would be very time-consuming because the MTRS consists of several thousand lines of BASIC code.

Figure 1. Sample traffic summons subsystem report.



```
                  STAUNTON POLICE DEPARTMENT                MAY 2, 1982
               TRAFFIC SAFETY INFORMATION SYSTEM

                     VIOLATIONS BY LOCATION

                    VIOLATIONS ON AUGUSTA ST.

------------------------------------------------------------------------------
                       MONTH OF VIOLATION

                           NUMBER      PCT.

                  MAR        17        33.33
                  APR        34        66.66
                           ------
                  TOTAL      51

------------------------------------------------------------------------------
                           TIME OF DAY

A.M.         NUMBER         PCT.        P.M.          NUMBER          PCT.

12-2          5             9.80        12-2           0              0.00
2-4           12            23.52       2-4            0              0.00
4-6           0             0.00        4-6            2              3.92
6-8           24            47.05       6-8            0              0.00
8-10          0             0.00        8-10           6              11.76
10-12         1             1.96        10-12          1              1.96

                           TOTAL     51

------------------------------------------------------------------------------
                           DAY OF WEEK

                           NUMBER      PCT.

                  MON        20        39.21
                  TUE        18        35.29
                  WED        1         1.96
                  THU        2         3.92
                  FRI        2         3.92
                  SAT        3         5.88
                  SUN        5         9.80
                           ------
                 TOTAL       51

------------------------------------------------------------------------------
                          COURT REFERRED

                           NUMBER      PCT.

              GENERAL DISTRICT 50      98.03
              JUVENILE         1       1.96
                           ------
                TOTAL          51

--------------------------------------------------------------
                                   ACCIDENT INVOLVED?

                                          NUMBER      PCT.

                              YES           1         1.96
                              NO            50        98.03
                                          ------
                              TOTAL         51

--------------------------------------------------------------
                                      VIOLATION TYPE

                                          NUMBER      PCT.
      D.U.I.                                4         7.84
      RECKLESS DRIVING                      0         0.00
      FAIL STOP FOR POLICE                  0         0.00
      FAIL OBEY HIWAY MARKING               3         5.88
      DEFECTIVE VEH. EQUIP                  2         3.92
      FAILED TO YIELD                       0         0.00
      FAIL TO KEEP PROPER LOOKOUT           1         1.96
      NO/EXP. INSP. STICKER                 1         1.96
      NO/IMPROPER REGISTRATION              2         3.92
      NO CITY TAG                           0         0.00
      NO STATE TAG                          1         1.96
      NO OPERATOR'S LICENSE                 2         3.92
      HIT AND RUN                           0         0.00
      SPEEDING                              29        56.86
      DRIVE ON SUSPENDED LIC.               1         1.96
      IMPROPER TURN                         0         0.00
      FOLLOWED TOO CLOSELY                  0         0.00
      ALL OTHERS                            5         9.80
                                          ------
                  TOTAL                     51

--------------------------------------------------------------
                                   WEATHER CONDITIONS

                                          NUMBER      PCT.

                              CLEAR         28        57.14
                              CLOUDY        18        36.73
                              FOG           0         0.00
                              MIST          0         0.00
                              RAINING       5         6.12
                              SNOWING       0         0.00
                              SLEETING      0         0.00
                                          ------
                              TOTAL         49

--------------------------------------------------------------

                              TOTAL VIOLATIONS   51
                              TOTAL VIOLATORS    44
```

Figure 2. Sample accident records subsystem report.



```
                     STAUNTON POLICE DEPARTMENT                 MAY 2, 1982
                   TRAFFIC SAFETY INFORMATION SYSTEM

                      GENERAL ACCIDENT STATISTICS

                           CITY WIDE LEVEL
--------------------------------------------------------------------------------
                          MONTH OF ACCIDENT

                                NUMBER      PCT.

                        MAR      42        51.21
                        APR      40        48.78
                               ------
                       TOTAL     82
--------------------------------------------------------------------------------
                             TIME OF DAY
A.M.         NUMBER          PCT.        P.M.           NUMBER          PCT.

12-2         8               10.25       12-2           6               7.69
2-4          5               6.41        2-4            7               8.97
4-6          0               0.00        4-6            10              12.82
6-8          7               8.97        6-8            7               8.97
8-10         6               7.69        8-10           7               8.97
10-12        10              12.82       10-12          5               6.41

                             TOTAL    78
--------------------------------------------------------------------------------
                             DAY OF WEEK

                                NUMBER      PCT.

                        MON      14        17.07
                        TUE      17        20.73
                        WED      10        12.19
                        THU      10        12.19
                        FRI      12        14.63
                        SAT      9         10.97
                        SUN      10        12.19
                               ------
                       TOTAL     82
--------------------------------------------------------------------------------
                     ACCIDENTS BY TYPE OF LOCATION

                                NUMBER      PCT.

                  INTERSECTION   32        42.66
                  SEGMENT        43        57.33
                               ------
                     TOTAL       75
--------------------------------------------------------------------------------
                     ACCIDENTS BY COLLISION TYPE

                                     NUMBER

                       AUTO            77
                       TRUCK           4
                       MOTORCYCLE      1
                       MOPED           0
                       COMMERCIAL BUS  0
                       SCHOOL BUS      0
```

```
                 ANIMAL              0
                 BICYCLE             0
                 PEDESTRIAN          2
                 TRAIN               0
                 FIXED OBJECT        11
                 NON COLLISION       0
                 OTHER               3
------------------------------------------------------------
              ACCIDENTS BY WEATHER CONDITIONS

                          NUMBER        PCT.

                 CLEAR     49           59.75
                 CLOUDY    20           24.39
                 FOG       0            0.00
                 MIST      4            4.87
                 RAINING   7            8.53
                 SNOWING   2            2.43
                 SLEETING  0            0.00
                 OTHER     0            0.00
                          ------
                 TOTAL     82
---------- -------------------------------------------------
                ACCIDENTS BY DRIVER ACTION

                                                    NUMBER

        D.U.I. - (C)                                  12
        RECKLESS DRIVING - (C)                        13
        DISREGARD HIWAY MARKING - (C)                 2
        SPEEDING - (C)                                0
        HIT AND RUN - (C)                             2
        FOLLOWED TOO CLOSELY - (C)                    3
        FAILED TO YIELD - (C)                         7
        FAIL KEEP PROPER LOOKOUT - (C)                6
        IMPROPER TURN - (C)                           1
        OTHER IMPROPER DRIVING - (C)                  1
        IMPROPER TURN - (NC)                          1
        TOO FAST FOR COND. - (NC)                     1
        DISREGARD HIWAY MARKING - (NC)                0
        FOLLOWED TOO CLOSELY - (NC)                   3
        FAILED TO YIELD - (NC)                        4
        DRIVER INATTENTION - (NC)                     9
        OTHER                                         13
------------------------------------------------------------

                   ACCIDENTS BY SEVERITY

                           NUMBER       PCT.

         FATAL CRASHES      0           0.00
         INJ. CRASHES       10          12.19
         PDO CRASHES        72          87.80
                          ------
         TOTAL CRASHES      82
------------------------------------------------------------

         TOTAL KILLED       0
         TOTAL INJURED      14
```

Another required enhancement of the first-generation MTRS is the removal of all hardware-dependent code, such as screen cursor control commands, idiosyncratic POKES and PEEKS, and nonstandard BASIC commands. These changes, combined with a conversion of the MTRS to a standardized operating system (such as CP/M), would greatly ease the burden of transferring MTRS code from one machine to another.

A second area for consideration is the removal of restrictions on the complexity of accident cases (e.g., restrictions on the number of vehicles, passengers, and pedestrians). This will require a redesign of the accident data entry module to free memory for storage of intermediate data.

A third area for further development is the enhancement of response times for system output. Several approaches are available: (a) conversion of the system to a compiled language, (b) restructuring the accident and traffic summons file to permit faster access to records of interest, and (c) use of preprocessing techniques at the time of data entry to hasten data interpretation at report production time.

A final area for investigation is the expansion of system capabilities to include full location editing at the time of data entry, incorporation of traffic count data for use in normalization of accident distributions for comparison purposes, expansion of the data element list to include more traffic engineering elements (roadway characteristics, traffic control, etc.), incorporation of a multiyear analysis capability, and inclusion of basic statistical functions (and perhaps graphics) to help localities scientifically evaluate traffic safety countermeasures.

CONCLUSIONS

The application of microcomputer technology to the traffic records needs of small-city police agencies appears to offer a practical solution to their information storage, management, and analysis problems. The MTRS produces a variety of outputs that are useful in monitoring general accident and traffic arrest levels; identifying the geographic distribution of accidents and traffic arrests; pinpointing the months, days of the week, and hours of the day when most accidents occur and traffic arrests are made; examining the characteristics of certain classes of accidents and traffic arrests that are of common and continuing interest to all safety agencies; and monitoring the field performance of officers assigned to traffic duties. In addition, the widespread availability of low-cost hardware brings the costs of microcomputer technology within reach of all but the smallest communities.

Such a purchase is even more sensible with the growing availability of software such as the MTRS. Coupled with modern management techniques, the information produced by the MTRS can enhance the efficiency and productivity of police agencies, provide support for justifying programs, and help to reduce the incidence of motor vehicle accidents and traffic violations.

In spite of the success of the first generation of MTRS, work remains to be done to make it an even better product. Areas that need to be investigated include improvement of the transportability of the software, removal of all software restrictions on accident case complexity, enhancement of system response times, and expansion of system capabilities to incorporate traffic engineering and statistical functions.

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Systematic Procedure for Incorporating Exposure Factors in Truck Accident Analysis

SNEHAMAY KHASNABIS AND T.R. REDDY

The development and testing of a methodology for assessing the involvement rate of trucks in highway accidents are described. Existing procedures for incorporating exposure factors in truck accident analysis have been reviewed and their merits and demerits are discussed. Three alternative approaches for analyzing truck accidents are discussed, and approach 3 is identified as the most logical one based on its ability to incorporate exposure factors for arriving at appropriate measures. In the suggested methodology, a set of three vehicle-accident categories are identified: truck-only accident (TOA), passenger-car-only accident (POA), and combined accident (CA). A procedure for developing rates (accidents per vehicle mile of travel) for each category is defined that incorporates appropriate exposure factors. To check the validity of the proposed approach, Michigan accident data for a 10-year period (1970-1979) have been used as a case study. Standard statistical techniques (ANOVA and t-test) were applied. A comparison of accident data among TOAs, CAs, and POAs indicated that there is a significant difference in fatal, personal-injury, and property-damage accident rates when the three vehicle categories are considered together. When a comparison is made between TOAs and POAs, TOA rates are significantly higher for fatal and property-damage accidents. In addition, the CA category, which comprises a significant number of trucks, has generally a higher accident rate compared with others. Overall, trucks appear to have experienced a higher accident rate.

Passenger cars and trucks are the prime users of highway facilities. For example, during the year 1977, a total of 65 000 million vehicle miles of travel (VMT) was generated by all motorized vehicles in the state of Michigan, approximately 11 335 by trucks and 49 000 by passenger cars (1). Thus, approximately 93 percent of all travel in the state is attributable to trucks and passenger cars alone, and the remaining 7 percent of the travel is generated by other vehicles, including buses, motorcycles, and other commercial vehicles. Furthermore, the fact that the relative proportion of travel for these vehicle categories has remained unchanged during the past 10 years indicates that the year 1977 is typical in this respect.

The relative involvement rate of trucks and passenger cars in the incidence of highway accidents has been a topic of research interest for a number of years. In Michigan in the year 1977, a total of 636 259 vehicles were involved in all highway accidents--91 000 trucks and 505 000 passenger cars. This indicates that more than 95 percent of all vehicles involved in accidents were either trucks or passenger cars (1). A review of the national accident data base for the year 1977 shows that the same proportion generally holds true when all accidents on the nation's highways are considered (2). Table 1 gives the data compiled for the nation and for Michigan. Furthermore, when one considers fatal accidents alone, similar trends generally hold true when nationwide data are compared with Michigan data. As Table 1 indicates, approximately 18 percent of all vehicles involved in fatal accidents in Michigan in 1977 were trucks and 62 percent passenger cars. Corresponding figures compiled on a nationwide basis are 22 and 67 percent, respectively.

PROBLEM STATEMENT

The intent of the above discussion was to present some basic accident and exposure data and to demonstrate that the state of Michigan is typical of most states in the nation relative to highway accidents and that in terms of both travel and accidents the role of trucks is significant. However, little research reported in the literature addresses the question of whether trucks are carrying a heavy or light share of highway accidents. The purpose of this paper is to develop and test a methodology for assessing the relative involvement of trucks in highway accidents.

As a part of this methodology, one must establish at the outset an appropriate measure that can be used to compare accident experience by different vehicle categories over an extended time period. The development of such a measure appears to be a simplistic task; however, certain conceptual and operational problems must be resolved when the objective is to separate accident data into two or more vehicle categories (i.e., trucks, passenger cars, etc.). The problem arises from an apparent lack of agreement among traffic experts as to what constitutes exposure to accident, particularly when a comparison of accident data by different vehicle categories is involved. Although limited research in the area of exposure estimation has been reported in the literature, there is little agreement among researchers on how to incorporate exposure factors in accident analysis (3-5).

The problem addressed in this study is the question of exposure factors in analyzing accident data for the purpose of assessing the involvement rate of trucks in the incidence of overall highway accidents. This paper is presented in two separate sections. First, the development of a methodology for considering exposure factors in truck accident analysis is presented. Next, the application of this proposed method is demonstrated by using the Michigan data base. The data sources for this study are publications of the Michigan Department of State Police (1) and the U.S. Department of Transportation (DOT) (2), earlier work reported by Khasnabis and Atabak (6,7), and other work (8-10).

TRADITIONAL APPROACH

The measure used in most accident studies can be described as follows:

Accident rate = number of accidents/VMT (1)

Note that the denominator of Equation 1 is designed to discount the effect of varying amounts of travel generated in different facilities and has commonly been referred to as "exposure." Implicit in the designation of VMT as exposure is the premise that the more the amount of travel generated on a given facility, the greater the amount of risk or exposure to accidents to which the vehicles on the facility are subjected; therefore, the rate must reflect the effect of varying amounts of travel.

The above rate is quite appropriate in comparing accident data for different types of facilities or different locations. However, certain problems in logic would appear if one were to use the same measure in comparing accident data for different vehicle categories. By extrapolating the above definition, the rate for trucks can be defined as

Truck accident rate = number of accidents in which trucks were involved
÷ VMT generated by trucks (2)

The use of the above measure implies that, on a given facility or a network containing a number of facilities, exposure to accidents for a given type of vehicle (trucks in this case) is caused by travel generated only by that type of vehicle. However, if one departs from the original concept of exposure and redefines exposure as opportunity for interaction between different types of vehicles, the use of an alternative measure for exposure might appear appropriate.

It can be argued that exposure to accident for a particular vehicle type i is created not only by travel generated by type i itself but also by travel generated in part by all other types of vehicles present in the traffic stream. For example, referring back to the 1977 truck accident data base in Michigan, a total of 84 640 truck accidents was recorded in the state, where a truck accident is defined as one that involves at least one truck. Note that these truck accidents involved approximately 90 000 trucks and 63 000 nontrucks, mostly passenger cars. An argument could be made that truck accidents are, at least in part, the result of conflicts between trucks and nontrucks (as exemplified by the involvement of 63 000 nontrucks). Thus, the measure used should reflect the exposure effect of these nontrucks or, alternatively, the rate should have in the numerator those accidents that involved only trucks.

Another difficulty associated with the traditional approach is related to the use of the term "truck accident." A truck accident is generally referred to as one that involves at least one truck. By the same token, an accident that involves at least one passenger car is a passenger-car accident. The question remains as to how to treat an accident between a truck and a passenger car. These questions are addressed below.

METHODOLOGY

In this research, three possible approaches for incorporating exposure factors in truck accident analysis were originally developed.

Approach 1

Approach 1 requires the categorization of the accident data into truck accidents (accidents involving at least one truck) and passenger-car accidents (accidents involving at least one passenger car). Next, the percentage of passenger cars in truck accidents is computed, and the VMT attributable to passenger cars is included in the denominator along with the VMT for trucks. A similar procedure is followed for including truck VMT in the compilation of the passenger-car accident rate. This rate can then be written as

Truck accident rate = number of accidents involving at least one truck
÷ (VMT by truck + contribution of VMT by
passenger cars) (3)

It was also postulated that the contribution of VMT by passenger cars could be estimated as a fraction of all passenger-car VMT, prorated for the number of passenger cars involved in truck accidents and the number of all passenger cars involved in all accidents. For example, in the year 1977, 505 000 passenger cars were involved in all accidents, and 59 000 of these were involved in truck accidents (11.7 percent). Thus, method 1 calls for including 11.7 percent of passenger-car VMT in the denominator of truck accident rate.

Note that the purpose of including the contribution of VMT by passenger cars in Equation 3 is to add a surcharge to the exposure, attributable to the increased opportunity of interaction resulting from the presence of other vehicles in the traffic stream. It should also be noted that, in computing the accident rate for passenger cars, a similar contribution by trucks in the VMT attributable to the truck-car accidents needs to be added.

This method was not adopted, however, because of one inherent deficiency. The comparison of the accident rates for the two vehicle categories by this method does not ensure the use of two mutually exclusive data bases. The rates for both trucks and passenger cars included accident data from the other vehicle category, which resulted in some overlap in the sample space. Specifically, an accident between a truck and a passenger car would be accounted for in both categories by this method.

Table 1. Comparison of vehicle involvement in highway accidents in U.S. and Michigan in 1977.

	All Accidents		Fatal Accidents	
Vehicle Category	U.S.	Michigan	U.S.	Michigan
All vehicles	29 900 000	636 259	63 700	3037
Trucks				
Number	4 700 000	91 000	14 100	532
Percent	15.7	14.3	22.1	17.5
Passenger cars				
Number	23 900 000	505 000	42 900	1874
Percent	79.9	79.4	67.3	61.7
Trucks and passenger cars combined (%)	95.6	93.7	89.4	79.2

Approach 2

Approach 2 required the development of a rate based on a numerator containing the number of vehicles involved in accidents rather than number of accidents. This approach would represent a significant departure from the traditional approach used in most accident analysis, where the number of accidents (as opposed to the number of vehicles) has been used in the numerator. Thus, according to this approach,

$$\text{Truck involvement rate} = \text{number of trucks involved in accidents} \div \text{total truck VMT} \qquad (4)$$

Note that Equation 4 would automatically ensure the use of mutually exclusive data bases and there would be no overlap of sample space in the two rates to be compared. However, the method totally disregards the concept of the opportunity for interaction (between different vehicles) by separating trucks and passenger cars in the two distinct categories. The 1977 data base for Michigan shows that, of a total of 374 751 highway accidents, 84 640 accidents involved at least one truck (termed "truck accident"). These truck accidents involved approximately 90 000 trucks and 60 000 passenger cars, whereas the remaining 290 111 nontruck accidents involved 505 000 passenger cars and only 40 000 other vehicles (the majority of which are trucks).

It was felt that the use of vehicles in the numerator (as opposed to accidents) would inflate the rate for passenger cars due to the simple fact that most multivehicle truck accidents involve passenger cars as the other vehicle whereas most multivehicle passenger-car accidents involve another passenger car. Thus, because it was believed that the use of vehicles would have a tendency to overly exaggerate the adverse role of passenger cars in highway accidents in comparison with trucks, this approach was not pursued.

Approach 3

Approach 3 is an outgrowth of approach 1 and is an attempt to develop an analysis procedure by using mutually exclusive data bases with the provision that no overlapping sample space is considered. It was believed that the only way to avoid the use of a nonmutually exclusive data base would be to compare three sets of accident rates, even though the objective is to compare accident involvement by two types of vehicles. The following three rates were developed:

$$\text{Truck-only accident (TOA) rate} = \text{number of accidents involving trucks only} \div (F_t \times \text{truck VMT}) \qquad (5)$$

$$\text{Passenger-car-only accident (POA) rate} = \text{number of accidents involving passenger cars only} \div (F_c \times \text{passenger car VMT}) \qquad (6)$$

$$\text{Combined accident (CA) Rate} = \text{number of accidents involving all other vehicles} \div \text{VMT attributable to all other vehicles} \qquad (7)$$

where F_t is the ratio of the number of trucks involved in all truck accidents to the number of all vehicles involved in all truck accidents, and F_c is the ratio of the number of passenger cars involved in all nontruck accidents to the number of all vehicles involved in all nontruck accidents.

In Equation 5, the numerator is the number of accidents in which all of the vehicles involved were trucks as opposed to the definition used in Equation 3, where any accident involving at least one truck is to be included. Thus, an accident involving a truck and a passenger car, or a truck and a motorcycle, is to be excluded from the numerator according to the new definition of TOA. The numerator would include single-truck or multiple-truck accidents (i.e., truck-fixed object and truck-truck). The same procedure would be used in deriving the rate for passenger cars given in Equation 6.

The advantage of using this numerator is that, because accidents involving a given type of vehicle are analyzed, the question of opportunity for interaction with other types of vehicles (and associated difficulties with exposure estimation) does not arise. Each of the three categories to be compared would thus represent mutually exclusive data bases with no overlap in the sample space.

It should also be noted that the denominators in Equations 5 and 6 represent the fraction of VMT (of the given type of vehicle) that is attributable to the fraction of the accident being considered in the numerator. The factors F_t and F_c in these two equations are designed for the purpose of transforming the denominator at the same base as the numerator. The factors F_t and F_c were derived as the ratio of vehicles of a given kind involved in a particular type of accident and all vehicles involved in the given accidents. Thus,

$$F_t = \text{number of trucks involved in all truck accidents} \div \text{all vehicles involved in all truck accidents} \qquad (8)$$

$$F_c = \text{number of passenger cars involved in all nontruck accidents} \div \text{all vehicles involved in all nontruck accidents} \qquad (9)$$

Both the numerator and the denominator of the last rate (Equation 7) are the complements of the accidents and exposures, respectively, considered together in Equations 5 and 6. Thus, all accidents and exposure data not considered in the previous two equations are contained in the last equation, which thus essentially represents a catch-all category. This category is specifically developed to preclude the use of overlapping sample space and to overcome the difficulties of estimating exposure associated with opportunities for interaction with other types of vehicles.

Figure 1 shows a flowchart depicting the process discussed above (approach 3), the method used in this study. Note that the process starts with consideration of all accidents and exposure data, sequentially progressing toward the goal of developing accident rates that constitute mutually exclusive data bases. Also note that the proposed approach lends itself to application through the use of data bases commonly available in most states.

CASE STUDY RESULTS

Approach 3 was used with the Michigan data base with two specific objectives in mind:

1. To demonstrate the applicability of the methodology and
2. To determine whether there is any significant difference in the accident experiences of the three vehicle classes (i.e., trucks only, passenger cars only, and all other vehicles) as reflected by the 10-year data base (1970-1979).

Availability of the necessary accident and exposure data and our familiarity with such a data base are the two primary reasons for selecting Michigan data for this study.

Standard statistical techniques were used to test the significance of difference between the mean rates. The null hypothesis tested was that there is no significant difference between the rates. The acceptance of this hypothesis would indicate the ab-

Figure 1. Flowchart of proposed methodology (approach 3).

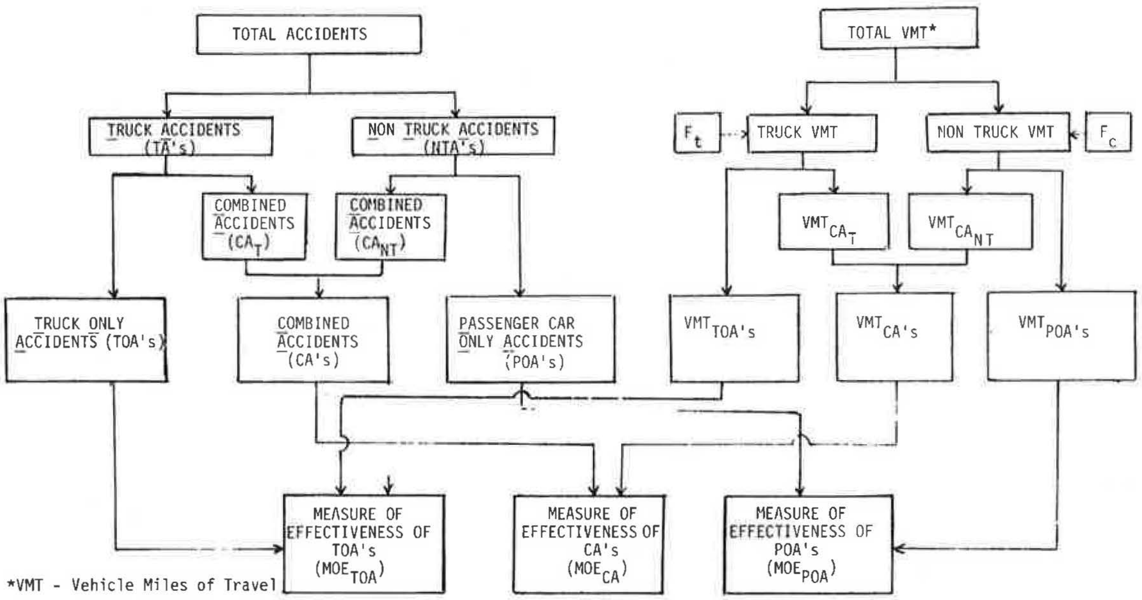

Table 2. Number of accidents involving trucks and all other vehicles and corresponding VMT data: 1970-1979.

	Type of Accident				VMT (000 000s)	
Year	Fatal	PI	PD	Total	Truck	Nontruck
Accidents Involving Trucks						
1970	363	9 620	22 935	32 918	7 301	
1971	354	11 183	29 884	41 421	7 726	
1972	390	15 245	39 792	55 427	8 948	
1973	420	16 146	42 874	59 440	9 119	
1974	345	14 837	43 408	58 590	9 225	
1975	363	15 932	45 108	61 403	9 616	
1976	433	19 125	54 801	74 359	10 644	
1977	492	21 939	62 209	84 640	11 335	
1978	546	24 828	67 268	92 642	12 132	
1979	511	25 174	65 487	91 172	13 301	
Accidents Involving All Other Vehicles						
1970	1500	92 258	187 039	280 797		45 894
1971	1536	89 264	181 794	272 594		47 848
1972	1607	98 428	204 283	304 318		48 896
1973	1529	94 139	195 756	291 424		49 328
1974	1306	80 536	184 331	266 173		46 522
1975	1248	82 305	188 604	272 157		46 644
1976	1297	87 938	202 006	291 241		50 993
1977	1249	87 670	201 192	290 111		53 518
1978	1156	89 440	205 954	296 551		51 475
1979	991	85 320	188 970	275 281		48 308

Note: PI = personal injury and PD = property damage.

Table 3. Summary of accident data for 1977 developed by using proposed methodology (approach 3).

Category	Fatal	PI	PD	Total
Total accidents	1438	111 880	261 286	374 604
Truck accidents (TA - 84 640)				
TOA	254	13 119	36 988	50 361
CA$_T$	169	9 987	24 122	34 278
Nontruck accidents (NTA - 289 965)				
POA	870	81 811	185 961	268 642
CA$_{NT}$	145	6 963	14 215	21 323
Total CA = (CA$_T$ + CA$_{NT}$)	314	16 950	38 337	55 601
Accident rate[a]				
TOA	0.0436	1.95	5.48	7.4736
POA	0.0201	1.65	3.75	5.4201
CA	0.0402	1.98	4.51	6.5302

Note: CA$_T$ = CA associated with trucks (truck accidents - truck-only accidents) and CA$_{NT}$ = CA associated with nontruck vehicles (nontruck accidents - passenger-car-only accidents).

[a] VMTs for TOA, POA, and CA were calculated as 6748, 49 580, and 8525, respectively, by using the procedure described in the text. The F$_t$ and F$_c$ values for the year 1977 were estimated as 0.5953 and 0.9264, respectively. Accident rate for each category was obtained by dividing the number of accidents by the corresponding VMT.

sence of any significant difference, and the rejection would indicate otherwise.

Table 2 gives the basic Michigan accident data in four severity categories--fatal, personal injury (PI), property damage (PD), and total--for the two basic vehicle categories (trucks and nontrucks) along with the VMT information. Table 3 gives the development of the data for the three categories (trucks only, passenger cars only, and combined) for one given year (1977) by using the procedure described above. Similar tables for each of the 10 years were developed as a part of this study but are not given here for the sake of brevity. Table 4 summarizes all of the annual accident rates (expressed in number of accidents per million VMT) by the same four severity groups for each of the three vehicle classes. These rates were then subjected to standardized statistical testing procedures to determine the presence or absence of any significant difference. Two types of tests were conducted and these are briefly described below.

Test 1: Difference Between Mean Accident Rates for the Three Vehicle Categories Considered Together

In test 1, the null hypothesis tested was as follows:

$$(\mu_{TOA})_i = (\mu_{POA})_i = (\mu_{CA})_i \qquad (10)$$

where

$(\mu_{TOA})_i$ = mean accident rate for TOA for severity type i,
$(\mu_{POA})_i$ = mean accident rate for POA for severity type i, and
$(\mu_{CA})_i$ = mean accident rate for CA for severity type i.

Table 4. Accident rates by severity and type of vehicle.

	Accident Rate (accidents/million VMT)											
	TOA				CA				POA			
Year	F	PI	PD	Total	F	PI	PD	Total	F	PI	PD	Total
1970	0.0493	1.33	3.13	4.5093	0.0391	1.89	3.37	5.2991	0.0284	2.08	4.02	6.1284
1971	0.0481	1.46	3.87	5.3781	0.0454	1.91	3.59	5.5454	0.0261	1.84	3.83	5.6961
1972	0.0450	1.70	4.43	6.1750	0.0425	2.09	4.06	6.1925	0.0274	2.02	4.18	6.2274
1973	0.0473	1.79	4.68	6.5173	0.0435	2.13	4.04	6.2136	0.0255	1.89	3.99	5.9055
1974	0.0323	1.62	4.69	6.3423	0.0371	1.89	4.07	5.9971	0.0224	1.70	3.99	5.7124
1975	0.0372	1.66	4.68	6.3772	0.0401	1.88	4.24	6.1601	0.0208	1.74	4.07	5.8308
1976	0.0420	1.81	5.13	6.9820	0.0350	1.90	4.46	6.3950	0.0216	1.72	3.97	5.7116
1977	0.0436	1.95	5.48	7.4736	0.0201	1.65	3.75	5.4201	0.0402	1.98	4.51	6.5302
1978	0.0457	1.96	5.62	7.6257	0.0402	1.95	4.80	6.7902	0.0213	1.74	3.99	5.7513
1979	0.0402	1.81	5.00	6.8502	0.0317	1.89	4.43	6.3517	0.0199	1.77	3.91	5.6999
Total	0.4307	17.09	46.71	64.2307	0.3747	19.18	40.81	60.3648	0.2536	18.48	40.46	59.1936
Mean	0.0431	1.71	4.67	6.4231	0.0375	1.92	4.08	6.0365	0.0254	1.85	4.05	5.9194

Table 5. ANOVA results comparing accident rates for all three vehicle categories.

Type of Accident	Source of Variation	Sum of Squares	df	Mean Square	Calculated F-Ratio[a]	Conclusion
Fatal	Total	0.003 53	29			Reject null hypothesis (significant difference)
	Between	0.001 65	2	0.000 826	11.88	
	Within	0.001 88	27	0.000 069 5		
PI	Total	0.89	29			Reject null hypothesis (significant difference)
	Between	0.27	2	0.14	5.92	
	Within	0.62	27	0.02		
PD	Total	9.41	29			Reject null hypothesis (significant difference)
	Between	2.70	2	1.35	5.44	
	Within	6.70	27	0.25		
Total	Total	11.88	29			Accept null hypothesis (no difference in accident rates)
	Between	1.87	2	0.94	2.52	
	Within	10.01	27	0.37		

[a] Critical F-value for 29 df @ $\alpha = 0.05 = 3.35$: If $F_{cal} \geqslant F_{crit}$, reject null hypothesis; if $F_{cal} < F_{crit}$, accept null hypothesis.

The results of the analysis of variance (ANOVA), based on the data from Table 4, are given in Table 5. Note that at the 5 percent level of significance the F_{calc} value for fatal, PI, and PD accidents exceeded the F_{crit} value of 3.35 at (2,27) df, which indicates that the null hypothesis is to be rejected. Simply stated, there is a significant difference in the accident rates studied. In addition, the data in Table 5 indicate that, when all accidents are studied together (i.e., the "total" category), there is no significant difference between the rates of these three vehicle groups.

Test 2: Difference Between Mean Accident Rates for Vehicle Categories Compared by Pairs

Because test 1 indicated the presence of a significant difference, the purpose of test 2 was to establish more clearly which pairs of the vehicle categories were significantly different in terms of accident experience. Essentially, three sets of null hypotheses were tested:

$$(\mu_{TOA})_i = (\mu_{POA})_i \tag{11}$$

$$(\mu_{TOA})_i = (\mu_{CA})_i \tag{12}$$

$$(\mu_{POA})_i = (\mu_{CA})_i \tag{13}$$

The t-test of means was used for this purpose. At a 5 percent level of significance and 18 df, the t_{crit} value was established at 2.101 from standard statistical tables. If the t_{calc} value exceeded the t_{crit} value, the null hypothesis was to be rejected, which would indicate the existence of a significant difference between the two sets of means. On the other hand, the acceptance of the null hypothesis (when t_{calc} is less than t_{crit}) would suggest the absence of any significant difference.

The data in Table 6, which compares TOA and POA, indicate that in cases of fatal and PD accidents TOA rates are significantly higher, whereas in the other two cases (PI and total) no major difference is observed. The data in Table 7 indicate that TOA rates are significantly lower than CA rates for PI accidents and that in all three remaining categories no major difference is observed between TOA and CA. Table 8 compares POA and CA and the data indicate that CA rates are significantly higher for fatal and PI accidents but that there is no perceptible difference in the other two categories.

CONCLUSIONS

This study was conducted as part of an unsponsored research project at the Department of Civil Engineering, Wayne State University, in 1981-1982. The objective of the study was to develop a procedure for evaluating the relative role of trucks in highway accidents and to demonstrate the feasibility of the approach by applying it to an actual case study.

Three separate approaches have been presented in this paper, and special emphasis has been given to how to incorporate exposure factors in truck accident analysis. Approach 3, which calls for categorization of accident data in three vehicle groups (TOA, POA, and CA), was selected as the most logical approach, the one that appropriately assigns exposure factors to each vehicle group. The case study, conducted by using the Michigan accident data base for the 10-year period 1970-1979, led to the following conclusions:

1. When all three vehicle categories are considered together, a significant difference in the fatal, PI, and PD accident rates is observed.
2. In the case of fatal and PD accidents, TOA rates are significantly higher than POA rates. This finding appears intuitively logical because all TOAs include primarily rollovers, jackknife situations, and similar severe single-truck accidents, and truck-truck accidents are likely to be rare.
3. In case of PI accidents, the rate for TOA is significantly lower than that for CA.
4. The CA vehicle category has a significantly higher accident rate than POA for fatal and PI accidents. The reader should note that a majority of the CAs are likely to be car-truck accidents and that motorcycles, buses, and other nontruck vehicles would contribute an insignificant fraction of the CAs.
5. Overall, trucks involved in accidents appear to have a significantly higher fatality rate, as exhibited in the comparison of TOA versus POA and POA versus CA. (Note that the CA vehicle category comprises a significant number of trucks.)

Table 6. Student's t-test results of comparison of accident rates between TOA and POA vehicle categories.

Accident Type	Mean Rate		t_{cal}[a]	Conclusion
	TOA	POA		
Fatal	0.0428	0.0231	9.34	Reject null hypothesis (TOAs higher)
PI	1.71	1.82	-1.36	Accept null hypothesis (no difference)
PD	4.67	3.97	2.94	Reject null hypothesis (TOAs higher)
Total	6.4275	5.8121	2.01	Accept null hypothesis (no difference)

[a] t_{crit} for 18 df @ $\alpha = 0.05 = 2.101$: If $t_{cal} \geqslant t_{crit}$, reject null hypothesis; if $t_{cal} \leqslant t_{crit}$, accept null hypothesis.

Table 7. Student's t-test results of comparison of accident rates between TOA and CA vehicle categories.

Accident Type	Mean Rate		t_{cal}[a]	Conclusion
	TOA	CA		
Fatal	0.0425	0.0390	1.59	Accept null hypothesis (no difference)
PI	1.71	1.94	-3.32	Reject null hypothesis (TOAs lower)
PD	4.67	4.14	2.00	Accept null hypothesis (no difference)
Total	6.4275	6.1170	0.95	Accept null hypothesis (no difference)

[a] See Table 6.

Table 8. Student's t-test results of comparison of accident rates between POA and CA vehicle categories.

Accident Type	Mean Rate		t_{cal}[a]	Conclusion
	POA	CA		
Fatal	0.0231	0.0390	-9.04	Reject null hypothesis (POAs lower)
PI	1.82	1.94	-2.40	Reject null hypothesis (POAs lower)
PD	3.97	4.14	-1.18	Accept null hypothesis (no difference)
Total	5.8121	6.1170	-2.00	Accept null hypothesis (no difference)

[a] See Table 6.

6. The proposed approach uses the concept of opportunity for interaction in determining exposure measures and results in the use of mutually exclusive data bases in truck accident analysis. Furthermore, the procedure lends itself to application through the use of commonly available data bases, as demonstrated by the Michigan case study.
7. Although the proposed methodology is feasible and can be applied to any data base, conclusions 1-5 are valid only for Michigan data.

REFERENCES

1. Michigan Traffic Accident Facts. Michigan Department of State Police, Lansing, annual.
2. Highway Statistics. Office of Highway Planning, FHWA, annual.
3. D.L. Greene and A.S. Loeble. Vehicle Miles of Travel Statistics, Lifetime Vehicle Miles of Travel and Current Methods of Estimating Vehicle Miles of Travel. Oak Ridge National Laboratory, Oak Ridge, TN, ORNL/TM-6327, Feb. 1979.
4. L.K. Li and P.F. Waller. Heavy Trucks and Fatal Crashes: An Unresolved Dilemma. Society of Automotive Engineers, Warrandale, PA, Tech. Paper 810518, 1981.
5. A Report to the Congress on Large Truck Accident Causation. NHTSA, July 1982.
6. S. Khasnabis and A. Atabak. Comparison of Accident Data for Trucks and for All Other Motorized Vehicles in Michigan. TRB, Transportation Research Record 753, 1980, pp. 9-14.
7. S. Khasnabis and A. Atabak. Comparative Analysis of Accident Data in the State of Michigan. College of Engineering, Wayne State Univ., Detroit, MI, Final Rept., 1979.
8. F.L. Krall and G.W. Rossow. Heavy Truck Safety: The Need to Know. Traffic Quarterly, Vol. 25, No. 3, July 1981, pp. 337-358.
9. Fatal and Injury Accident Rates on Federal-Aid and Other Highway Systems. FHWA, annual.
10. Truck-Accident Data Systems: State of the Art Report. TRB, Transportation Research Circular 231, Sept. 1981.

Discussion

Benjamin V. Chatfield

The authors have selected a timely subject on which enlightenment is badly needed. Measures of exposure are complex and not well understood by most of us who are involved in the analysis of accident data. Sources of reliable information on exposure are hard to find. If the state of the art is to improve, papers of this sort must be given more attention. They should not languish on the shelf because potential users of the proposals they contain are uncertain about their merits. If the proposals are good, they should be used; if not, their deficiencies should be clearly identified to expedite development of better proposals.

Measures of exposure are commonly used as the denominator in computing accident rates. These rates are used most often as indexes or as probabilities. (It has been noted by others that all probabilities are rates but not all rates are probabilities.) As indexes, rates may be relatively insensitive to approximations and other assumptions made in quantifying the numerator and denominator as long as the methods used are consistent. On the other hand, when rates are interpreted as probabilities for the purpose of analysis, the results may be very sensitive to minor differences in the way approximations and assumptions are made. In such cases, it is necessary to consider what the limitations of validity may be.

In their paper, Khasnabis and Reddy clearly intend that the rates they define be interpreted as probabilities. The comments that follow are meant to refer only to rates in the probability context.

After pointing out problems with current practice, the authors set up three clearly defined approaches to the resolution of these problems. Although they deal with trucks and passenger cars, the methods they propose could apply as well to any two categories of road vehicle (large car-small car, truck-motorcycle, etc.). Currently decreasing passenger-car sizes and increasing truck sizes make the relative roles of different vehicle categories a matter of major concern.

In dealing with rates as probabilities, exposure may be thought of, for example, as the number of attempts to travel a vehicle mile without becoming involved in an accident (E). Some of these attempts will fail (F) and some will succeed (S). From the basic axioms of probability theory, $E = F + S$ or, stated another way, $(F/E) + (S/E) = 1$. If the accident involvement rate (F/E) is to be regarded as a probability, the sum of successful attempts and failures must be equal to the total number of attempts.

Two aspects of the approaches described by the authors warrant particular consideration. The first deals with the treatment of failures in the numerator of rates. The second relates to the measure of exposure in the denominator.

First, an attempt has failed in the example above when there is an involvement in an accident. Using accidents in place of involvements in the numerator in computing a rate violates the axioms of probability theory if there are multivehicle accidents. In such a case, the rate understates the probability that an attempt will fail. This understatement is inconsistent with the requirement that the sum of the probabilities of success and failure be equal to one. It would be useful to determine under what circumstances, if any, this inconsistency alone may invalidate conclusions based on the authors' approaches 1 and 3.

Second, the measures of exposure in approaches 1 and 3 may not be valid. In approach 3, vehicle miles of exposure are divided into three distinct parts that are used in computing rates. The denominator used in computing each rate includes vehicle miles of travel by passenger cars or trucks or both. If these denominators are regarded as the number of attempts to travel a vehicle mile without an accident involvement, it is difficult to understand why none of the failures in the first two groups involves both trucks and passenger cars and why all failures in the third group occur in multivehicle accidents in which two or more types of vehicles are involved. Why is a unit of truck exposure in the third group less likely to result in a single-vehicle accident than a similar unit of exposure in another group? There may be interpretations of these exposure measures for which the rates are valid as defined, but these interpretations are not readily evident and should be explained.

In their paper, Khasnabis and Reddy appear to have made an implicit assumption that passenger cars and trucks are both traveling in the same environment. Under these circumstances, approach 2 may be promising. Instead of dividing accidents into categories such as truck only, passenger car only, etc., it might be productive to ask questions such as the following:

1. Is an attempt to drive a truck a given distance more likely to result in a single-vehicle accident than an attempt to drive a passenger car the same distance?
2. Is an attempt to drive a truck a given distance more likely to result in a collision in which the second vehicle is a passenger car than an attempt to drive a passenger car the same distance?

One of the biggest problems in comparing the relative safety of various types of vehicles is the lack of adequate exposure data. Part of the reason for this lack of data is the current confusion about what data are needed and how they are to be used. Development of easily applied criteria for distinguishing between valid and invalid exposure measures would be a major advance in the state of the art of accident analysis. New approaches such as those suggested by the authors should be analyzed more rigorously to resolve technical matters and to ensure that when good approaches are developed they are recognized.

Authors' Closure

We greatly appreciate Chatfield's thoughtful and constructive comments on our paper. We fully agree with him that measures of exposure are not well understood and that reliable exposure data are difficult to find. The basic purpose of the paper was to address the above two issues. Specifically, the objectives of the paper were twofold:

1. To demonstrate the complexity involved in measuring exposure in situations in which a comparison of the accident involvement rates of different types of vehicles is desired and
2. To identify and evaluate different procedures that can be used in such comparisons.

In more specific terms, the procedures presented were directed toward comparing historical accident experiences of trucks and passenger cars. However, as Chatfield points out in his discussion, the methods proposed could also be applicable to any two vehicle categories (e.g., large cars versus small cars and trucks versus motorcycles).

Chatfield raises the question that in cases of multivehicle accidents the rate that uses accidents in the numerator may understate the probability that an attempt to travel a vehicle mile without an accident will fail. In such cases, the sum of the probabilities of successes and failures indeed may not be equal to unity. We agree with the comment and would suggest that the definitions of success and failure may have to be modified so that the basic axioms of probability are satisfied. As the discussant points out, there is a need for more research in this area before the question can be satisfactorily resolved.

Our choice of approach 3 was based on the need to create mutually exclusive data bases so that the overlapping of sample spaces could be avoided during the comparison of accident data. To this end, approach 3 has more merit than approach 1. (It may be recalled that approach 3 is an outgrowth of approach 1.) Specifically, an accident between a truck and a passenger car would be accounted for in both accident categories--namely, truck rate and passenger-car rate--in approach 1. On the other hand, these combined accidents are accounted for in the third category in approach 3.

Regarding Chatfield's comment on why "all failures in the third group occur in multivehicle accidents," the third vehicle category itself is the multivehicle category that includes accidents involving trucks and passenger cars and is therefore the logical category in which these combined accidents could be considered. As Equations 5 and 6 in the main body of the text show, accidents involving trucks only and passenger cars only are captured in the first two rates. Furthermore, in each of the three rates in approach 3, the VMTs used in the denominators represent our best estimate of the exposure attributable to the accidents included in the corresponding numerator. Further insights into and better understanding of the exposure phenomenon through future research could lead to better estimates in this regard.

Chatfield suggests that approach 2 may be more promising when one considers the assumption that passenger cars and trucks are both traveling in the same environment. We fully agree with the comment and believe that further research is indeed necessary before a complete evaluation of approach 2 can be made. Our decision to discard approach 2 was made primarily on intuitive grounds. Specifically, it was believed that the use of vehicles (involvement rate) in the numerator would tend to overexaggerate the adverse role of passenger cars in highway accidents simply because of the vast majority of passenger cars in the distribution of the entire vehicle population. One could also argue that, because passenger vehicles represent the vast majority, the corresponding accident rate should be inflated accordingly. Again, approach 2 requires further investigation before one can justify the rationale of computing the rates for the purpose of comparison.

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The Promise of New Technology: Implications for Traffic Record Systems

WILLIAM W. STENZEL

Despite the technological revolution that is occurring with the availability of easy-to-use, low-cost, small computers, the development of automated traffic record systems for small police agencies will be a difficult task. The history of data-processing use by law-enforcement agencies over the past 15 years is reviewed, and it is concluded that the record is less than remarkable. Police data-processing projects usually take longer than predicted, cost more than estimated, and produce less than expected. Unrealistic expectations, infatuation with equipment, and the absence of quality software are identified as key factors contributing to these failures. A dramatically changing data-processing marketplace will produce future problems for small agencies that plan to automate traffic record systems. In an analogy between books and their contents and computers and software, it is noted that, just as the major production cost of every book today is the cost of authorship, the major cost of automation has become the development of quality computer programs and not the machines they are designed to run on. Faced with a marketplace that will be cluttered with dozens of data-processing vendors who may not offer adequate service after a sale, the acquisition of appropriate software and support will continue to be difficult for small agencies getting into data processing for the first time.

The electronic revolution is upon us. From digital watches to video recorders, cordless telephones, programmed microwave ovens, and diagnostic readouts in the dashboards of cars, a new and sometimes overwhelming, sometimes frightening technology is with us at every turn. Like it or not, it is a technology on which we are quickly becoming dependent. For example, without microprocessors, the U.S. telephone system as we know it today could not operate.

Perhaps the most exciting and remarkable innovation of this age is the development of general-purpose programmable microprocessors or microcomputers. I am using the word computer in the way that many people have always thought of computers--that is, large, oversized pieces of equipment. In reality, the basic characteristics of room-sized mainframes can not be constructed into briefcase-sized personal computers. Those characteristics include a central processing unit (CPU), data input-output devices, and some form of off-line data-storage capability. The Timex Sinclair Z100, which sells for about $100, is generally identical to the CDC Cyber 205. Both have the ability to follow a sequence of instructions supplied by the user as long as the instructions are formulated according to a precise set of rules. The only limitation to what can be accomplished by these instructions (code) is the imagination and programming skills of the user. (My purpose at this point is to stress the functional similarities of large and small computers. Functional similarity, of course, is not synonymous with performance similarity. The Cyber 205 is capable of billions of arithmetic operations per second; the capability of the Sinclair is much less.)

Despite their current performance limitations, small computers are rapidly becoming as common as hand-held calculators because of their low cost and small size. For the first time, a computer is a practical reality for almost everyone. If the past few years have taught us anything, it is that nothing is more uncertain than long-range forecasts of new technology. Despite the difficulty of tracking future trends, a few cautious predictions can be made. New technology over the next few years will succeed in cramming more and more circuitry into smaller and smaller volumes for remarkably little increase in cost. One tangible fallout of this trend will be the increased capability and use of hand-held computers that are no larger than the calculators people now carry in their vest pockets or purses. In fact, it is becoming increasingly evident that the only true limits to further size reductions may be human characteristics (e.g., finger size).

Equally important will be the accessibility of virtually unlimited off-line storage capacities at extremely low cost. In fact, it is possible that the use of storage capacity as an indicator of the capability of a computer system may soon lose its meaning completely. Once megabyte levels of storage become available, how significant will another 10 or 20 million bytes be? These advances will represent a continuation of the technology breakthroughs that started in the mid-1960s, became visible to most people by the mid-1970s, and are continuing today. The question is not when this technology will occur; it is happening now. The questions are: How will this new technology affect our lives and our society? What social impacts will the widespread use of computers have on our society? How will it alter the way in which we perceive the world around us? Will it alter how we communicate with one another and how we design solutions to social and economic problems?

The word used most often in discussing the new technology of microprocessors is promise--the promise of less work, more productivity, more information, more leisure time, and so on. The promise of small computers has also been advanced for traffic safety. One scenario sounds something like this: Low-cost computers will be used to support comprehensive traffic record systems to provide administrators, planners, engineers, and enforcement personnel with information to administer programs, design roadways, and enforce traffic laws in the most effective ways possible. Information about roadway characteristics, accident types, and enforcement activities will be instantly retrievable in whatever form is desired. Just push the right buttons and all knowledge is possible. Clerks, file cabinets, and report delays will be things of the past.

But is all what it appears to be on the surface?

PURPOSE AND ASSUMPTIONS

The focus of this paper is on the emerging use of small computers for automated traffic record systems. The purpose is to highlight and examine some of the issues that may significantly affect the manner in which traffic record systems are implemented and used on small computers. A small computer is arbitrarily defined here as any system that sells for less than $20 000. It is assumed that agencies (or subunits within agencies) that use small computers have limited in-house data processing (DP) experience to draw on or limited access to such experience within the agency. This assumption is based on my experience with many small law-enforcement agencies. In addition, the following assumptions are made:

1. Most small agencies are unprepared for the technological changes that will occur throughout the remainder of this decade.
2. New technologies are being promoted and sold (and bought) as solutions rather than as components or tools to be used in finding solutions.
3. Appropriate attributes and characteristics for traffic record systems for small agencies are still largely undefined. The concept, much less the use, of decision support systems for traffic records within law-enforcement agencies is virtually an unexplored area.
4. The availability of federal support for the development of systems and purchase of equipment will be limited throughout this decade.

HISTORY OF POLICE USE OF DATA PROCESSING

It will be useful to draw on several lessons from the history of computer implementation and use by law-enforcement agencies in the 1970s. The applicability of these lessons to traffic records stems from several similarities between what has happened in the recent past and what will occur over the next few years.

Except for a few departments, the vast majority of police agencies in this country are quite small. (The average department in the United States has only 10 or 11 officers.) The promise of computerization in the late 1960s and early 1970s had the same Camelot-like quality that is perceptible today. Fifteen years ago, few departments had seriously examined their information needs in terms of overall department objectives. Most often, manual record systems reflected years of patchwork evolution with little direction or documented rationale. The emergence and growth of the Law Enforcement Assistance Administration (LEAA) was marked by a parallel growth in the availability of federal dollars for equipment, including computers. Although some departments implemented automated systems with few problems, honest appraisals of the experiences of most agencies have led many observers to the following conclusions about the implementation and use of automated record systems within police agencies: (a) it takes longer than expected; (b) it costs more than estimated; and (c) it produces less than promised.

In a recent article in Police Magazine (1), I noted the following:

> Some [police] departments have spent millions of dollars buying and installing elaborate data processing machinery, but have spent years trying to get their systems...in operating order. Others bought the systems with federal funds, and never even attempted to make efficient use of them.

A number of reasons have been identified for the slow pace of automation within the police community. The following are the most frequently cited:

1. Unrealistic expectations--Perhaps more than any other reason, a basic lack of knowledge among senior-level officers about what computers can and cannot do has contributed to the underlying problems.
2. Infatuation with equipment--Also contributing to the failures of the past was the ability of computer vendors to capitalize on the fascination and trust exhibited by many law-enforcement officials regarding new types of equipment and hardware. Some of the most damaging stories cited by critics of the LEAA are related to instances of equipment "overkill" made possible by abundant federal dollars (e.g., the purchase of an antiriot vehicle by a small department in central Iowa). These actions reveal a belief (or hope) in the simple answer neatly packaged in the "right" piece of equipment--that is, a belief that "if I only had the right tool, I could do the job." It does not take a gigantic leap of imagination to see the consequences of such attitudes for data processing.
3. Inadequacy of police-specific software--Although there are thousands of police agencies in the United States, the total market represented by law enforcement is relatively small. There are, for example, more than 5 times as many hospitals and more than 50 times as many hotels in this country as there are police agencies. As a result, the law-enforcement community has never attracted, and likely never will attract, significant commercial interest. In addition, support for the few software packages that were developed was often marginal at best. To fill this gap, many larger departments and regional information systems developed their own software, financed largely with federal dollars. In general, however, acquisition and use of software by

the law-enforcement community have been haphazard at best.

ANALOGY OF INFORMATION TRANSFER

Many of the foregoing problems with the implementation and use of small computers can be more easily seen by using an analogy that relates computer hardware and software to books and their contents. A book can be thought of as consisting of two parts. One part consists of the materials that make up its physical components--that is, paper, ink, covers, glue, etc. Collectively, these parts can be called the hardware of a book. The second part of a book is obvious but more difficult to define: it consists of symbols and diagrams and the sequence of their presentation, which completes the transfer of information from author to reader. These symbols and their sequence represent the software of a book. Different written languages and dialects are paralleled in the world of computers by different programming languages and dialects within generic programming languages.

With this analogy in mind, it is useful to trace briefly the history of the production and use of books in order to understand better the management and social issues that may accompany the democratization of computer use in the 1980s. The pivotal event was the invention of movable type by Johann Guttenberg in the 15th century. Before that time, the production of each book--the hardware--was an enormously expensive operation. Each volume was created by copying one page at a time by hand. As a result, few books existed and each was highly valued. Because there was little access to books, literacy was not considered an important survival skill and only a small portion of the population could read or write. In Western civilization, most books contained religious themes and the clergy assumed the role of interpreting the meaning of the written word for the general population.

Following Guttenberg's invention, the nature of book production and authorship changed dramatically. Because multiple copies of identical pages could now be produced in a fraction of the time that it used to take, the cost of producing individual books dropped sharply. Books became more widely available and literacy more common. However, literacy was still restricted primarily to wealthy. Barriers to universal literacy were the absence of public education and resistance of religious and government leaders, who feared that placement of books directly in the hands of the people would lead to misinterpretation of important works.

The next phase began in the mid-19th century and continues today. The dominant features are universal literacy and the mass availability of low-cost books. Key stimulants in this phase have been the availability of publicly supported education and continued reduction in production costs with the use of soft-cover books.

The latter phenomenon deserves special comment. Although soft-cover books, mostly in the form of pamphlets, first appeared shortly after the invention of movable type, their distribution was limited. Pamphlets were used primarily for the distribution of information on current political and religious issues. In the last half of the 19th century, as more people learned to read, enterprising publishers quickly filled the public's appetite for entertainment by producing penny novels and adventure stories. The low-brow quality of these pulp booklets and magazines became associated with soft-cover books in general. It has only been in the past 20 years that the distinctions between soft cover and hard cover have disappeared. Today, almost every book is available in either form.

One final dramatic change over the past 500 years of book production should be noted. Before the invention of movable type, almost all publishing costs were for the production of the hardware of books. Today, the overwhelming cost item of every book is the cost of authorship, the software.

With this brief history as background, we can now examine the development of computer systems over the past 40 years. The early years, up to the 1960s, were characterized by the development of large, expensive computers. Few were built and each required special installation and maintenance. Few people knew how to operate them or how to write programs for them. Rapidly, a new class of technicians emerged with a variety of titles--e.g., programmers, systems analysts, and information specialists. They became the human link, the interpreters, between the computers and the end users.

Beginning in the early 1960s, the development of transistors and other new technologies produced dramatic changes. Computers became smaller, less costly, and more powerful. More and more applications and users emerged as small agencies found that they could, for the first time, afford data processing. Although computer literacy slowly increased among users, data-processing professionals continued to serve as the key link between the hardware and the user.

The third phase of development began in the mid-1970s and continues today. This period is characterized by the development of microprocessors, chip technology, and low-cost portable computers; a rapid growth in computer literacy among users; and the proliferation of new programming languages designed for user-programmers. The most significant change, however, has been the dramatic change in the relative costs of hardware and software. In the future, software costs will represent the major component of every automated record system.

Whereas the history of book production and use and that of data-processing development exhibit many similarities and in turn suggest many generalizations, the following observations are most important:

1. The data-processing industry has undergone tremendous changes. In a development that parallels the dramatic changes that occurred as universal literacy and low-cost soft-cover books became realities, the DP industry will soon find itself serving marketing dictates driven by the proliferation of millions of low-cost personal and small business machines.
2. The management of data-processing resources will change. Because more end users will have direct access to computing power through microcomputers and intelligent terminals, the interpreter role of the data-processing center will diminish and the need for information centers to facilitate user programming and processing will grow.
3. Market imperatives will relegate discussions about quality languages and efficient operating systems to the background. The driving forces will not be controllable by DP professionals, who criticize the widespread use of primitive languages.
4. Despite claims to the contrary, more quality programs and applications will emerge. Although personal computers purchased from discount electronic and department stores will be described as mere toys, the availability of useful home and desktop planning tools will legitimize the use of machines that cost less than $1000.

IMPACT OF SMALL COMPUTERS ON DEVELOPMENT OF TRAFFIC RECORD SYSTEMS

The issues raised above suggest several factors that will influence how automated traffic record systems will be used on small computers:

1. The complete service orientation of the relatively small number of hardware vendors of the past decade will change significantly. Consumers will find that, as more computer services and equipment are offered through retail stores and mail-order houses, the warning, "buyer beware," will be more relevant than ever.
2. Most user agencies that attempt to automate their record systems in the future will be small and will have little data-processing experience or on-staff expertise.
3. The rapid development of new technology will precipitate organizational pressures within many agencies that will be aggravated by differences in education and experience such as those characterized in the table below:

Position	Age (years)	Decade in Which Education Was Completed
Senior management	50-60	1950s
Middle management	40-50	1960s
Senior staff	30-40	1970s
Junior staff	20-30	1980s

Whatever the pace of technology change, the management structure of most organizations still evolves on roughly a 40-year cycle. As technological advances occur at a rate that is significantly more rapid than this, organizational pressures are produced as entry-level personnel view upper management as outdated. It is important to note that pressures induced by rapid technological change are in addition to the normal push-pull relationship that always exists between senior management and junior staff members.

To catch a glimpse of the unexpected turns in the road ahead, we must examine the implications of small agencies, organizational generation gaps, a consumer-driven marketplace, and a rapidly changing technology. What do these hazards portend for agencies that will attempt to implement traffic records on a small computer? It will probably mean a number of problems exacerbated by unrealistic expectations about the implementation process and the final benefits of the system, a significant reduction in vendor support, and a haphazard process of software development.

Unrealistic Expectations

The problem of unrealistic expectations was identified earlier as having been a major factor in the lackluster history of computer development in the law-enforcement community. It is not unreasonable to believe that the staffs of many small agencies will encounter problems in the future because of unrealistic expectations about the implementation and uses of an automated traffic record system. A number of indicators support this view.

Staff Experience

Ideally, in an agency that is implementing a record system, the process will be coordinated by individuals who are familiar with the operations and needs of the agency and who have specific training and experience in the design, implementation, and operation of an automated system. However, as the number of agencies considering automation increases, the likelihood that such specialists will be found on staff decreases. As a result, it will be necessary to assign these responsibilities to regular staff persons who, while knowledgeable about traffic records, often have limited knowledge about data processing. This scenario will become increasingly common as more and more small police agencies attempt to implement automated systems.

In an article cited earlier (1), I examined the state of the art of data processing in policing and concluded that, in most cases, police do not fully utilize the computers they have because they do not understand what computers can do. The article quotes the chief of a large eastern police department as follows: "A lot of law enforcement agencies have little or no idea what computers can do for them and don't even know what questions to ask." When this lack of understanding is coupled with an abiding faith in equipment (such as computer hardware) to solve problems, the opportunities for unrealized expectations become obvious.

Vendor Oversell

As the computer market becomes more diverse and directed toward mass commercial operations, the number of retail distributors will increase dramatically. This, in turn, will result in greater competition between vendors. Although such competition will keep prices down, it will also require novice buyers to deal with vendors who increasingly may be willing to promise whatever is necessary to sell the product. Oversell tactics will also be encouraged by the increasing number of novice users and the decrease in vendor follow-up support (discussed further below).

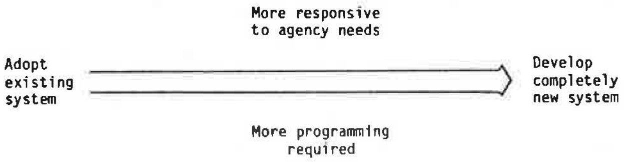
Need for Automation

In many smaller agencies, manual record systems have evolved haphazardly without any overall plan or direction. Automation is often mistakenly viewed as a way to fix record system problems. In many agencies, however, the most pressing need is not to implement an automated system but rather to make a realistic assessment of what problems exist in the current system, what the system is used for, and what alternative solutions (including automation) exist. Preliminary investigations by the Northwestern University Traffic Institute suggest that well-designed manual systems can handle the traffic record needs for approximately 80 percent of all police agencies in the United States. For another 15 percent of departments, the decision whether to automate depends on a number of factors, including the number and kinds of reports wanted, the availability of existing hardware, and anticipated growth patterns for the jurisdiction. The recommended methods of accident data collection for police agencies, based on the volume of accident data reporting, are cited below:

No. of Accidents and Citations Reported per Year	Estimated Percentage of Agencies	Recommended Techniques	
		Manual	Automated
0-3999	80	X	
4000-9999	15	X	X
≥10 000	5		X

What is important to note is that for these agencies the benefits derived from automation are not likely to include significant cost savings. As a result, even the most successful implementations will have to be evaluated on the basis of measures that are traditionally difficult to capture quantitatively ir service-oriented agencies, such as productivity, efficiency, access to more data, and increased accuracy. This suggests that, for these

Figure 1. Alternatives of software development expressed as a continuum of possibilities.



agencies, automating record systems is a venture in which tangible measures of success will be difficult to document.

Less Vendor Support

The changing market for computer sales will cause fundamental changes in the traditional form of support that end users have learned to expect from hardware vendors. The days of IBM-type cradle-to-grave care are over for all but a few large customers. The decreasing margin on unit sales will drive most hardware vendors to emphasize high-volume sales tactics with minimum support. Although warranties will still provide hardware maintenance, traditional vendor support for planning implementation, software development, and operator training will be increasingly less common or will only be available at additional cost.

Although the number of full-service vendors will decrease, consumers will have no problem finding vendors. The proliferation of new businesses in the data-processing industry will be one of the major business stories of the 1980s. This growth will be a mixed blessing for buyers. Although increased competition holds down costs, prospective users will be faced with a virtual army of sellers from which to select. Unlike more established industries, the data-processing field has established a disturbing pattern of volatility in which companies fail and new ventures arise on a monthly basis. It has been estimated (2) that two out of every three vendors in business in 1981, representing all facets of the DP industry, will be out of business by 1985.

Perhaps the most telling commentary on the changing nature of the customer-vendor relationship is the fact that the fastest-growing facet of the industry is client-vendor litigation. Discussing this phenomenon in a June 1981 article in ComputerWorld, Johnson (2) offered several reasons for increased litigation:

1. Disagreements based on the expectations of the customers--an increasing problem because vendors are offering less support and customers are less knowledgeable;
2. Machine reliability--a growing problem because of the proliferation of small machines used in uncontrolled environments;
3. System performance--user expectations based on vendor oversell;
4. The nature of the computer industry--numerous small, under-capitalized companies; and
5. The fact that the industry is not renowned for its sales ethics (questionable ethics are not restricted to vendors; widespread software piracy by microcomputer users is an insidious industry problem).

Complexities of Software Development

The decade of the 1980s will require extensive retraining for most persons who have grown up envisioning a piece of equipment whenever computers are discussed. In the years ahead, the importance of hardware will diminish for most users. Although paper computers have not been predicted yet, throwaway computers have. It has been forecast that the low cost of computer hardware will produce a more calculator-oriented approach to system acquisition; that is, the primary question will be whether the machine can support the software applications package that has been selected. If it cannot, a different machine will be considered.

The reason for this change is quite simple: the cost of computer hardware will become increasingly insignificant compared with the cost of software development. For this reason, it will become increasingly important for users to understand the complexities and difficulties of software acquisition. Returning to the book analogy presented earlier, it will require that users learn to look between the covers of the book before they buy; the outside cover (i.e., the hardware) will become increasingly less important.

Who will develop small-computer software in the future? Although programming and systems analysis skills will still be needed, the DP professional may not be. The skills of the programmer and systems analyst will be used by increasing numbers of non-DP professionals. These skills will include the activities described briefly below.

Learning to Describe Agency Software Needs

It is not enough to say that the agency needs a traffic record system. To describe adequately the kinds of software required, it is necessary to articulate the goals and objectives of the system--that is: What is it supposed to do and why? The process of answering these questions will stimulate the examination of several other issues:

1. What are the problems with the current system?
2. What alternatives are available to correct these problems?
3. What are the likely costs of and payoffs from implementing each alternative?
4. Why is automation the preferred alternative?

Learning to Shop for Software

There are several approaches that can be used to acquire software. Each represents certain risks and disadvantages. As expected, minimizing the risks requires that an agency be willing to compromise on the final product it obtains. The alternatives of software development can be conceptualized as a continuum of possibilities characterized by the use of an existing system with no changes at one end and the development of a completely new system at the other end, as shown in Figure 1. As the diagram indicates, more programming effort is required in moving from left to right on the continuum. It is also true that programming is expensive and time-consuming and that it involves greater risk because the end product may not be what was expected. The advantages associated with various alternatives are discussed below.

Adopt an Existing System

The first alternative, adopting an existing system, assumes that virtually no programming changes are made. It has the significant advantages of low cost and--if the system can be observed in operation in another agency--minimum risk. The major drawback is the fact that there is no capability to tailor the system to the particular needs of the department. In fact, if the new system requires significantly different kinds of information, the implementation process may require considerable redefinition of data collection forms and procedures.

Modify an Existing System

Like the first alternative presented above, the second approach, modifying an existing system, assumes that a system is modified to satisfy department needs. Tailoring, of course, requires programming additions, deletions, and changes. The extent of these changes determines the cost and risk incurred. A key decision is who will do the programming. Options include using in-house personnel or contracting with a software consultant.

Again, both options present unique problems. In-house personnel may be knowledgeable about the agency but may not be as technically competent as a consultant. In turn, consultants may have considerable data-processing experience but may lack specific knowledge about traffic records. Another potential disadvantage with consultants may be total cost if the project takes longer than expected, a common (almost certain) occurrence in software development.

Tailor a Generic Records System

At the price of losing some flexibility, it is possible to adapt a generic data base management system to the terminology and format required for a traffic record system. This tailoring may not involve as much risk as modifying an existing system because generic record systems are usually designed to be user-tailored when first implemented. A more risky approach is modification of a data base management system originally designed for a different application. Often these systems are promoted by management consulting firms that tend to minimize the actual programming required for the modifications. Effective use of a consulting firm requires that the user agency and the consultant specify in written form what the final system must be able to do, the schedule for completion of the project, and the total cost.

Develop a New System

The most ambitious approach is the development of a new system. This alternative offers the greatest opportunity to obtain a product that is consistent with the needs of the agency. Although this may be an important issue, its value must be weighed against the risks and costs involved. The key issues to be considered are how closely the automated system should emulate the current manual system and who should design and program the new system. On the surface, using an existing manual system as the model for an automated system seems simple. But it must not be assumed that an inadequate manual system will be miraculously corrected when it is automated. The usual result of such an approach is an ill-designed system that makes the same mistakes as the manual system but at a much faster rate. To be successful, this approach requires that an agency objectively assess the strengths and weaknesses of its manual system and aim to retain the strengths and redesign the weak points. The creation of a completely new system represents risks that few agencies should take. The uncertainties involved in the design, cost, and schedule of any software project make this an extremely risky approach. An agency should not consider in-house development unless it has highly capable, experienced personnel who can be committed to the project.

CONCLUSIONS

It is clear that within the next decade most agencies concerned with the use of accident and law-enforcement records will, regardless of their size, have access to computers for the storage and analysis of data. What is also likely is that the process of acquiring and using these automated systems will not be as easy as advertised. The lack of data-processing experience among the personnel of small agencies, coupled with dramatic changes in the marketplace, will make the automation of record systems a risky and difficult process for many agencies. However, if agency administrators are alert to the pitfalls cited in this paper, the task of automation can be accomplished with realistic expectations and maximum payoff to the agency.

REFERENCES

1. Police and Computers: The Revolution That Never Happened. Police Magazine, Sept. 1982, pp. 8-18.
2. Explosion in Industry Lawsuits Seen by '85. ComputerWorld, June 1, 1981.

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Application of Small Computers to Traffic Records Systems in Small Communities

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The application of small computers to traffic records systems in small communities is investigated. The study is based on an assumption that small computers (micros) are useful for the management and analysis of traffic records in communities of 5000-100 000 population. Factors bearing on the apparent hesitancy of small communities to use small computers for traffic records are examined. It is concluded that the volume of traffic records generated by small communities is within the capacity of present small computer systems and that the systems are adequate in terms of secondary storage, primary memory, speed, and input-output devices. Costs are modest. It is suggested that available generic software has not been exploited for traffic records management and that, with some exceptions, there is a lack of specialized applications software for traffic analysts. Remaining barriers to the use of small computers include data-quality concerns, organizational issues, justification of purchase, acceptance of the equipment by agency personnel, and management problems. Adoption of small computers for traffic records systems will depend on how these issues are resolved.

In the past five years, economically priced small computers have become widely available. There were an estimated 1.3 million small computers in homes in the United States in 1981, an estimated 800 000 of which were bought that year. In addition, it is estimated that there are now 200 000 microcomputers on desktops in large corporations (1).

In 1982, the National Safety Council Traffic Records Committee for Data Analysis conducted a survey that provided responses from 63 users in 29 states (2). When respondents were asked what system or devices were used for various types of analyses, the microcomputer was mentioned 29 times out of a total of 332 responses (8.7 percent). The respondents who mentioned using small computers were almost exclusively from law-enforcement agencies in California and Illinois. The sampling and the questionnaire design do not allow adequate control to make valid conclusions. But the results provide some indication of the limited extent of current use of small computers in traffic records. Although better data are not available on the extent to which the small computer is in use in state and local government, extensive contacts with police and the transportation engineering community indicate that there is a lag in the use of these machines.

It is assumed that the small computer can be useful to police and the transportation engineering community in their common effort to enhance highway safety. This assumption led to the analysis of one application of the small computer to the traffic records system of a small community. The purpose of the analysis was to determine whether technological barriers could be identified and specific applications evaluated.

FORMAT FOR ANALYSIS

The format selected for analyzing small-computer applications to traffic records involved the specification of three basic hypotheses related to the technological issues:

1. The hardware is inadequate.
2. The software is inadequate.
3. The costs are too great.

Although there exists a multitude of other issues, these were selected for immediate focus. Certainly there are a number of human factors and organizational issues involved in applying new technology. Some of these are addressed later in this paper.

In dealing with the technological issues, it is necessary to examine the current trends in small computers in sufficient detail to determine the status of key attributes in relation to traffic records systems requirements. First, however, some of the key parameters involved are defined.

Small Community

The small community represents the greatest pool of potential users of the small computer. In Illinois, for instance, whereas the state has accident data for 258 communities in the 5000-100 000 population range, it has data for only 3 cities with populations greater than 100 000 (see Table 1). Among the possible safety applications, the traffic records system probably represents the greatest data-handling test of the small computer.

Traffic Records System

System Elements

A traffic records system is generally considered to include the following elements or files: accident, vehicle, driver, citation, roadway, and control device. These can represent substantial quantities of data and, where automated, are generally considered feasible for operation only on mainframes.

Although the files listed above are considered desirable for a comprehensive system, many small communities currently maintain only an accident file (if any) on an automated basis. Even in cities with populations greater than 100 000, citation, roadway, and other files may not be automated. Therefore, for the purposes of this paper, the core system needed for a small community to conduct effective safety analyses is considered to include the accident and citation files.

Volume of Data

As previously noted, Table 1 gives the most recently available accident frequencies for Illinois communities in the 5000 to 100 000 population range. Accidents are related to community size. The table indicates that all cities with less than 10 000 population had fewer than 1000 accidents/year and that all cities with more than 40 000 people had more than 1000 accidents/year (the maximum was about 5000 accidents).

Data-storage requirements for these accidents are determined not only by the number of records in the system but also by the length of each record. Record length, in turn, depends on the number of data elements in each record and the coding conventions that are used for data entry. The digitizing of locations, dates, times, etc., can substantially reduce the size of fields. The judicious limitation of data elements can be even more important. Because few communities are likely to use identical record formats, how are the length parameters for a typical traffic record to be determined?

To obtain information on the length of a record, two systems are used to represent upper and lower bounds. Washington State has an elaborate coding scheme for accident records processed by its mainframe computer (3). The coding is so detailed that, in the event of a "collision with a pedal-cyclist," the system can provide separate tabulations for "unicycles," "bicycles," and "tricycles." Each accident record takes 212 bytes of storage. (A byte

Table 1. Motor vehicle accidents reported during 1981 by Illinois communities.

	No. of Communities by Population[b]							
	5000-9999		10 000-39 999		40 000-100 000		Total	
No. of Accidents[a]	No.	Percent	No.	Percent	No.	Percent	No.	Percent
0-399	77	91.7	39	26.5	0	0	116	45.0
400-999	7	8.3	83	56.5	0	0	90	34.9
1000-2999	0	0	25	17.0	20	74.1	45	17.4
3000-4999	0	0	0	0	7	25.9	7	2.7
Total	84		147		27		258	

[a] Accident data are from the Illinois Department of Transportation.

[b] Population data are from the 1980 U.S. Census.

can be considered as the amount of computer storage necessary to hold one character of information.) The Washington State coding scheme was used as an indicator of the upper limit for record size.

A lower boundary for accident record size was derived from a report that proposed a record format for the city of Newport News, Virginia (4). The coding scheme captured the essentials of an accident record in 24 data elements coded into a total of 50 characters. As a consequence, 50 bytes/record was taken as a reasonable lower boundary for the size of a collision record.

A desirable system would contain three years of historical accident files and a current year-to-date file. This would result in a maximum of four years of accident data on file at any time.

The discussion to this point has assumed a single basic file type, although a hierarchical file design may be desired. In such a case, the record is segmented into a master file, a vehicle file, and occupant-pedestrian files. In addition, a location index file is required for locational analyses.

Figure 1 translates the basic file type defined above into data storage requirements. Hierarchical file structures and a location index file will add some storage requirements (say, 50K, where K = 1024 bytes), but the range shown is considered sufficient as an estimate of system requirements for accident data. The range of annual accidents shown in the graph is likely to be representative of cities with populations of up to 200 000 to 250 000.

Accident records have been noted above as only one part of a comprehensive traffic records system. The citation record has been identified above as the other element of a core safety analysis subsystem. Citation files are to be distinguished from the driver file, which is a history of individuals usually maintained by the state motor vehicle department for licensing and other purposes. The citation file contains records of traffic offense actions taken by the police officer. Typical data elements for a local citation file would include the location, type, time, and date of the offense. Individual driver and disposition data are of interest administratively but are not essential for safety analyses in general.

Estimating the number of citations in a community, especially in relation to the population, is not a simple task due to lack of data. Experience has shown, however, that the number of citations can be related to the number of accidents as a crude indication of the level of enforcement activity. A general rule of thumb used in the law-enforcement community is that a ratio of 20 citations/injury accident represents a point of diminishing returns. On the other hand, 8-10 citations/injury accident represents a reasonable level of effective enforcement action. If one takes into account property-damage-only accidents, it is reasonable to expect ratios of 10:1 and 3:1 as bounds. Although these are not well-documented values, they do make it possible to estimate a reasonable range for data storage requirements.

It is believed that only a single year's citation history needs to be on file for most analyses. The greater number of citations per year, compared with

Figure 1. Data storage required for accident records.

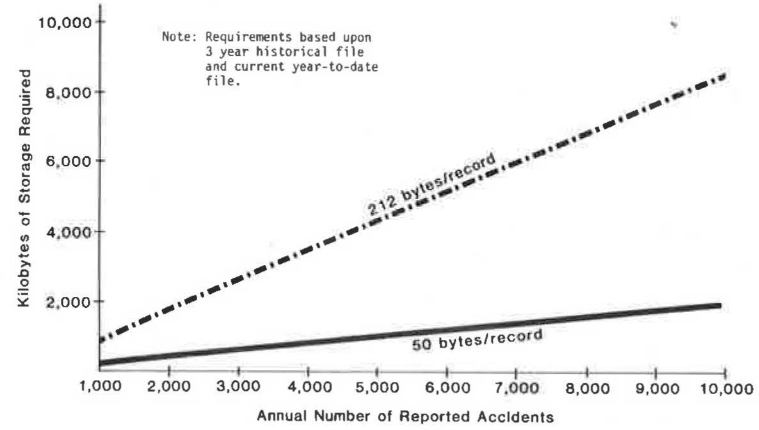
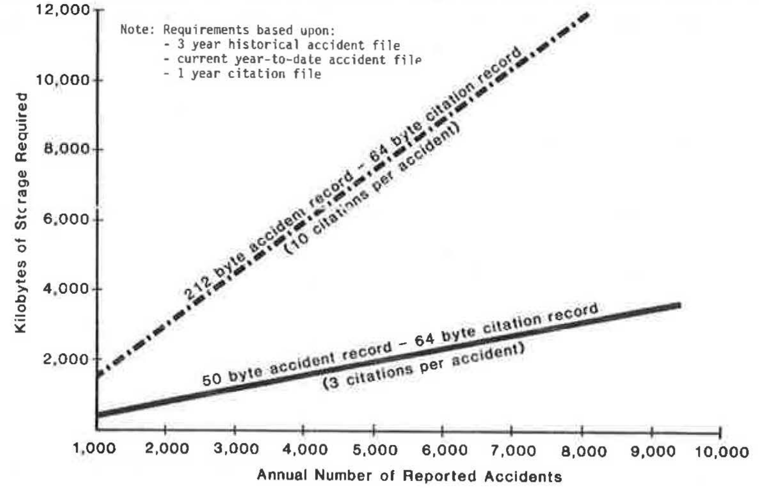


Figure 2. Data storage required for accident and citation records.



accident frequencies, provides an adequate statistical base if maintained on an annual basis. Current enforcement activity can be compared with accident histories to determine whether enforcement actions are appropriate and how they may be planned for the future. In addition, comparisons between enforcement and current accident patterns can be made to evaluate effectiveness. Figure 2 shows a graphic summary of the data storage requirements necessary to add a citation file to the previously defined accident file.

Small Computers

It is necessary to have some understanding of what is being referred to under the classification of small computer. In general, in this paper a small computer is one that costs between $2500 and $20 000, including peripheral devices. This is a general definition because distinctions at this time are fuzzy and the technology is changing rapidly.

The remainder of this paper examines each of the hypotheses in the light of available information.

HYPOTHESES TO BE TESTED

The background given above allows an analysis of the technological issues around which the hypotheses have been formulated.

Adequacy of Hardware

Primary Memory

Primary memory is one of the principal characteristics that distinguish small and large computers. In large measure, primary memory is determined by chip technology. Eight-bit chips simply do not have the direct addressing capability of 16-bit chips, which, in turn, lack the addressing capability of 32-bit chips, and so on. The vast majority of small computers in use today are based on 8-bit technology, but 16-bit machines such as the IBM PC and the TRS 16 have been enthusiastically received. Recently, National Semi-Conductor and other chip designers have developed 32-bit microprocessors. This will permit not only greater memory capacity but also more versatility.

There is a general disposition among computer enthusiasts that memory is good and the more the better. In the early days of computers, primary memory was extremely expensive and memory, beyond the essential requirements, represented a considerable cost burden for a computer system. Widely used small-computer business systems typically have 48K or 64K memory for 8-bit equipment. The newer machines offer 128K to 256K, and some go higher.

The impact of memory size will vary according to the principal use made of the equipment. Large data bases, involving matrices of substantial dimensions, will rapidly eat up memory. Compared with 48K or 614K machines, systems with 256K and 512K memory are more desirable for data base management because they permit reasonably large files to be manipulated entirely within internal memory. The payoff is greater processing speed and more convenience in file maintenance. When a file does not fit into the machine--as frequently happens with machines with limited primary memory--then the file must be segmented. Portions of the file must be moved back and forth between the computer and secondary storage devices.

Currently, small computers have many times the memory of the second-generation mainframes that were used by large corporations in the early 1960s. Those corporations processed files that exceeded the primary memory available then. The current 64K- to 512K-capacity range is adequate for the file sizes shown in Figures 1 and 2.

Secondary Storage

The secondary storage capabilities of the small computer represent a key potential constraint, given the above discussion on data storage requirements. As indicated in Figure 1, maintaining an automated accident records system in most communities in Illinois requires secondary storage of 1000 to 4500 kilobytes (1 to 4.5 megabytes), depending on the level of detail maintained. The lower limit is within the current floppy disk technology, and the upper limit is well within the current hard disk technology. Figure 2 shows that the impact of adding a citation file results in 3.5 to 11 megabytes of secondary storage. Once again, this is well within current hard disk technologies.

Large (8-in) floppy disks can now hold more than 1 megabyte of data (double sided, double density). Increases in floppy storage capacity are announced monthly. Hard disk drives are commonly available in 5-, 10-, and 20-megabyte capacities. Moreover, systems can be configured with several drives so that 80 megabytes are commonly advertised. The cost of the drive is also becoming less and less of a factor. At present there is extreme competition among drive manufacturers. Apple Computer, for example, which originally listed its 5-megabyte drive at $4000, has reduced the price to $2900, and knowledgeable commentators predict even further reduction. Furthermore, hard disk technology is developing at a fast pace: a 100-megabyte drive is currently in the experimental stage. Secondary storage is definitely adequate for the needs identified here.

Speed

Machine Aspects

Small computers can sometimes seem aggravatingly slow. Sorting of large files may take an unreasonably long time on a microcomputer. This can be the case even when the computer has sufficient primary memory to accommodate the entire file internally. Are small computers too slow to be used for the analysis of local traffic records?

Careful examination of the speed issue suggests that small computers are slow only in a relative sense--i.e., compared with their mainframe counterparts. Moreover, the apparent lack of speed is often traceable to factors other than the computer itself. For example, the 6502 chip is a popular 8-bit microprocessor used in Apple, Atari, Commodore, and a variety of other microcomputers. The slowest 6502 instruction executes in 7 µs with a 1-MHz clock (5, pp. 30, 31, and 87). By mainframe standards, this is not fast, but it permits the computer to perform an enormous amount of processing in the time that would normally be required for a mechanically based peripheral device to perform a task. Computer execution times are infinitesimal compared with disk drive access times and the time it takes printers to generate output. Because the computer must wait for the peripherals, programs that frequently access secondary devices indeed run slowly, but the fault is not with the computer.

Other speed considerations relate to the software. Small-computer programming technique frequently leaves much to be desired. In-house software development often results in routines that are not optimized. The programs work, but not efficiently.

Recursive routines such as sorts can result in long processing delays if the routines are not carefully selected. For example, a bubble sort is often used in software that is developed in-house. The bubble sort is notoriously slow in comparison with other sort techniques, such as a shell sort.

For comparison purposes, 200 random numbers were generated and subjected to a bubble sort and a shell sort. These were run by using an interpreted BASIC language on an Apple microcomputer. By the crude measurement of a stopwatch, the bubble sort executed more than eight times slower than the shell sort. Programming technique, rather than the machine itself, is often a major factor in the apparent lack of speed associated with small computers.

The selection of a programming language is another software area that contributes to the apparent lack of speed of small computers. BASIC is probably the most widely used language in the micro field, but it is an interpreted language that requires the machine to translate each instruction at every step of the program. In a loop, some incredible inefficiencies are encountered. Every instruction in the loop must be retranslated at every loop cycle. The time consumed in interpreting program instructions can be enormous in terms of both relative and real time. A routine that uses nested loops to count from 255 down to zero 255 times will execute in machine language in 329 ms (5). The same logic written in Applesoft BASIC takes approximately 2 min, 32.3 s to execute based on stopwatch timing.

The bottom line is that lack of speed is usually not so much a limitation of the computer as a limitation imposed by peripherals and by the software typically associated with small computers. On both fronts, much is being done to resolve the problems. Several software houses now market compilers for BASIC. Compiled BASIC runs 3 to 10 times faster than interpreted BASIC if the claims of software vendors are taken at face value. In addition, popular brands of microcomputers are often supported by various applications programs and utilities that make use of efficient machine language routines.

The problem of peripheral performance time has been approached in several ways. Printer speeds have increased, and logic-seeking print heads are more widely available. Print buffers now permit computers to pass relatively large quantities of output to the printer and then get on with their computational tasks without having to wait for the printer to do its job. There has been even more progress with secondary storage access. Winchester-type hard disk drives, now commonly available at affordable prices, operate much faster than drives for floppies. Data transfer speed has been substantially increased. Bubble memory in the form of cards, called semi-disks, disk emulators, or a variety of other names, has become available. Because bubble memory is nonvolatile, these cards store data in much the same way as a disk, but they have eliminated the mechanical aspects of storage access. Access is done at electronic speeds.

Cost and Turnaround Aspects

If one were to ask why speed is important, the reply would probably involve two major concerns: (a) computer time costs money and (b) the results are needed as soon as possible. Each of these is important when one considers using small computers in lieu of, or as a supplement to, mainframes.

The cost of computing (as opposed to the cost of computers) is low with the small computer. The machine costs are relatively minimal for the small computer in comparison with the mainframe (cost is discussed further later in this paper). As a result, small-computer use generally does not involve an amortization and maintenance fee. The mainframe represents a major capital investment and maintenance cost, which is often passed on to the user on a time-in-use basis. Thus, whereas speed is often cost to the mainframe user, it is not to the user of the small computer. However, it should be recognized that, in some government accounting systems, an agency may not bear any cost of computing on a central mainframe system. In such cases, not only is speed not an issue but the capital cost of a small computer in that agency's budget would become an extra burden.

Another side of the speed-is-cost issue is the personnel time that may be required. The small computer, if significantly slower than the mainframe, is also usually much closer at hand. Thus, although a technician or professional may be running a program that takes a significant amount of time, the machine can usually crank along on its own while the user does other tasks nearby.

Another issue is the speed that the user experiences. This is often termed turnaround time--that is, the time required from the moment a question is formally asked to the moment of delivery of the data needed to answer the question. Although this does not apply to regularly scheduled computer reports, it does have application to frequent, unscheduled needs. This has been a problem in government environments where central data processing groups are understaffed and computing facilities are used by many different agencies, and levels, of the local government. In that context, the safety analyses desired are often of low priority and thus response is not quickly forthcoming. Time-share systems have helped overcome this to a certain extent. However, in comparing the small computer with the mainframe, although central processing speeds may not be comparable, turnaround times may be; in fact, the small computer may be superior in some cases.

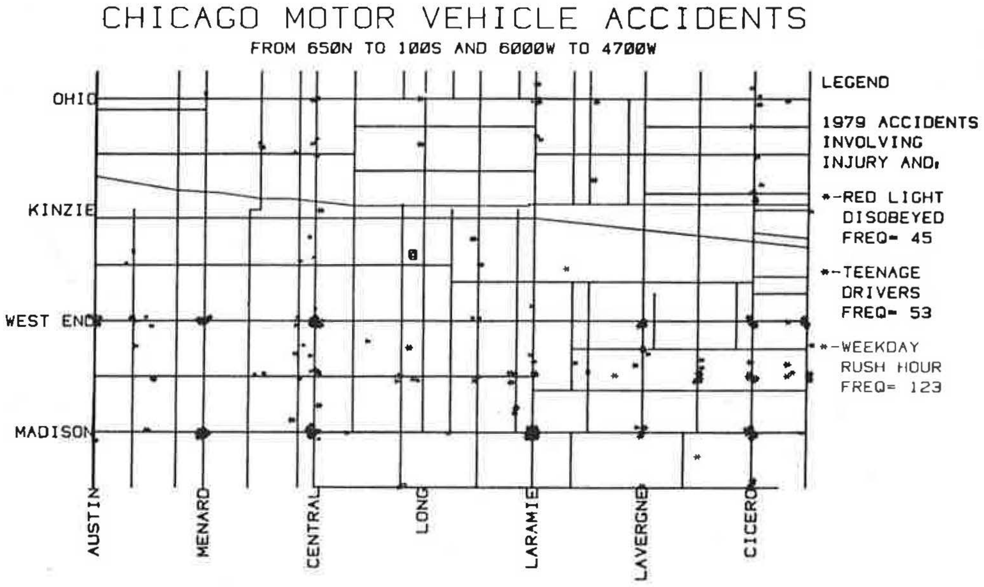
Output Devices

The mainframe computer can generate reports on a cathode ray tube (CRT or television screen) and on paper. It can produce graphs of all sorts, including bar charts and pie charts. It can even create a collision diagram for an intersection, and all at a level of sophistication that is camera-ready for report reproduction. Is it possible that these report generative features discourage the use of small computers? In general, the answer must be no. Small computers designed for general business and scientific use have the ability to drive the same output devices as the mainframes. Although the prices of such peripheral devices are high relative to the cost of the central processing unit, they are well within the reach of the budgets of small communities.

Output devices for small computers include CRTs (with or without color), printers (of varying quality), plotters (with or without multicolor output), modems (for data transmission), synthesized speech, and other audio formats.

The key output devices applicable to traffic records systems are CRTs, printers, and plotters. CRT units are especially important in running programs where user interaction is involved. It is often desirable to go through report design interactively for a particular problem. This can be done on the machine by using the CRT as the user prompter. Monitors with a 10- or 12-in screen and white-on-green or white-on-black image can be purchased for less than $125 and are quite adequate for most applications. Most small computers can be connected to standard television sets with an inexpensive device.

Figure 3. Example of small-computer and plotter output.



Printers represent a more substantial investment but are essential to obtain information in a form that can be easily disseminated. Small computers can drive a wide variety of printers. The most economical are the dot-matrix type. Some dot-matrix printers can be used to create graphics outputs as well as letters. The more sophisticated of these approach letter quality. True letter quality is achieved, however, by driving an electric typewriter, which is slow, or a daisy-wheel printer, which can provide speed and selection of type fonts. Excellent dot-matrix printers are available for less than $1000; a good letter-quality printer will range in price from $3000 to $6000, and more expensive printers are also available.

Plotters are also available for small computers. They provide better resolution and flexibility than printers with graphics capabilities and can be useful if a significant volume of output is desired in the form of maps, diagrams, and graphs. An example of a plotter-generated spot map is shown in Figure 3. Plotters can produce report-quality graphics and can do it in multiple colors. They can be purchased for prices starting at $1500.

Input Devices

Input devices for small computers include keyboard, magnetic disks and tape cassettes, analog devices, modem (data transfer), paper tape, light pen (CRT), digitizer (graphics tablet), capacitance-sensitive screen, punched cardreader, speech recognition devices, and mark-sense devices.

The key input devices applicable to the traffic records systems include the keyboard and magnetic disks. Modem (telecommunication) units, analog devices, paper tape, digitizers, and light pens also have potential application. It is important to note that accident and citation records must be keyed in for the mainframe (whether through a card keypunch or direct entry) as well as for the small computer. The large computer appears to offer no particular advantage with regard to input and output capabilities.

Adequacy of Software

Most mainframe traffic records systems software has been developed by state and large-city data-processing units and their contractors. Some commercially developed systems have been applied in more than one context, but these systems are generally custom built. One major exception is the Accident Data and Analysis System (ADAAS) developed for NHTSA by the University of Michigan to be a general-service system for traffic accident records users (6). The ADAAS system is accessed via remote terminal on an interactive, time-share basis. Several state, city, county, federal, and research accident data bases are currently on the system. Agencies are charged for the system on an as-used basis.

The mainframe traffic records systems vary in accessibility and user friendliness. Some, such as ADAAS, are end-user operated and oriented. Others are batch process only, using predefined and inflexible report formats. Some have exceptional graphics capabilities whereas others have none.

Programming Languages

Small computers are supported by most major programming languages, including FORTRAN, PASCAL, COBOL, and BASIC. There are perhaps more dialects of these languages than one finds in the mainframe arena. The unfortunate result of the proliferation of dialects is that present software is not readily transferable from one machine to another. However, language standardization in the small-computer field has not been so out of control that the situation is hopeless. In addition, both hardware and software manufacturers are creating new means to achieve interchangeability of all types of software.

Generic Software

There are two general software areas that are of interest to local police and engineering safety planners: generic programs and special-application software. In the first category are included generalized data-base management routines and common statistical tests. These may be termed generic software in the sense that they have been developed to meet a variety of user needs. A generic data-base management program, for instance, can be used in a retail or manufacturing environment for inventory control. It can also be used in a mail-order business for customer records. It could be used by an engineering or police agency for maintaining traffic records. Generic statistical packages do much the same thing with commonly used statistical tests: They permit the statistical analysis of a wide range of data that could reflect sales and marketing figures, survey responses, or traffic accident experience.

One of the valuable aspects of generic software is that most of the packages presume little technical knowledge of computers on the part of the user. This is not to say that the programs are always simple to run. (There are books written by third parties to help users learn some of the more popular generic packages.) Generic software packages such as VISICALC and DB Master commonly sell from about $50 through $500. Although the application of some of these packages seems appropriate in the traffic records area, little has been done to test them. Furthermore, it should be remembered that, although these are general-applications packages, once they are acquired they can be used for other purposes, such as administrative records.

Special-Applications Software

Special-applications software would be that designed specifically for traffic records use. Although some of this can be developed by an agency's own data-processing people (in-house), others--both commercial and government--have developed special applications software that can be applied in more than one agency context. The development of programs in-house is an option that, except for unusual circumstances, is usually not cost effective. Nevertheless, some in-house program development is probably inevitable once a small computer is installed on-site. The few agencies that have made use of small computers have already developed some home-grown applications software. In some cases, local university students and faculty have provided able assistance. For the most part, however, these programs are developed for a specific use by an amateur programmer. Although they may be quite adequate for that user, in that context, the program design usually does not contain the error trapping, adaptability, and user friendliness desired for general use, nor is it normally documented adequately so that others may independently operate the package.

Software specifically developed for small computers, to conduct traffic records analyses, is just beginning to become available commercially. These programs are limited primarily to accident records and street and control-device inventories. Little has been developed in the public domain. One exception is the City Accidents Rapid Evaluation (CARE) system developed by Auburn University for the state of Alabama (7, p. 43). This system downloads a city's accident records from the state tape to a hard disk, after special reformatting to reduce file size. The user is then presented with a choice of 11 actions, including identification of high-accident-rate locations, frequency distributions, and cross tabulations. The system has certain limitations, but it demonstrates the potential for application of a small computer in an interactive mode.

Although the CARE system was developed for use by cities in a particular state, it is being marketed commercially for general use. Other accident and citation analysis programs exist for small computers developed in-house. Those of which we are aware generally exhibit the limitations of in-house-developed software noted above. There is some promise of more generally usable packages, as exhibited by a recent report of a small-agency system now being tested (8, p. 102). The system consists of accident records, citation records, street index, and officer badge files created in a hierarchical structure. The program allows the user to select among a number of predesigned reports involving general and location-specific accident and citation summaries as well as identification of high-accident-rate locations and officer activity summaries. The system is designed to accommodate approximately 1000 accidents and 3000 citations. Developed as part of university student course work, the system is being tested in a city with a population of 20 000.

It is interesting to note that, while this relative paucity of development has occurred on the traffic records side, police crime records applications and traffic engineering applications have been developing at a rapid rate. The POSSE system is a crime records analysis system developed by the U.S. Department of Justice for use by small departments on minicomputers and microcomputers. It was developed to meet the growing demand by a variety of local police agencies around the country. An even greater flurry of activity has occurred in the transportation planning and traffic engineering areas of application for small computers. A brief analysis of an UMTA status document (9) shows the extent of the development effort:

Topic Area	No. of Items Developed or in Process
Transportation planning	
Data management	7
Travel demand	10
Design and evaluation	8
Public transportation	
Planning and design	11
Operations	12
Transportation design and operations	
Data management	7
Signal analyses	8
Design	1
Accident analyses	2
Total	66

In summary, it may be said that software availability and design may represent past barriers to the use of the small computer in the traffic records area. Generic packages have not been tested in this context. Applications software developed in-house is generally costly, and what is done is usually limited. Commercially developed, or public domain, packages exist but are of recent vintage and not widely tested. Although these may represent past barriers, the trend of the art is such that henceforth there should be no hesitancy by an agency to venture into such an application. Key attributes that must, however, be built into the new software developments are end-user orientation and friendliness so that the package can be readily adapted for individual agency use and used by personnel for whom the computer is an unknown that is feared.

Cost

The issue of cost is the one that initially attracts attention to the small computer. In view of the fact that the small systems currently available can deliver sufficient computing capability to allow basic safety analyses to be conducted in a small community, the relatively low initial investment required makes them attractive to agencies with no other readily available automation option. Table 2 gives examples of two levels of systems that might be appropriate for this application. It demonstrates that such systems are well within the budgets of small agencies.

Of course, there are costs other than those for the basic system. Space, materials, maintenance, and personnel costs are all involved. In general,

Table 2. Attributes of small computer systems for traffic records applications.

Element	Lower Bound	Upper Bound
Primary storage	8 bit, 64K	16 bit, 512K
Secondary storage	Two floppy disk drives	Hard disk, 20 megabytes
Printer	Dot-matrix	Daisy wheel
Plotter		Multicolor
Monitor	No color	Color
Software[a]	Utilities, data base, electronic worksheet	Utilities, data base, electronic worksheet, word processor, statistical analysis, graphics generator
Cost[b]	$2500	$20 000

[a] Assumes engineering applications software available in public domain.
[b] Approximate.

these costs are also considerably less than those for mainframe systems. The space required is no more than that needed for a normal enclosed workstation. The price of the materials required is comparable to that of many other types of electronic office equipment. Maintenance can be obtained on a contract basis, as with other office equipment, and at comparable fees. Personnel requirements are not nearly so demanding as for mainframe systems. Small computers and the related software are generally designed for an untrained end user. The personnel who maintain the system need not be data-processing professionals, but they do require some special training, which is often available through dealers, local community colleges, or other adult education programs.

CONCLUSIONS

The preceding discussion has demonstrated that hardware is not the issue in considering the use of small computers for operating a basic traffic records system in a small community. Certainly, there is a need for improved software that can be operated by personnel with no special training and can be adapted to meet a variety of needs. The costs associated with the acquisition and operation of the small computer are well within the budget levels of small agencies, especially when the small system is to replace a mainframe service for which the agency is bearing the costs.

Data Quality

There are, however, a number of other organizational and human-factors issues that, although a subject for another paper, one must consider. One of the key factors in achieving a useful system is the provision of accurate data in the form, and at a time, that is appropriate to aid in making the decision for which it is needed. Consideration of this factor points to the recurring problem of technology outpacing human capabilities in such areas as data input and decisionmaking. The quality and accuracy of accident data are below the quality and accuracy obtainable from the reporting systems. This is exacerbated by the declining resources available to police agencies for data collection. Reduced reporting levels, reduced traffic-law enforcement, training, and general deemphasis on traffic-law enforcement due to community emphasis on crime control are a result.

Another aspect of the data-quality issue is the manner in which the data are reported to end users. As in many other fields subject to the control of data-processing professionals, data are often reported in forms not readily understood, or used, by the decisionmakers and their technical advisors. Reports from such systems have been highly inflexible. Systems are needed that produce reports designed to answer the questions at hand. Some of these may be recurring questions, justifying regularly generated, standardized output. But the unique request must be provided for in order to encourage creativity among safety analysts by removing barriers to the accessing of information. Some of this is being achieved on mainframes, but apparently not enough. Consider the case of a large brokerage firm (large data files needed), as reported recently (10, p. 15):

> Three hundred employees at Merrill Lynch, Pierce, Fenner & Smith ... have bought personal computers to help them in research work, analysis, administration and customer support. The company does not buy the personal computers for its employees, but when many of them started investing in their own equipment, it decided to help the process. One reason ... why micros are so popular at Merrill Lynch as well as other companies is that centralized data-processing departments cannot satisfy all the needs of individual employees. When an executive devises a new, computerized way to manage a portfolio, he or she can try it out on a personal computer without running into delays that are often associated with centralized data-processing departments.

Multiple Applications

It may sometimes be difficult to justify the purchase of a unit with a price tag in the $5000 to $20 000 range for a single dedicated purpose. The small computer, however, offers the option of multiple uses within an agency. The generic software, noted above, offers the agency the potential of a sophisticated word processor and a data-base manager for personnel and other applications, plus any special applications for which programs may be developed. This flexibility may be an important factor in considering this type of investment.

Management Barriers

Even if the feasibility question is not an issue, there may remain barriers within management to the use of the small computer. This may arise for several reasons, such as lack of willingness to deal with something not well understood, seeing the small computer as a toy (confusing the $300 Atari with the $5000 TRS 80), concern over the loss of control with decentralized computing, and resistance from the centralized computing facility, which may see this as a threat to its existence rather than a new opportunity for service.

Personal Barriers

Although the programs for small computers are designed for the end user and attempt to be friendly, there exists the fact that a computer is involved. This is enough to discourage many people because the machine is associated with the mysterious black boxes of the past. The potential user often associates use of such a machine with highly mathematical, technical competence. Thus, even when such a person can be convinced to try the computer, it is approached with a fear of failure. When the small computer is applied to the traffic records function, the system should be developed to allow clerical operators to be employed and to allow for technical analysts within the agency to use the system. Thus, the ultimate acceptance of such a system may depend on overcoming these personal barriers.

Need for Management

A recent article by one of the most respected members of the data-processing community (11) contained the following observations:

> The language and software for creating commercial DP [data processing] applications are really improving and will continue to do so. Nonprocedural languages and facilities now permit many applications to be created without conventional programming and in some cases permit them to be created by end users. The image of a computerized corporation of the near future which the reader should keep in mind is one in which many people are creating and adjusting the electronic procedures. They have user-friendly software that enables them to do this rapidly. Inexpensive computers are spreading and there is a terminal on most desks. The challenge for both DP and corporate management is: How do you control this environment? The most important aspect of control is coordinating the data used. If this is not done, there will be a Tower of Babel effect.

As the small computer becomes widely used, its use, even more than the introduction of other electronic office devices, can have a marked impact on personnel activities and office layout and organization. The effective implementation of these systems requires sound management. There are many pitfalls in implementing a small computer system (12). The age of application of this new technology has just begun but it will soon be in full bloom. If the potential is not recognized and planned for, by innovative management within an agency, later pressures for its installation will make the transition much more difficult. The process should be begun now.

REFERENCES

1. New Study Sheds Light on Micro Use. InfoWorld, Vol. 11, July 5, 1982.
2. Traffic Records Committee for Data Analysis: 1982 User Survey. National Safety Council, Chicago, Preliminary Rept., Aug. 1982.
3. Local Traffic Records System User Manual. Washington Office of Traffic Records Programs, Olympia, Jan. 1980.
4. Newport News Accident Surveillance Systems. Wilbur Smith and Associates, New Haven, CT, Nov. 1970.
5. L. Scanlon. 6502 Software Design, 1st ed. Howard W. Sams and Co., Inc., Indianapolis, IN, 1981.
6. The HSRI Accident Data System. Highway Safety Research Institute, Univ. of Michigan, Ann Arbor, June 1979.
7. D.B. Brown. CARE System Overview and User Guide. Alabama Office of Highway and Traffic Safety, Montgomery, Feb. 1982.
8. W.E. Kelsh. Development of a Microcomputer Based Traffic Records System for Small City Police Agencies. Univ. of Virginia, Charlottesville, 1982.
9. Microcomputers in Transportation: Information Source Book. U.S. Department of Transportation, Aug. 1982.
10. D. Wise. Merrill Lynch Is Bullish on Personal Computers. InfoWorld, Vol. 4, No. 28, July 1982.
11. J. Martin. An Overall Plan. Computer World, Oct. 4, 1982.
12. W.W. Stenzel. The Promise of New Technology. National Safety Council Traffic Records Forum, St. Paul, MN, July 1983.

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Evaluating and Planning HOV Lane Enforcement

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The different high-occupancy-vehicle (HOV) strategies introduced on California freeways in recent years have included reserved ramps, preferential lanes, and bypass lanes at metered ramps. Several factors have frustrated efforts to enforce the traffic laws that accompany these strategies; these include personnel limitations, enforcement priorities, public hostility, confusion, and physical constraints imposed by the geometry and engineering features of specific projects. As a consequence, violations have increased on certain types of HOV lanes. A summary is presented of the results of a two-year study designed to measure and evaluate the effect of different enforcement options, engineering features, and educational programs on violation rates for various transportation system management freeway strategies and trace the resulting impact of these violation rates on safety, freeway performance, and public attitudes. During the study, statistics were assembled on violation rates, enforcement levels, and operating performance on California HOV lanes; drivers were surveyed; special design features were investigated; and different levels and combinations of routine and special enforcement activities were tested on a variety of HOV lanes. Violation rates were measured before, during, and after the assignment of Highway Patrol officers to enforce specific HOV lanes and metered freeway ramps, accident levels were recorded before and after the installation of HOV lanes, the benefits and costs of HOV lane enforcement were analyzed, and the results of the analysis were used in recommending a program of future enforcement for California HOV lanes.

Adequate control of violation rates on preferential high-occupancy-vehicle (HOV) facilities requires an effective mixture of enforcement, engineering design changes, and public education. Although past operating experience has given the California Department of Transportation (Caltrans) and the California Highway Patrol (CHP) a number of insights regarding the potential effectiveness of different enforcement strategies, engineering changes, and education programs, this experience has not been documented with the quantitative precision necessary to identify the appropriate levels and mixture of these factors needed to obtain adequate motorist compliance.

The purpose of the study described in this paper was to provide a detailed, quantitative, and objective assessment of the effects of different enforcement options, engineering features, and educational programs on violation rates for various transportation system management (TSM) freeway strategies and to trace the resulting impact of these violation rates on safety, freeway performance, and public attitudes.

STUDY OVERVIEW

The investigation described in this paper covered nearly two years and followed a detailed study design laid out by SYSTAN, Inc., in June 1979 (1). Interim reports were prepared after the sixth and twelfth months (2,3); the results obtained through the first six months were published in an earlier paper (4). This paper summarizes the contents of the final project report (5) and covers the full span of the project, including the implementation phase; preenforcement and postenforcement surveys; four waves of special enforcement activities; investigations of special design features, safety aspects, and the costs and benefits of TSM project enforcement; and the development of a recommended program of future enforcement for California HOV lanes.

Projects Evaluated

Main-Line HOV Lanes

In the case of main-line HOV lanes, the different engineering options evaluated were limited to the major projects currently in place on California freeways. These projects include the nonseparated right-of-way on US-101 in Marin County north of the San Francisco Bay Area; the preferential lane of Interstate 580 in Alameda County, which is separated from regular traffic by a buffer lane; and the 11-mile San Bernardino Busway east of Los Angeles, where the preferential lane is separated from general traffic by concrete barriers on the western end of the freeway and by a buffer shoulder and pylons on the easternmost 7 miles of the project. Detailed descriptions of each of these projects can be found in the study design (1).

Ramp Bypass Lanes

In the case of ramp bypass lanes, the full spectrum of lane designs represented on California freeway ramps was tested to determine the impact of design characteristics on enforcement and violations. Existing bypass lanes were classified in groups according to a number of important geometric features, design choices, and performance characteristics, including the availability of a refuge area, the visibility of the enforcing officer, and the current violation rate. More than one-third of the more than 130 ramp bypass lanes operating in Los Angeles at the start of the study were analyzed in detail along with all bypass lanes in San Diego and the San Francisco Bay Area. In addition to the variety of characteristics available for analysis on existing ramps, certain innovative engineering options were tested during the study, including metered HOV bypass lanes, special signing and striping, and separated HOV bypass lanes.

Other Projects

A small sampling of metered ramps without bypass lanes was also investigated, as were the preferential lanes at the toll plaza of the San Francisco-Oakland Bay Bridge.

Enforcement Options

Different levels and combinations of routine and special enforcement were tested to ascertain their effectiveness in controlling violations both on newly opened projects and on those that had been operating for some time. CHP officers were assigned, singly or in teams, to particular bypass lanes and other HOV projects for a specified number of days over periods of 1, 4, or 12 weeks. Typically, special enforcement assignments covered the entire peak commuting period for 1, 2, or 4 days/week. Particular attention was paid to the behavior of motorists after special enforcement activities ceased. In addition, an enhanced version of routine enforcement was studied in which every beat officer on duty during the morning and evening peaks was instructed to spend 10 min/day on ramp enforcement.

Data Collection Patterns

A typical pattern of field observations for a specific HOV project is shown in Figure 1. The pattern called for two or three days' observation of violation rates before the introduction of special enforcement activities and then as many as five observations during the two months after these activities. Four waves of special enforcement were scheduled on ramp bypass lanes, and at least two separate waves were tested on each main-line HOV lane.

HISTORICAL ENFORCEMENT LEVELS AND VIOLATION RATES

Table 1 summarizes key California HOV projects during the study implementation phase, before the introduction of any special enforcement programs.

Enforcement Levels

Past citation rates on main-line HOV lanes ranged from a low of 4 tickets/weekday on I-580 in Alameda County to 14 tickets/weekday on the San Bernardino Busway. The CHP had historically relied on routine enforcement to control violation rates on Alameda County I-580 and assigned motorcycle officers to special enforcement duties during the evening peak on US-101 in Marin County. On the San Bernardino Busway, a combination of routine and special enforcement had been used in which special units were assigned intermittently to lane enforcement.

Violation Rates

The percentage of vehicles using California main-line HOV lanes illegally during the spring of 1980 ranged from 8.8 percent on the San Bernardino Busway to 30.5 percent on the controversial Alameda County I-580 diamond lanes. Occupancy violations on the shoulder-separated right-of-way of the San Bernardino Busway averaged 7.3 percent of all vehicles in the lane during the morning peak and 10.5 percent of all vehicles in the afternoon. These violation rates were lower still (estimated at 3-4 percent) on the portion of the busway where a physical barrier makes lane switching impossible. Violation rates on the San Bernardino Busway and Alameda County I-580 had not increased appreciably over prior measurements, but the 21.5 percent violation rates recorded on Marin County US-101 represented an increase over the 5-15 percent violation rates reported roughly one year earlier.

Ramp Meter Bypass Lanes

Enforcement Levels

In the past, the CHP had applied a policy of relatively low-priority, routine enforcement to bypass lanes, using available personnel to enforce the lane restrictions in addition to regular patrol duties. As the number of bypass lanes in Los Angeles exceeded 150, however, the supply of bypass lanes in some CHP command areas actually outnumbered the supply of officers available for all patrol duties during the peak traffic periods. As a result, the average number of occupancy citations issued per bypass lane was slightly more than one per week at the start of this study.

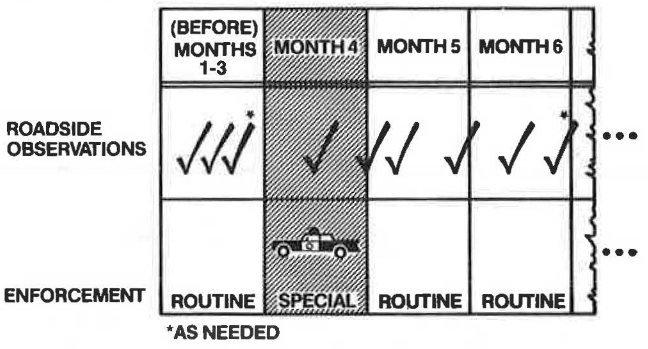
Violation Rates

Under the prevailing enforcement policy, violations increased annually on most ramp meter bypass lanes in the Los Angeles area, and bypass lanes that had been operational for several years had significantly higher ramp violation rates than newly opened lanes.

Before the start of this study, the average lane violation rate for a sampling of 39 metered ramps with HOV bypass lanes in the Los Angeles area was 37.7 percent, appreciably higher than the comparable violation rate on any main-line HOV project in California. This corresponded to an average ramp violation rate of 12.8 percent. In Los Angeles, the relative number of vehicles using bypass lanes illegally ranged from 13.4 percent on one heavily enforced ramp (Colorado Boulevard on LA-5) to more than two-thirds of all vehicles in the bypass lane on the Western Avenue ramp to the westbound Santa Monica Freeway.

In San Diego, where the peak traffic periods are shorter, meters are traffic-responsive, and the HOV lanes themselves are meter-controlled, HOV lane violation rates were found to be considerably lower (averaging 19.5 percent on a sampling of seven HOV bypass lanes, a 3.0 percent ramp violation rate.

Figure 1. Typical pattern of field observations.



Ramp Meter Violations

The number of drivers who ignore meter restrictions by running the red light is relatively low and is not considered to be a major problem by either Caltrans or the CHP, particularly because such violations tend to occur when traffic volumes are low and ramp queues are short or nonexistent. In Los Angeles, the level of meter violations is significantly higher on ramps without bypass lanes than on ramps with such lanes (3.8 percent versus 1 percent of all vehicles on the ramp) because the bypass lane itself provides a convenient pathway to those potential violators who might otherwise simply run the red light.

Bridge Toll Plaza

The lowest lane violation rate recorded on any HOV project in California was the 5.4 percent violation rate on the San Francisco-Oakland Bay Bridge, which consistently offers carpoolers substantial time savings of 4-5 min in addition to a toll-free trip across the San Francisco Bay.

ENFORCEMENT IMPACTS

Ramp Meter Bypass Lanes

Special Enforcement Activities

Four waves of special ramp enforcement activities were scheduled in Los Angeles, San Diego, and San Jose between June 1980 and August 1981. During each enforcement wave, officers were assigned to particular ramps for a specified number of days each week for periods of 1, 4, or 12 weeks. These special assignments were applied randomly and interspersed with periods of routine enforcement that lasted at least 9 weeks. The composite results of each wave of enforcement are summarized in Table 2.

The first wave of enforcement was easily the most effective in reducing violation rates. During the first wave, special enforcement activities proved successful in reducing occupancy violations on almost every ramp where they were tried. Even the lowest levels of special enforcement (one officer, one day per week, for four weeks) had a significant, measurable impact in lowering violation rates (see Figure 2). Moreover, violation rates tended to

Table 1. HOV project violation rates and routine enforcement levels: base period, spring 1980.

	Violation Data		Enforcement Data		Operating Data
Project	Lane Violation Rate (%)	Ramp or Freeway Violation Rate (%)	Past Citation Rate (no./day)	Apprehension Rate (%)	Avg HOV Time Savings (min during peak hour)
Main-line HOV lanes					
Nonseparated lanes					
Marin 101	21.5		11.6	2.6	N[a]
Santa Monica[b]	15.1	1.0	55		5-6
Separated lanes					
Alameda I-580	30.5		2.5	0.8	N[a]
San Bernardino	8.8		10.8	3.3	5-7
Metered ramps					
Without bypass lanes	3.8[c]	3.8[c]	NA	NA	NA
With bypass lanes					
Los Angeles	37.7	12.8	0.27[d]	0.18	1.3
San Diego	19.5	3.0	0.07[d]	0.24	0.4
Exclusive HOV bridge lane					
San Francisco-Oakland Bay Bridge	5.4	0.7	2.4	1.1	4-5

[a] Negligible, average less than 20 s. [b] Project discontinued. [c] Meter violation rate. [d] Per ramp per day.

remain low for as long as four to eight weeks after the cessation of special enforcement activities.

Although the relative effectiveness and residual impact of special enforcement diminished somewhat after the first wave, heavier enforcement levels (enforcement two or more times a week) still caused violation rates to decline (see Figure 3), and the lower enforcement levels (enforcement once a week or less) generally managed at least to keep rates from rising and maintain earlier reductions.

Table 2. Composite impacts of successive special enforcement waves.

			Ramp Violation Rate (%)			
			Enforcement Period			
Wave	Time Period	No. of Ramps	Before	During	After	Change
First	June-September 1980	37	11.8	7.6	7.9	-32.7
Second	September-December 1980	27	8.9	7.8	7.9	-12.2
Third	January-April 1981	34	8.7	7.1	7.4	-14.3
Fourth	May-August 1981	32	8.6	6.7	7.2	-16.9

Figure 2. Composite enforcement impacts: low enforcement levels.

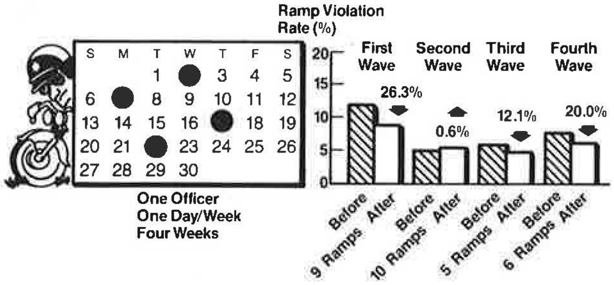


Figure 3. Composite enforcement impacts: high enforcement levels.

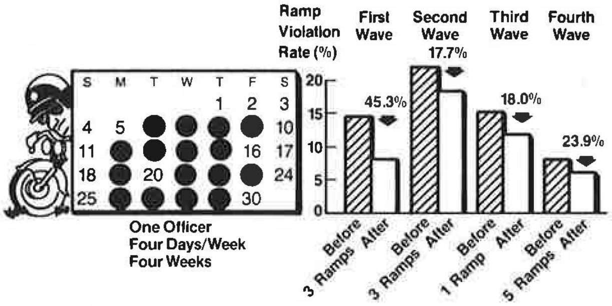
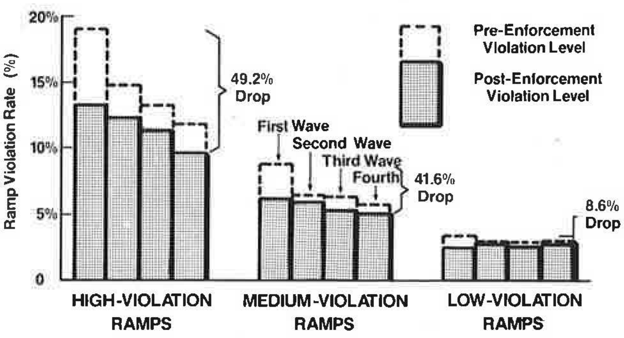


Figure 4. Enforcement impacts on ramps classified by historical violation levels.



At the close of the fourth wave, violation rates on the ramps subjected to special enforcement stood at 6.5 percent, a 45.4 percent reduction below the 11.9 percent rate that characterized those ramps at the start of the study. In all, almost 10 000 citations were issued during special ramp enforcement efforts, and the number of violations on the average ramp dropped by 72 violations/day. The median span of time before violation rates approached preenforcement levels was two weeks after the later waves of enforcement compared with eight weeks after the first wave.

Special Enforcement Tactics

The most popular and effective tactic for enforcing ramp bypass lanes required that officers park their vehicles beyond the meter and assume a stationary position in order to wave violators over to a safe refuge area where a citation could be issued. Officers who were able to stand out of the view of potential violators issued more citations per day than officers who assumed more visible positions. Some officers appreciated the extra margin of safety afforded by in-view enforcement, however, and these officers tended to be no less effective in reducing violations. Violations were somewhat slower in returning to preenforcement levels when enforcement officers took up less visible positions.

Enforcement tactics involving vehicle pursuit were much less efficient than stationary enforcement in generating citations, reducing violations, and providing a cautionary example to other ramp users.

Effect of Violation Levels

Special enforcement was most effective on ramps where violation rates were medium or high to begin with (see Figure 4). On ramps where violation rates were already low (i.e., less than 6.5 percent), special enforcement was less effective in reducing occupancy violations further and violation rates returned to preenforcement conditions much faster. This suggests that there is a practical limit on the reductions that can be brought about by enforcement and, consequently, that special enforcement efforts should not be made in an attempt to make tolerably low violation rates lower still.

The need to relate enforcement levels to existing violation rates underscores the need for close, continuing cooperation between the enforcement agency and the agency responsible for maintaining, operating, and monitoring ramp meter bypass lanes.

Duration of Special Assignments

Twelve-week periods of enforcement were not found to be significantly more effective than four-week periods either in reducing violations further or in generating longer residual impacts. The diminished effectiveness of longer periods of enforcement, coupled with the lessened impact of later waves of special enforcement and the difficulty of driving ramp violation rates below 4 or 5 percent, suggests that enforcement impacts are subject to a law of diminishing returns.

Number of Officers

Assigning two officers to a single ramp was almost, but not quite, as effective as assigning a single officer for twice as many days (see Figure 5). On some heavily violated ramps, the officers preferred working in pairs so that fewer violators went unticketed and help was close at hand in the event that apprehended drivers became unruly while waiting to be ticketed.

Figure 5. Effect of multiple officers.

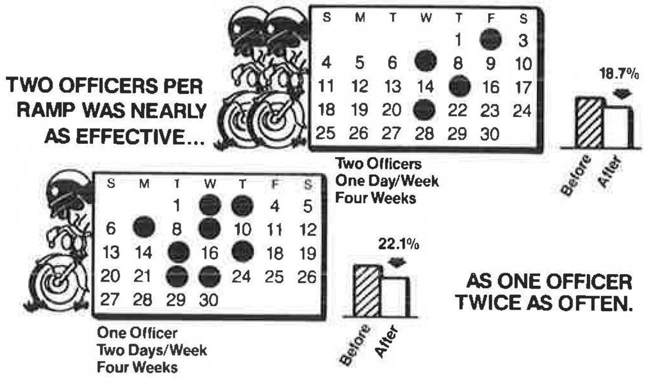
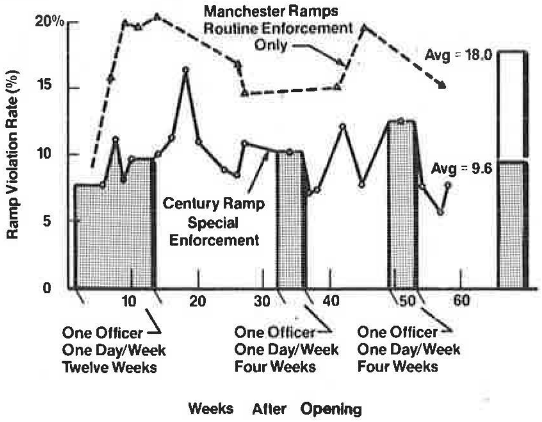


Figure 6. Effect of routine and special enforcement on newly opened bypass lane.



Bail Schedules

Bail schedules for HOV lane occupancy violations vary from $21 to $52 in the CHP's Southern and Golden Gate Divisions and are set at a low of $13.50/offense in the San Diego area. There is no evidence that higher fines lead to significantly lower violation rates.

Impacts on Traffic Flow

As special enforcement encouraged more single-occupant automobiles to join the metered queue rather than use the HOV lanes illegally, queue lengths grew and the average delay encountered by drivers entering Los Angeles freeways rose from 45 to 54 s. In addition, special ramp enforcement actions were found to reduce speeds on adjacent freeways by between 20 and 30 percent in the vicinity of the ticketing activity.

Start-Up Strategies

Start-up enforcement strategies were tested by selecting matched pairs of newly opened ramp bypass lanes similar in geometric configuration and enforcement visibility and initiating special enforcement activities on one ramp of each pair while restricting the other ramp to low-priority routine enforcement. Special enforcement activities lasted for four weeks and were repeated quarterly on certain ramps. After one year of ramp operation, ramps that received special enforcement during the opening weeks had significantly lower violation rates than their opposite numbers. The composite ramp violation rate on ramps with special enforcement was 7.3 percent compared to a rate of 14.0 percent on control ramps exposed only to routine enforcement. Figure 6 shows violation rates measured during the first year of operation for a matched pair of bypass lanes on the San Diego Freeway in Los Angeles.

Special enforcement activities should be initiated immediately after a ramp is opened and be continued for at least two days a week during the first month of operations. If an initial grace period is desired, it should last no more than a week and should generally not be publicly announced. Officers should be present throughout that week to issue warnings, answer questions, and instill a degree of respect for the HOV restrictions.

Routine Enforcement

In the absence of special enforcement, routine enforcement proved to be an ineffective means of controlling ramp violation rates. Under a policy of routine enforcement, ramp violation rates in Los Angeles had risen steadily before the start of this study. Attempts to increase routine enforcement levels by requiring officers to spend 10 min each day on ramp enforcement also proved ineffective. Such efforts produced a low level of citations, were difficult to direct and control, were unpopular with some officers, and tended to encourage one-shot enforcement tactics that involved pursuit rather than a sustained effort from a stationary position.

Routine ramp enforcement can be effective if applied in conjunction with special enforcement in a selective enforcement program. Violation rates rose relatively slowly during the periods of routine enforcement between special enforcement sessions on sample ramps. As drivers became aware of special enforcement activities on sample ramps, moreover, violation rates dropped on other routinely enforced ramps. On six Los Angeles ramps subjected only to routine enforcement, violation rates dropped 20 percent between the first and fourth waves of special enforcement.

MAIN-LINE HOV LANES

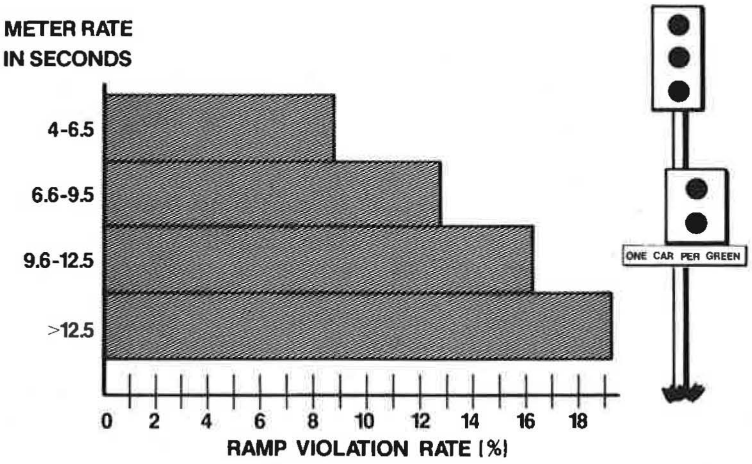
Special Enforcement Activities

Two waves of special enforcement activities were scheduled on each main-line HOV lane in California between May 1980 and June 1981. During the first wave, from two to four additional officers were assigned to each project for a two-week period in May 1980. During the second wave, a similar number of officers were assigned to enforcement throughout either the morning or evening commuting hours (but not both) for a period of four weeks.

The first wave of special enforcement reduced violation rates significantly on all three projects. Violation rates on both Alameda County I-580 and the San Bernardino Busway remained lower than preenforcement levels for at least eight weeks, when the summer vacation period began. On US-101 in Marin County, there were large reductions in violation rates during both the morning and evening peaks even though special enforcement activities were only scheduled during the evening commuting hours. The percentage reduction, however, was smaller in the morning, and conditions returned to normal faster.

On both I-580 and the San Bernardino Busway, the second enforcement wave reduced violation rates during both commuting periods even though special enforcement was limited to the evening peak in Alameda County and the morning peak on the San Bernardino

Figure 7. Impact of meter rate on ramp violations.



Busway. Violations returned to preenforcement levels within two to six weeks after special enforcement ceased. For the morning peak in Alameda County and the evening peak on the busway, however, these violation levels were significantly lower than those measured a year earlier at the start of the study. In Marin County, violation rates fluctuated wildly after the second enforcement wave and reached levels considerably higher than those measured before enforcement. During the morning peak period, which had received only relatively low levels of routine enforcement throughout the study, violation rates on US-101 had doubled by the close of the study. There was no significant increase during the evening peak, during which there were higher levels of routine enforcement than on any other HOV project.

The results of the study suggest that a program of selective enforcement in which a month of special enforcement is undertaken at relatively infrequent intervals can control violation rates on main-line HOV lanes as long as routine enforcement is not neglected during the intervening periods. Routine enforcement levels averaged 2 citations/peak period on I-580, 4/period on the San Bernardino Busway, and nearly 11/period during the evening peak on US-101. It is cost effective to concentrate special enforcement during any month in a single peak period as long as neither peak is neglected in the long run. Enforcement should be concentrated most often in the direction that least interferes with traffic flow.

Impact of Enforcement on Traffic Flow

When main-line lanes are congested, special enforcement activities can cause further traffic disruption as gawkers slow to observe ticketing activities. To minimize the effect of these activities on main-line flow, special enforcement officers should avoid bunching together, limit stacking so that no more than one car is waiting to be ticketed at any time (in addition to the vehicle being cited), release cited motorists into the busway rather than into the main-line lanes, and avoid pursuing violators across several lanes of traffic.

DESIGN IMPLICATIONS

Several aspects of HOV project design have a critical bearing on enforcement and violation rates. Foremost among these are the need for collaboration between design and enforcement agencies early in the planning process and the need for adequate refuge areas to support field enforcement activities. Early collaboration between design and enforcement agencies will (a) open a channel of communication and promote cooperative relations, (b) ensure that enforcement costs will be reflected in budget projections and alternatives analysis, (c) incorporate enforcement requirements in project design, and (d) provide advance warning so that field officers can be alerted to special enforcement requirements. Adequate refuge areas for apprehending and ticketing violators are essential for the safe and efficient enforcement of ramp meter bypass lanes, main-line HOV lanes, and exclusive lanes to toll plazas.

Ramp Meter Bypass Lanes

Impact of Design on Violations

Delay

Driver delays on metered ramps are a function of both queue lengths and the designed metering rate. Little correlation was found between the duration of these delays and ramp violation rates. Although violation rates under conditions of routine enforcement increased slightly with the delay in the queue, increasing to an average of 19 percent for delays of 2 min, the violation rate recorded for delays of less than 20 s was a still formidable 12 percent. Because drivers tended to overestimate the time to be saved by using the ramp bypass lanes, even the shortest delays were accompanied by significant violation rates. Short delays were not uncommon on Los Angeles and San Diego ramps: the majority of the data points recorded by roadside observers showed delays of less than 20 s.

Metering Rate

Although violation rates varied widely and unpredictably with ramp conditions, there was some evidence to suggest that drivers' perceptions of delay stemmed not so much from the queue length as from the metering rate. Given the same delay, drivers appeared to be more willing to stay in a long queue that was moving relatively fast than in a short queue that was moving slowly because of a long red phase in the meter cycle (see Figure 7).

Visibility

Geometric configurations that hid patrol officers from the view of potential violators contributed surprisingly little to the effectiveness of enforcement activities. Special enforcement actions taken from hidden positions had slightly longer residual impacts than enforcement actions taken in full view of motorists entering the ramp. From the standpoint of reduced violation rates, however, the differences between the results of ramp enforcement actions taken from visible and nonvisible positions were neither striking nor statistically significant. Visible enforcement proved to be nearly as effective as nonvisible enforcement, and many officers felt that added visibility increased the safety margin associated with roadside enforcement.

Special Striping

During the first six months of bypass lane operation, sample ramps with bold stripes painted to form a continuous diamond pattern had significantly lower violation rates than ramps with conventional striping. As time went on, however, the deterrent effect of special striping apparently diminished, and after nearly two years of operation comparison tests showed no significant difference between violation rates on routinely enforced ramps with and without special striping. The first wave of special enforcement caused violation rates to drop appreciably on ramps with and without special striping, and the presence of special striping apparently had little impact on violation rates during and after special enforcement activities.

Delineators

Candlestick delineators separating the HOV lane and general traffic lane had no measurable effect on violations, and the short life span of the delineators made their use expensive as well as ineffective.

Trapping Ramps

Certain ramp designs have the potential for trapping law-abiding drivers against their will in reserved lanes, particularly when left turns are permitted from a surface street onto a ramp where the left-hand lane is reserved for buses and carpools. Violation rates are almost universally higher on these ramps when the right-hand lane overflows onto the surface street so that left-turning vehicles are trapped in the carpool lane. Such "trapping" designs pose special problems for both drivers and enforcing officers and should be avoided if possible.

Problems are minimized on such ramps, and violation levels respond to enforcement efforts, when overflows are infrequent and relatively few automobiles make the turning movement that springs the trap. When most of the vehicles entering a ramp make the turning movement that can potentially leave them trapped in the carpool lane, however, violation rates are not likely to respond to enforcement. In such cases, carpool restrictions should be avoided and all lanes should be opened to general traffic.

Metering HOV Lanes

Violation statistics in California provide no strong support for or against metering the HOV lane itself. With pretimed meters, more drivers run the red signal when both lanes are metered (3 percent versus 1 percent of all drivers on ramps with an unmetered bypass lane) because the HOV lane no longer provides a convenient avenue around the metered signal. Meter violations are not noticeably higher when both lanes are metered with traffic-responsive meters because the meters tend to be inoperative during slack periods when meter violations would be highest. Enforcement actions are somewhat simpler and safer when both lanes are metered because occupancy violators are generally traveling slower after stopping to observe the red signal.

Impact of Violations on Freeway Performance

Less than 20 percent of the drivers using ramp bypass lanes illegally do so through maneuvering that could represent a direct safety hazard to other drivers. By using bypass lanes illegally, however, all violators represent an indirect threat to the long-term time savings, accident relief, and other benefits obtainable through metered ramp control. A sensitivity analysis undertaken on a model of a single roadway, the Santa Monica Freeway, suggested that violations are likely to have a disproportionate impact on these benefits.

The relation of ramp violations to freeway flow is heavily dependent on the characteristics of the individual roadway, the number of ramps provided with bypass lanes, and the metering strategy selected. In most cases, however, the following general design procedures should limit the adverse impacts of ramp violations on freeway flow:

1. Designers should treat the possibility of violations explicitly and assume that a violation rate of 5 percent will exist on all ramps provided with HOV bypass lanes. Metering rates should be set to accommodate this level of violations.
2. Sensitivity analyses should be undertaken to identify those critical ramps (generally those ramps just upstream from bottlenecks) on which violations are likely to have the most negative impact on freeway flow. On these ramps, designers should either provide no HOV bypass lanes or build into the metering rate a safety factor greater than the 5 percent level suggested above to offset the adverse impacts of violations.

Main-Line HOV Lanes

Hours of Operation

On US-101 in Marin County, violations tend to cluster on the fringes of the morning and evening operating hours; a high proportion occur just after restrictions come into play at 6:00 a.m., again at 4:00 p.m., and just before restrictions are removed at 9:00 a.m. and 7:00 p.m. In the case of I-580 in Alameda County, preferential lane restrictions begin officially on Monday at 6:00 a.m. and are legally in force until Friday at 6:00 p.m. However, an unusually high proportion of violations occurs between 6:00 p.m. and 7:00 p.m. every weekday, which suggests that a large number of drivers wrongly interpret the operating hours to be 6:00 a.m. to 6:00 p.m., Monday through Friday. In this case, a significant proportion of peak-period violations could be eliminated by either redesigning the signs or changing the operating hours.

On the separated right-of-way of the San Bernardino Busway, violations during the evening peak coincide with peak traffic volumes whereas violations during the morning peak are concentrated during the first hour of lane operations, when darkness and CHP shift changes combine to create a lull in enforcement activities.

The limited number of projects examined provides little insight into the question of whether all-day operation is preferable to peak-period operation for main-line HOV lanes. The opening of such lanes to all-day operations is not likely to increase either violation level or enforcement requirements appreciably and may simplify signing problems and reduce confusion during the changeover times. At the same time, it is impossible to enforce occupancy restric-

Table 3. Accident rates on main-line HOV lanes.

		Morning Peak			Evening Peak		
		Before HOV (accidents per million vehicle miles)	Increase over Before Period (%)		Before HOV (accidents per million vehicle miles)	Increase over Before Period (%)	
Lane Type	Project		First HOV Year	Subsequent Years		First HOV Year	Subsequent Years
Nonseparated	Marin County US-101	1.71	-17	-39	4.18	+122	+62
	Santa Monica Freeway	1.36	+201	-	1.76	+221	
	San Francisco-Oakland Bay Bridge Toll Plaza	4.86	+210	+56			
Buffered	Alameda County I-580	1.50	-40	-79	1.67	-11	-29
	San Bernardino Busway, eastern segment	1.72	-20	-15	1.24	+94	+36
Physically separate	San Bernardino Busway, western segment	1.15	-21	-29	2.34	-22	-39

tions after dark, and the additional hours of HOV lane operation at times when there is no time advantage to be gained from using the lane are not likely to encourage many additional carpools.

Refuge Area

Both the San Bernardino Busway and I-580 have adequate refuge areas either on the buffer strips separating the preferential lanes from general traffic or on the median. The absence of such areas on US-101 highlights the need for suitable refuge areas.

On US-101, the lack of buffers separating the carpool lane from general traffic, coupled with the narrowness of the lanes and the absence of a median, made it necessary for officers to escort violators across heavy traffic to issue citations on the shoulder of the roadway. Because patrol cars had particular difficulty making the maneuvers needed to pursue and apprehend violators under these circumstances, motorcycle patrols had to be used for special enforcement. In this case, then, certain project design features made enforcement difficult and required the use of special officers. Surveys showed, moreover, that the need to issue tickets on the shoulder of the roadway at a location well removed from the preferential lane left many drivers unaware that the lane restrictions were actually being enforced.

Lane Separation

By the close of the study, it appeared that the degree of separation between general traffic lanes and the preferential lanes had a measurable impact on violation rates. Lane violation rates were lowest (3-4 percent) on the lightly enforced western section of the San Bernardino Busway, where a physical barrier made lane switching impossible, and considerably higher (27 percent) on heavily enforced Marin County US-101, where there was no separation whatever between preferential and general lanes. Violation rates were also low (7 percent) on the buffer-separated portion of the San Bernardino Busway. Violation rates were highest (36 percent) on the lightly enforced buffer-separated lanes of the controversial I-580 project in Alameda County.

SAFETY IMPLICATIONS

Metered Ramps and Bypass Lanes

For a sample of freeways under ramp control, accident rates on the freeways alone dropped 10.4 percent, from 1.15 to 1.03 accidents/million vehicle miles, after the introduction of ramp metering. At the same time, accident rates on the ramps increased significantly, nearly tripling during the first year of meter control. Whereas accident rates dropped in subsequent years on ramps without bypass lanes, accidents on bypass ramps showed no sign of decline. Accident rates appeared to be highest and most persistent on ramps with high violation rates.

Even with the increases associated with metering and bypass lanes, the annual incidence of ramp accidents was relatively infrequent, averaging one peak-period accident every three years on a ramp with a bypass and one peak-period accident every four years on a metered ramp without a bypass. This increase was not sufficient to offset the decline in freeway accidents associated with ramp control. Total system accidents after ramp metering amounted to 1.28 accidents/million vehicle miles, a decline of 4.5 percent below premetering accident rates. (Accidents were measured during the peak periods of traffic flow and meter operations.)

Main-Line HOV Lanes

Table 3 summarizes accident statistics for several main-line HOV projects in California. Accident levels increased dramatically during the first year of operations on those three projects--US-101 in Marin County, the Santa Monica diamond lanes, and the San Francisco-Oakland Bay Bridge Toll Plaza--where there was no separation between the HOV lane and general traffic lanes. Although accident rates subsequently declined on US-101 and the Bay Bridge, these rates remained significantly higher than preproject levels five years after project implementation.

On the two projects where the HOV lane was separated from general traffic either by a buffer lane or a physical barrier--Alameda County I-580 and the San Bernardino Busway--there was no upward surge in accident rates during the first year of project implementation. In fact, accident rates have declined steadily on all sections of the San Bernardino Freeway since the implementation of the busway. No trends are discernible on I-580, where the relatively low accident levels fluctuate from year to year.

The increases in accident rates that accompanied barrier-free preferential lanes raise serious questions regarding the suitability of this design in certain settings. These questions appear to exist whether the lanes are created by reserving an existing lane, as was done on the Santa Monica Freeway, or by creating an entirely new lane, as was done in Marin County. Short segments of barrier-free HOV lane operation--as on toll plazas, ramps, and freeway-to-freeway connectors--are not likely to generate accident increases great enough to offset the benefits of the carpool lane itself. Long stretches of barrier-free main-line HOV lanes operating next to stop-and-go traffic, however, can easily cause unacceptable increases in accident rates.

DRIVER ATTITUDES

Survey Results

Surveys mailed to a sample of single drivers, carpoolers, and carpool lane violators on 13 sample projects before and after special enforcement activities led to the following conclusions regarding driver attitudes.

General Attitudes

Although the differences between violators, carpoolers, and general users on a particular project are few and generally predictable, there are major differences in the attitudes and perceptions of users of individual projects. This was especially true on the main-line HOV lanes. All classes of drivers on the controversial I-580 project in Alameda County viewed the preferential lanes unfavorably. Drivers using US-101 in Marin County, the San Francisco-Oakland Bay Bridge, and the San Bernardino Busway were generally more tolerant of HOV projects: relatively few drivers on these three projects opposed the idea of more freeway lanes for carpools. Among the users of ramp bypass lanes, San Diego drivers viewed the idea of dedicated freeway lanes more favorably than Los Angeles drivers.

Perceptions of Enforcement

Drivers are significantly more aware of in-place, in-view enforcement than of enforcement that requires pursuit and ticketing on freeway shoulders. This distinction was particularly evident before special enforcement activities were initiated.

On the San Bernardino Busway, where violators are usually apprehended and ticketed in the buffer lane in full view of passing motorists, only 13 percent of all respondents said they had never seen the CHP ticketing violators. On Marin County US-101, however, where the CHP must escort violators to the side of the freeway before issuing tickets, 22 percent of all respondents reported that they had never seen an occupancy citation issued. On one San Diego ramp that had an ample refuge area where CHP officers could stand and wave over violators in full view of other drivers, 25 percent of all respondents reported that they had never seen a citation issued for illegal use of the carpool lane. On a nearby ramp with a scanty refuge area that forces officers to pursue violators and issue tickets some distance from the ramp, the corresponding percentage was 70 percent.

Although special enforcement activities significantly improved driver awareness of enforcement on the surveyed projects, a surprisingly high percentage of drivers using the ramps with bypass lanes remained oblivious to the presence of enforcement. After three waves of special enforcement, between 15 and 45 percent of the drivers on the sample ramps reported that they had never seen a driver ticketed for using the bypass lanes illegally. More than two-thirds of all drivers surveyed felt that enforcement levels "stayed about the same" during the year of special enforcement.

Drivers themselves perceive a need for more enforcement. Only about 10 percent of the drivers interviewed before the first wave of enforcement believed that current enforcement levels were sufficient. This was uniformly true on all projects surveyed except Alameda County I-580, where 33 percent of the respondents believed that there was no need for the CHP to enforce more often.

Perceptions of Ramp Metering

Ramp users have mixed feelings regarding the benefits of ramp metering. Although more than two-thirds of all drivers believed that metering had improved flow, less than 21 percent believed that it had shortened their individual trip times.

Perceptions of Violations

Drivers tended to overestimate low violation rates and underestimate high violation rates. Although drivers appeared to be sensitive to major improvements in the violation picture, they were not likely to detect changes in the range below a 25 percent lane violation rate (or a 6.5 percent ramp violation rate).

Most drivers feel that HOV lane violations are a minor problem. Drivers on the San Bernardino Busway and the Guadalupe Expressway felt that violations represented a more serious problem than did drivers on other projects, whereas drivers on I-580 in Alameda County were less concerned than other drivers about the presence of violators. Forty-three percent of the I-580 respondents thought that violators were no problem whatsoever, which presumably reflects the adverse media publicity and public hostility directed toward that project.

Perceived Time Savings

Violators, carpoolers, and general drivers alike greatly overestimate the average time savings afforded by HOV lanes (see Figure 8). This tendency to perceive greater time savings in the carpool lane undoubtedly makes the carpool lanes appear more attractive to drivers than to statisticians comparing raw numbers, and indicates that there may be a psychological advantage in providing a carpool lane even when the available time savings appear minimal. The illusion of greater time savings also helps to explain the relatively high violation rates observed on ramps in the face of negligible delays.

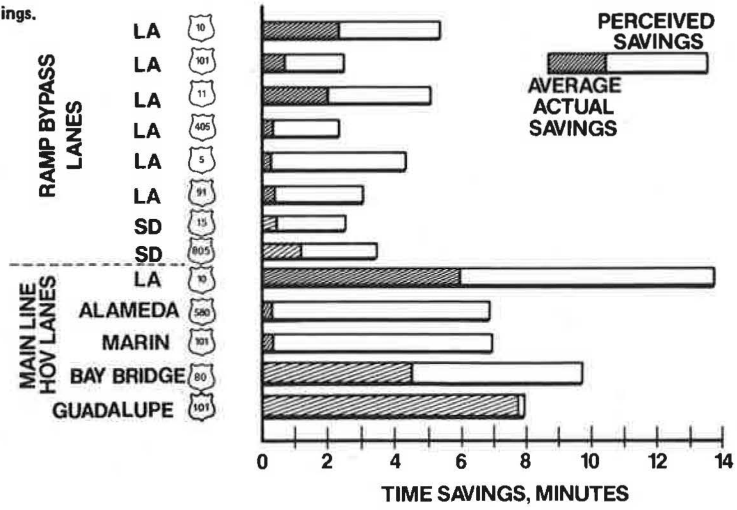
Driving Records

HOV lane violators are likely to have poorer overall driving records than nonviolators. An examination of driver records on main-line freeway lanes, bridges, and other HOV projects that serve drivers from a wide range of geographic areas showed that HOV lane violators on these projects had significantly worse driving records than nonviolators. On ramp bypass lanes that serve narrowly circumscribed geographic areas, however, few differences were found between the driving records of violators and nonviolators using a particular ramp. Nonetheless, comparisons among different ramps showed a strong correlation between the records of all drivers using the ramp and the ramp violation rate: The worse the driving record, the higher was the ramp violation rate.

Repeat Violations

The relatively low incidence of repeat violations over short periods suggests that HOV lane violation rates tend to reflect the actions of a large number of drivers transgressing at infrequent intervals rather than the day-to-day actions of a small group of repeaters. There was, however, a small group of

Figure 8. Actual and perceived HOV lane time savings.



persistent repeaters on certain projects who managed to remain undaunted by the first year of special enforcement.

PUBLIC INFORMATION

Media Coverage

Media coverage of California's HOV projects has tended to be sporadic and generally negative. Negative coverage has peaked during election years and has tended to focus on individual projects rather than on the concept of preferential lanes. In Los Angeles, the Santa Monica Freeway diamond lanes were mauled by the media whereas the San Bernardino Busway, further east on the same Interstate route, has generally been treated fairly and favorably. In the San Francisco Bay Area, Alameda County I-580 is the focus of predominantly negative press coverage and hostile public opinion whereas Marin County US-101 goes virtually unnoticed and the Bay Bridge toll plaza receives moderately favorable coverage.

Although it is impossible to quantify the impact of media coverage and public attitudes on violation rates, it is worth noting that the two California HOV projects that have received the most favorable press notices--the San Bernardino Busway and the San Francisco-Oakland Bay Bridge--have the lowest lane violation rates of all the projects included in this study. On the other hand, if media popularity were the sole criterion governing HOV lane compliance, the Santa Monica diamond lanes would have been packed bumper-to-bumper with violators. As it was, lane violation rates on this manifestly unpopular project fluctuated between 10 and 20 percent, well below the levels recorded on ramp bypass lanes, US-101, and I-580.

Education Campaigns

Education campaigns aimed at instructing the public regarding HOV lanes make use of many channels, including news releases, media campaigns, ramp and freeway handouts, driver education courses, public speeches, mailed brochures, freeway signs, and the driver's handbook published by the Department of Motor Vehicles. These campaigns tend to be concentrated at the beginning of a project to announce the opening date, explain the purpose of the project, and outline proper use of the new facility.

As with media coverage, it is difficult to gauge the impact of education campaigns on violations. An informal poll of violators taken by CHP officers revealed that relatively few apprehended violators (15 percent of those surveyed) pleaded ignorance of the law, which suggests that existing education programs have at least made noncarpoolers aware of the illegality of using the lanes. A previous study by Caltrans concluded that freeway handouts had little impact on violation rates.

As part of the current study, it was determined that a two-month radio and television campaign using public service announcements had no impact on ramp violation rates in the San Diego area. Although effective public information programs are essential at the time a project is introduced and may increase public acceptance during the life of the project, there is no evidence to date that they are able to affect violation rates.

PROPOSED ENFORCEMENT PROGRAM

A consideration of the effects of different enforcement options and design features on HOV project violation rates and the resulting effect of violations on freeway performance, safety, and public attitudes led to the development of a proposed enforcement program for HOV projects on California freeways. The proposed program was designed to keep both the costs of enforcement and the resulting violation rates within reasonable bounds.

Ramp Meter Bypass Lanes

Criteria for Tolerable Violation Rates

The task of keeping violation rates within reasonable bounds implies an ability to determine a tolerable or acceptable violation rate. Criteria for establishing tolerable ramp violation rates would include safety, freeway operations, public attitudes, legal integrity, and practicality. This study has provided insights into the impact of violations on several of these important criteria.

Safety

Less than 20 percent of the drivers who use ramp bypass lanes illegally do so through maneuvering that presents a direct safety hazard to other drivers. However, there is some statistical evidence that accident levels are significantly higher on ramps with high violation rates. Furthermore, increased violations reduce the effectiveness of the ramp metering system and tend to nullify the freeway accident reductions that result from entry control (discussed further in the following paragraph).

Figure 9. Ramp enforcement program.

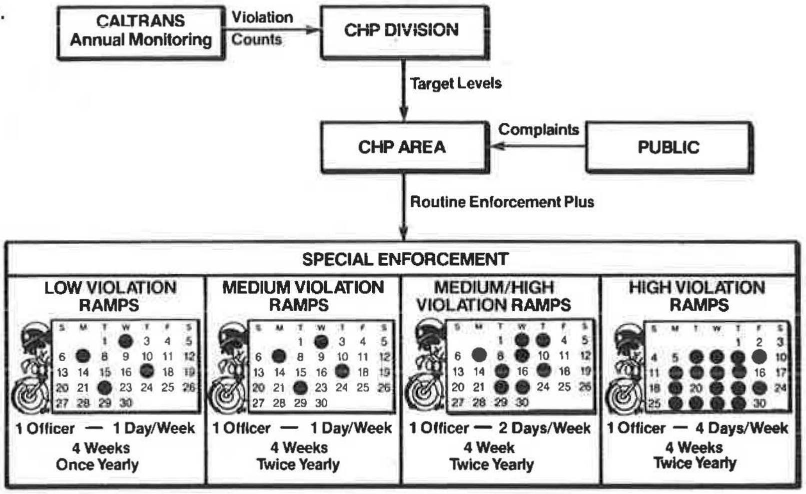


Figure 10. Average benefits and costs per ramp for metered-ramp/bypass-lane configuration.

INITIAL INVESTMENT
$27,000 (ramp meter)
4,000 (bypass lane)

TOTAL INVESTMENT:
$31,000

ANNUAL COSTS
$1,500 (operations)
3,000 (maintenance)
235 (power)
481 (increased ramp accidents)
$336 to $2,684 (traffic disruption resulting from enforcement)
$838 to $8,549 (out-of-pocket enforcement costs)

AVERAGE ANNUAL BENEFITS
$9,255 (improved freeway travel times)
815 (reduced freeway accidents)
717 (priority entry time savings)
$1,577n (savings per new carpool formed)

TOTAL COSTS:

Violation Rate	(Overtime)		(New Personnel)
High	$ 6,054	to	$ 6,281
Medium	7,495	to	8,177
Low	10,535	to	11,858

TOTAL BENEFITS:
$10,787 + $1,577n
(where n = number of new carpools formed)

Freeway Operations

By using bypass lanes illegally, all violators threaten the time savings, accident reductions, and other benefits obtainable through metered ramp control. For any particular freeway, the impact of violations on freeway flow will depend on roadway characteristics, the number of ramps provided with bypass lanes, and the metering strategy selected. A sensitivity analysis of a single freeway, however, suggests that ramp violations can have a disproportionate impact on freeway flow. Violation rates of 20 percent on the sample freeway brought about a 34 percent reduction in passenger time savings. Violation rates of less than 10 percent had a less pronounced impact.

Public Attitudes

The majority of the public regards ramp violations as a minor problem and tends to overestimate low violation rates and underestimate high violation rates. Drivers are not likely to be sensitive to changes in ramp violation rates below the 6.5 percent range. Law enforcement agencies should be alert to public complaints about violation rates, however, and respond with special enforcement when such complaints are aired.

Practicality

It is virtually impossible to get ramp violation rates significantly below 5 percent, even with relatively heavy levels of enforcement. These violation rates should definitely be tolerated; in fact, metering strategies should be designed to accommodate a 5 percent violation rate.

Program Description

In the light of these conditions, a proposed enforcement program was designed to meet the following objectives:

1. Reduce violations dramatically on ramps with violation rates greater than 12 percent (particularly on ramps with violation rates in excess of 20 percent),
2. Control violation rates and achieve further reductions on ramps with violation rates between 6.5 and 12 percent, and
3. Maintain violation levels on ramps with low violation rates (less than 6.5 percent) through a program of routine enforcement and a minimum amount of special enforcement.

An overview of the proposed ramp enforcement program is shown in Figure 9. The proposed program combines the annual monitoring of violations with scheduled applications of special enforcement interspersed with long stretches of routine enforcement:

1. Ramps with medium and high violation rates require twice-yearly applications of four-week periods of special enforcement.
2. Ramps with low violation rates (6.5 percent or less) will receive relatively low levels of special enforcement once a year.
3. Newly opened bypass lanes will receive four weeks of special enforcement at the levels recommended for ramps with medium and high violation rates during the first month of operation.

The proposed program will require the following commitments of officer time:

Level of Violation Rate	Enforcement (h/year)		
	Routine	Special	Total
Low	6	16	22
Medium	7	48	55
High	48	96	144

The enforcement levels recommended on ramps with medium and high violation rates are analogous to those that proved effective in reducing violation rates on comparable ramps during this study. As the proposed enforcement program progresses, it is anticipated that more and more ramps will be shifted into the low category, where they will require minimum attention.

Costs

The costs of the proposed program amount to an average of $1365/ramp if current officers receive overtime pay for special enforcement and $2000/ramp if new personnel are hired specifically for the program.

Operational Benefits and Costs

The out-of-pocket costs of the proposed enforcement program are roughly commensurate with the societal costs incurred in delays and increased freeway accidents if violations are not controlled. Figure 10 shows an overview of the average costs and benefits associated with a single metered-ramp/bypass-lane combination. (The costs and benefits shown in Figure 10 reflect average values that assume that all ramps have an equal impact on freeway flow. This is not the case, and it is possible that a low level of violations on a few critically positioned ramps could negate most of the positive benefits of ramp metering.)

Even if a bypass lane generates no additional carpools, the average annual benefits from installing a ramp meter and bypass lane comfortably exceed the average annual costs of ramp operations and enforcement on all but high-violation ramps. Although the effectiveness of ramp bypass lanes in encouraging the formation of new carpools is not well understood, even a modest degree of success in this area will generate enough benefits to offset both the cost of enforcement and the initial investment in the average bypass lane.

Main-Line HOV Lanes

Criteria for Tolerable Violation Rates

As in the case of ramp meter bypass lanes, questions of safety, freeway operations, and public attitudes have been explored in attempting to define a tolerable violation rate for main-line HOV lanes.

Safety

Although it is impossible to correlate accident rates with violation rates on any of the main-line projects, the practice of illegally weaving in and out of a main-line lane creates a direct safety hazard. Unsafe weaving has been and should continue to be the primary focus of officers assigned to HOV lane enforcement.

Freeway Operations

The practical capacity of a main-line HOV lane is estimated to be 1400 vehicles/h. Except for a 1-h period during the morning peak on the San Bernardino Busway, existing violation rates could increase substantially on all California main-line projects without substantially affecting flow in the carpool lane.

Violators do not improve general traffic conditions appreciably by leaving the main-line flow to enter the HOV lane. During congested periods, latent demand easily replaces the small number of violators drawn off into the carpool lanes. At less congested times, the potential for improvement is minimal.

Public Attitudes

Even on I-580, where public sentiment runs heavily against the HOV lane, most freeway users still think that the use of the HOV lane by violators is at least a minor problem. Drivers tend to overestimate violation rates on most main-line projects.

On the San Bernardino Busway, the tolerable lane violation rate is strictly defined by operational considerations to be 16 percent or less during the morning peak period. At other times, the violation rate could be greater from an operational standpoint. Realistically, a tolerable violation rate should be set at 10 percent or less at all times to keep violations from increasing beyond their present level and prevent the pool of violators from increasing to a point where morning-peak violation rates could hamper busway operations. For the other projects, the suggested acceptable violation rate is the current normal level. Thus, the main goal of the proposed program is to keep violations from increasing to a point where complaints from the public become common and mass disobedience to the law becomes apparent.

Program Description

The proposed program of enforcement for California's main-line HOV lanes is summarized in Table 4. This program is aimed at maintaining main-line HOV violations at current levels or lower and represents little change from existing levels on the San Bernardino Busway and the San Francisco-Oakland Bay Bridge. On Alameda County I-580 a small increase in special enforcement is suggested, whereas less enforcement could probably be used on Marin County US-101 without incurring adverse effects.

ACKNOWLEDGMENT

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Table 4. Proposed enforcement program: main-line HOV lanes and San Francisco-Oakland Bay Bridge.

	Person Hours per Year			
Route	Special Enforcement	Routine Enforcement	Total	Total Cost ($)
Marin County US-101	4800	^{a}	4800	111 600 (overtime) to 180 000 (new personnel)
Alameda County I-580	64	384	448	10 070
San Bernardino Busway	448	1920	2368	53 328
San Francisco-Oakland Bay Bridge	256	120	376	8628

[a] Negligible.

A steering committee composed of representatives from the CHP, Caltrans, the Office of Traffic Safety, and the public at large was responsible for overall project guidance and for approving the products of major project tasks. In addition to J.E. Smith, other members of the steering committee were William Oliver of the CHP Sacramento Office, David Roper of Caltrans District 07, William Schaeffer of the Caltrans Sacramento Office, Thornton Piersall of the League of California Cities, David Grayson of the Automobile Club of Southern California, and G. Van Oldenbeek of the Office of Traffic Safety. Valuable contributions were also made by Jesse Glazer of Crain and Associates and Adolf D. May of the Institute of Transportation Studies, University of California.

REFERENCES

1. J.W. Billheimer and G. Fondahl. Study Design for TSM Project Violation Rates. SYSTAN, Inc., Los Altos, CA, June 1979.
2. J.W. Billheimer, J. McNally, and R. Trexler. TSM Project Violation Rates: Interim Report I. SYSTAN, Inc., Los Altos, CA, Oct. 1980.
3. J.W. Billheimer and J. McNally. TSM Project Violation Rates: Interim Report II. SYSTAN, Inc., Los Altos, CA, May 1981.
4. J.W. Billheimer. Enforcement of TSM Projects. TRB, Transportation Research Record 816, 1981, pp. 58-65.
5. J.W. Billheimer, J. McNally, and R. Trexler. TSM Project Violation Rates: Final Report. SYSTAN, Inc., Los Altos, CA, Oct. 1981.

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Evaluation of Boise Selective Traffic Enforcement Project

GREGORY J. SALI

Boise, Idaho, implemented a Selective Traffic Enforcement Program (STEP) in October 1979. Before that time, the city typically had one of the worst accident rates in the state. The objective of the program was to reduce the number of injury accidents occurring in Boise. The program included both enforcement and a media information campaign to deter accidents. An impact evaluation was performed to determine what reductions had occurred during the first 22 months of implementation. A multivariate time series design was used, and a comparison group was selected. The Box-Jenkins technique was used. The analysis identified a statistically significant reduction of 14 injury accidents/month for Boise. This represents a 17 percent reduction from the base period. No significant reduction occurred in the comparison group. An estimated $1 600 000 in accident costs was avoided, and the total program cost was $788 000. Both traditional enforcement and media influence were determined to be essential elements of this successful program. Improved coordination and communication with other local agencies are also believed to have contributed significantly to the program.

The results of an impact evaluation of the first 22 months of a Selective Traffic Enforcement Project (STEP) implemented in Boise, Idaho, on October 1, 1979, are presented in this paper. The project was partially supported by federal highway safety funds under Section 402 of the Surface Transportation Assistance Act of 1966. The project evaluation was undertaken by the Idaho Office of Highway Safety. The methodology used in the study was selected to provide answers to the following questions:

1. Has there been a measurable reduction in injury accidents that can be correlated with implementation of STEP in Boise?
2. If such a reduction did occur, can it be reasonably attributed to STEP?
3. What were the relative cost savings to Boise citizens?

REVIEW OF LITERATURE

Identifying effective elements of STEP has been a matter of national concern since passage of the Highway Safety Act of 1966. That Act provided federal funds for implementation of improved police traffic-enforcement routines that would be effective in reducing the number of traffic accidents. This review addresses several evaluations that deal with the traditional enforcement model of compliance (i.e., strict sanctions induce high compliance) and the contextual model of compliance (i.e., compliance is influenced by the attitudes of peers and by social norms).

The traditional enforcement model was explored by Hauer and others (1) in a study that examined speed reductions induced by conspicuous enforcement (a clearly visible, stationary police cruiser). The study involved four experimental locations, each paired with a corresponding control site. Two different levels of conspicuity and durations of enforcement were tested. The authors concluded that conspicuous enforcement resulted in marked reductions in average speed at and near the site of enforcement. In fact, this improved compliance yielded an average speed that was close to the posted speed. The study by Hauer and others also provided a valuable discussion of both distance and time halo effects. Although the study admirably addressed compliance responses to enforcement, it did not address the link between improvements in compliance and changes in accident experience.

The relation between traditional enforcement and accident experience was discussed by Hauer and Cooper (2). Using four years of computerized accident records, they estimated expected accident rates for 1800 locations. The estimates accounted for trends and seasonal variations. In addition, a high-accident-location (HAL) list was issued every 28 days giving the 20 street sections that had the largest number of accidents during the prior observation period. The officers were asked to devote special enforcement attention to those sections. As a result, during each observation period some sections received higher-than-normal enforcement. It is not clear from the report whether or not the officers were advised of the driver actions that were contributing most heavily to accidents. For the sections that appeared on the HAL list, accident experience after increased enforcement was compared with expected accident experience. Hauer and Cooper reported that after a section appeared on the HAL list there was a statistically significant reduction in the number of accidents and concluded that the reductions were related to increases in enforcement.

The contextual model of compliance was discussed by Kohfeld and Likens (3), who attempted to contrast the relative impacts of traditional enforcement and contextual efforts on compliance. The compliance data studied were quarterly 55-mph compliance data for Missouri. Enforcement data were the quarterly speed citations reported by the State Highway Patrol. The media (contextual) measure was collected from the State Library clipping service and an independent search of major St. Louis and Kansas City newspapers. The statistical method used was regression analysis. Based on these analyses, the authors reached the following conclusions:

1. The traditional model of enforcement and compliance is weak. In fact, ticketing (enforcement) follows noncompliance instead of compliance following enforcement.
2. The contextual model of media influence and compliance is strong. In other words, what matters most in securing compliance is widespread public attention to proscribed behavior.

They further suggested that public attention should be assigned a central role in any theory of compliance.

The authors assumed that driver perception of certainty of enforcement was directly proportional to the number of speed arrests. This is an unfounded assumption because the number of tickets does not necessarily represent the level of enforcement. This assumption could likely have resulted in the authors' conclusion that speed arrests follow noncompliance instead of compliance following speed arrests. A better measure for enforcement would have been hours of patrol. Such a measure is probably available and might substantially alter the authors' conclusions. Despite the deficiency in the enforcement model, the authors' conclusions on the contextual model seem entirely valid.

Bensen (4) reported the results of a countermeasure that included both traditional enforcement and contextual influences. His study involved a before-and-after analysis of two North Dakota counties. No comparison group was cited. The enforcement project also included extensive coordination with other public agencies such as the prosecutors and the courts. A correlation study revealed an inverse relation between levels (hours) of enforcement and numbers of accidents. Bensen stressed the importance of quality rather than quantity of enforcement (tickets). He concluded that a well-planned public information program coupled with a highly conspicuous enforcement effort (well-marked police vehicles) will improve compliance and reduce accidents.

There is considerable support for the contention that both traditional enforcement and contextual efforts are important contributors to an effective highway safety program. Improved interagency coordination and communication also appear to aid such a program.

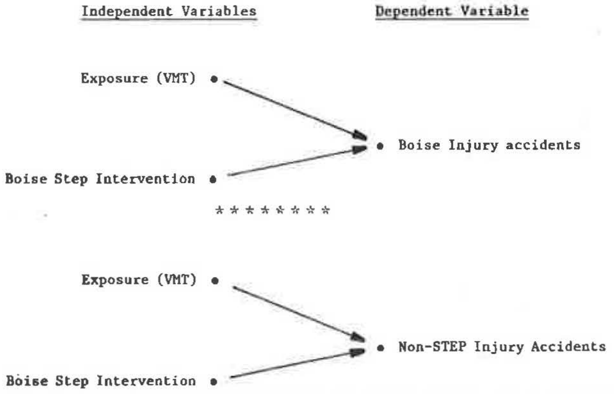
BACKGROUND AND PROJECT DESCRIPTION

Boise is a rapidly growing community of about 100 000 people (5). It is the state capital and is by far Idaho's largest city. Before the implementation of STEP, Boise routinely ranked either first or second in the state for injury accidents per thousand people. This problem was compounded by the low manpower level of the Boise Police Department (BPD). Boise had about 1.3 officers per thousand people, much lower than the national average of 2.3 officers per thousand people for cities of comparable size (6). Furthermore, because the BPD had not assigned specific responsibility for traffic enforcement to any division or section, traffic enforcement was relegated to random responses to traffic accident problem areas. There was no accident records system that would allow the BPD to identify times or areas with high accident rates or typical accident causation factors. These limitations combined to inhibit the city's ability to respond effectively to its traffic accident problems.

To address these problems, Boise implemented a STEP project. Eight officers were hired in addition to the 4 officers already on staff to form a 12-man STEP unit, which was supervised by 3 sergeants. The supervisors divided the unit into 4 teams, which were assigned to specific geographic areas. This induced a "beat pride" and encouraged the individual officers to become familiar with the particular problems of their areas of responsibility. It also produced a competitiveness among the officers to see whose area would have the most improvement. An accident and enforcement records system was established to aid in problem identification. Additional enforcement was focused on problem locations at the times when accidents typically occurred, and officers gave special attention to the types of driver violations that were resulting in accidents.

The Boise STEP project also included a strong public information and education component. The public was advised of hazardous locations, the types of unsafe driver actions that were observed there, and the type of enforcement activity that would be used to discourage such actions. Media coverage was extensive. Radio gave the most complete coverage: three local radio stations carried STEP advisory messages twice daily. Presentations were made for local driver education classes to reach newly licensed drivers and for local civic action groups to reach the older drivers. The public information and education efforts successfully portrayed the BPD as being genuinely interested in safety instead of just writing tickets.

Figure 1. Design of evaluation procedure for Boise STEP.



Effective liaison was also established with the Fourth District Magistrate Court, the Ada County Highway District, and the Boise School District. These improved lines of communication proved very beneficial. The Magistrate Court streamlined its citation-handling procedure, which was critically important because STEP resulted in a twofold increase in citations for hazardous moving violations. The BPD pointed out several locations where engineering deficiencies contributed heavily to accidents. Prompt attention to these areas by the Ada County Highway District often significantly reduced the workload of the BPD. As mentioned earlier, BPD contributions to driver-education classes concentrated attention on unsafe driver actions.

Intermediate-level evaluation data are not complete because the BPD did not have a citation record system before implementation of STEP. The BPD estimated the number of citations for hazardous moving violations for calendar year 1978 at 10 157. The estimate was based on radio clearance codes. The number of citations for hazardous moving violations issued in calendar year 1980, the first full year of implementation, was 23 641; 1981 yielded 20 677 citations. This indicates about a 100 percent increase in enforcement activity; however, this might be questioned because it is based on an estimated activity level for 1978.

Another indicator of increase in enforcement activity is the annual number of arrests issued by the BPD for driving under the influence (DUI), as reported in the Idaho Uniform Crime Report for the years 1975-1980 (7). A corresponding value was reported by the BPD for 1981. The problem of driving and alcohol was identified as one of Boise's most significant problem areas and is probably a good indicator of overall enforcement activity both before and after STEP was implemented.

The table below gives the number of DUI arrests for 1975-1981:

Year	No. of DUI Arrests	Year	No. of DUI Arrests
1975	415	1979	769
1976	404	1980	1468
1977	515	1981	1824
1978	501		

It is significant that 415 of the 769 DUI arrests made in 1979 were made in the three-month period after the implementation of STEP. This implies nearly a 200 percent monthly increase in DUI enforcement activity after implementation of STEP in Boise. Both DUI arrests and citations for hazardous moving violations indicate a sharp rise in the BPD's overall enforcement activity coincident with STEP implementation.

METHODOLOGY

Data

All accident data used in this study were retrieved from the Idaho Transportation Department (ITD) accident data base. This is the official state accident data base, and all Idaho jurisdictions contribute to it. Injury accident data were used because a change in the reporting level for property-damage accidents occurred during the study period, which made the data on total accidents less reliable.

Exposure data in terms of statewide vehicle miles of travel (VMT) were also collected from ITD. The actual values were derived from fuel consumption and yearly average fuel economy figures.

Monthly data were collected for each variable. The study period was from January 1974 through July 1981. This provides a 22-month intervention period and a 69-month base period. A lengthy base period was selected for the analysis because of the relatively low monthly values for Boise injury accidents.

Design

The evaluation uses a quasiexperimentally interrupted time series design. A comparison group was used to help predict what might have happened in Boise without the implementation of STEP. Selection of a comparison location was difficult because Boise is unique in Idaho due to its population and urban makeup. Comparable cities in other states are no better because virtually all northwest regional cities of this size have experienced some effects of highway safety programs during the study period. The comparison group finally selected was all of Idaho except those jurisdictions that had an impact-type highway safety project during the study period. This group is referred to as non-STEP. Admittedly, this group is not an ideal comparison group because of differences in population, urban-rural makeup, and exposure, but it is still believed to be the best available indicator for what might have happened in Boise without STEP.

Analysis of Boise and non-STEP data pointed out a need to relate injury accidents to some risk or exposure variable. Monthly statewide VMT was selected as the best available measure of exposure.

The evaluation designs for Boise and the comparison group can be modeled as shown in Figure 1.

Analysis Technique

The Box-Jenkins time series approach (8) was used to estimate transfer function and time series parameters. This technique accounts for the dependent-series seasonal and trend characteristics and thereby provides accurate estimates of the relations of dependent series to independent series. To quantify the impact of the STEP period on Boise and non-STEP injury accidents, this research considers zero-order transfer functions in multivariate models. The general form of the model is

$$Y_t = v(B)X_t + W_o I_t + N_t \tag{1}$$

where

Y_t = monthly injury accidents at time period t;
$v(B)$ = function that relates the independent variable X_t to the dependent variable Y_t;
X_t = monthly exposure (VMT);
W_o = impact of Boise STEP--i.e., average monthly change in Y_t;

I_t = dummy variable for presence of Boise STEP (when $t \leq 69$, $I = 0$; otherwise, $I_t = 1$); and

N_t = noise, stochastic background variation.

The t-test is used to determine parameter significance. Parameters are accepted at the 95 percent confidence level.

RESULTS

Findings

Exposure Series

Figure 2 shows the exposure series used in these analyses. The intervention point is referenced in the figure. Note the large jump in exposure in 1978 and then a return to pre-1978 levels. This trend also appears in Boise and non-STEP data.

Monthly values for Idaho VMT for the period January 1974 through July 1981 are given in Table 1. The data were derived from annual VMT, average annual fuel economy, and monthly fuel consumption. The univariate time series model for the data is:

$$(1 - B)(1 - B^{12})Z_t = (1 - \overset{(0.08)}{0.59}B)(1 - \overset{(0.05)}{0.8}B^{12})a_t \qquad (2)$$

where

Z_t = monthly VMT,

B = back-shift operator, and

a_t = noise.

Strong seasonality is obvious. No deficiencies were discovered in residual analysis.

Boise Series

The Boise series is shown in Figure 3. Again, the

Figure 2. Exposure series (VMT).

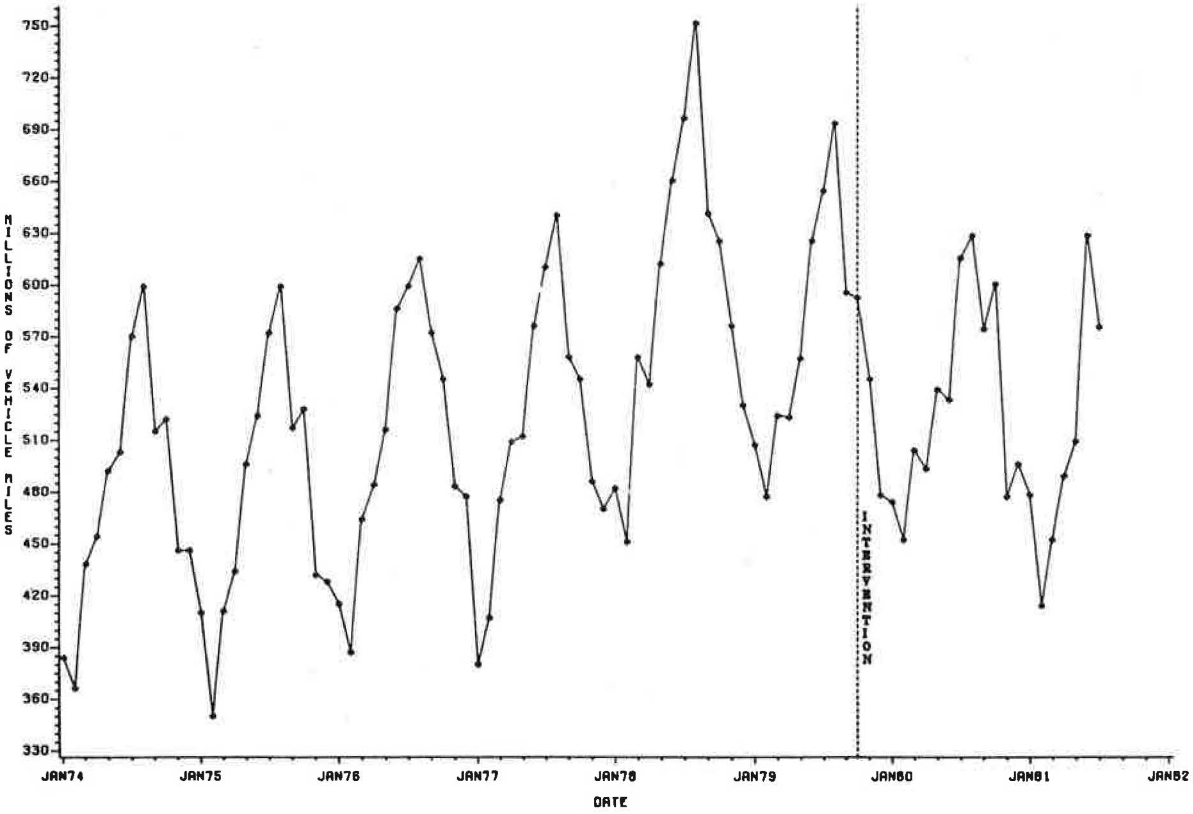


Table 1. Exposure data.

	VMT							
Month	1974	1975	1976	1977	1978	1979	1980	1981
January	384	410	415	380	482	507	474	478
February	366	350	387	407	451	477	452	414
March	438	411	464	475	558	524	504	452
April	454	434	484	509	542	523	493	489
May	492	496	516	512	612	557	539	509
June	503	524	586	576	660	625	533	628
July	570	572	599	610	696	654	615	575
August	599	599	615	640	751	693	628	
September	515	517	572	558	641	595	574	
October	522	528	545	545	625	592	600	
November	446	432	483	486	576	545	477	
December	446	428	477	479	530	478	496	

intervention point is referenced. As in the exposure data, there is a large jump in 1978 and then a return to pre-1978 levels. Note, however, the obvious shift in level after the intervention, which is clearly below any prior study level.

Table 2 gives the monthly values for injury accidents in Boise for the period January 1974 through July 1981. The univariate time series model for the data is

$$(1-B)(1-B^{12})Z_t = (1-\overset{(0.07)}{0.74}B)(1-\overset{(0.04)}{0.87}B^{12})a_t \qquad (3)$$

where

Z_t = monthly Boise injury accidents,
B = back-shift operator, and
a_t = noise.

The model indicates a highly seasonal series. No deficiencies were discovered in residual analysis.

The final multivariate model of the Boise series is

$$Y_t = \overset{(0.024)}{0.117}X_t - \overset{(-2.7)}{14.06}I_{t-3} + [(1-\overset{(0.09)}{0.66}B^{12})/(1-B^{12})]a_t \qquad (4)$$

where

Y_t = Boise injury accidents for time period t,
X_t = exposure (VMT) for time period t,
I_t = presence of intervention in time period t,
B = back-shift operator, and
a_t = noise component of Y_t after explained variance is removed.

Note that the term N_t of the general model is equivalent to the expression $[(1-0.66B^{12})/(1-B^{12})]a_t$.

The standard error of each parameter estimate is indicated in parentheses above the estimate. A delay of three months was identified for the impact of STEP, as indicated by the term I_{t-3}. All parame-

Figure 3. Boise series (injury accidents).

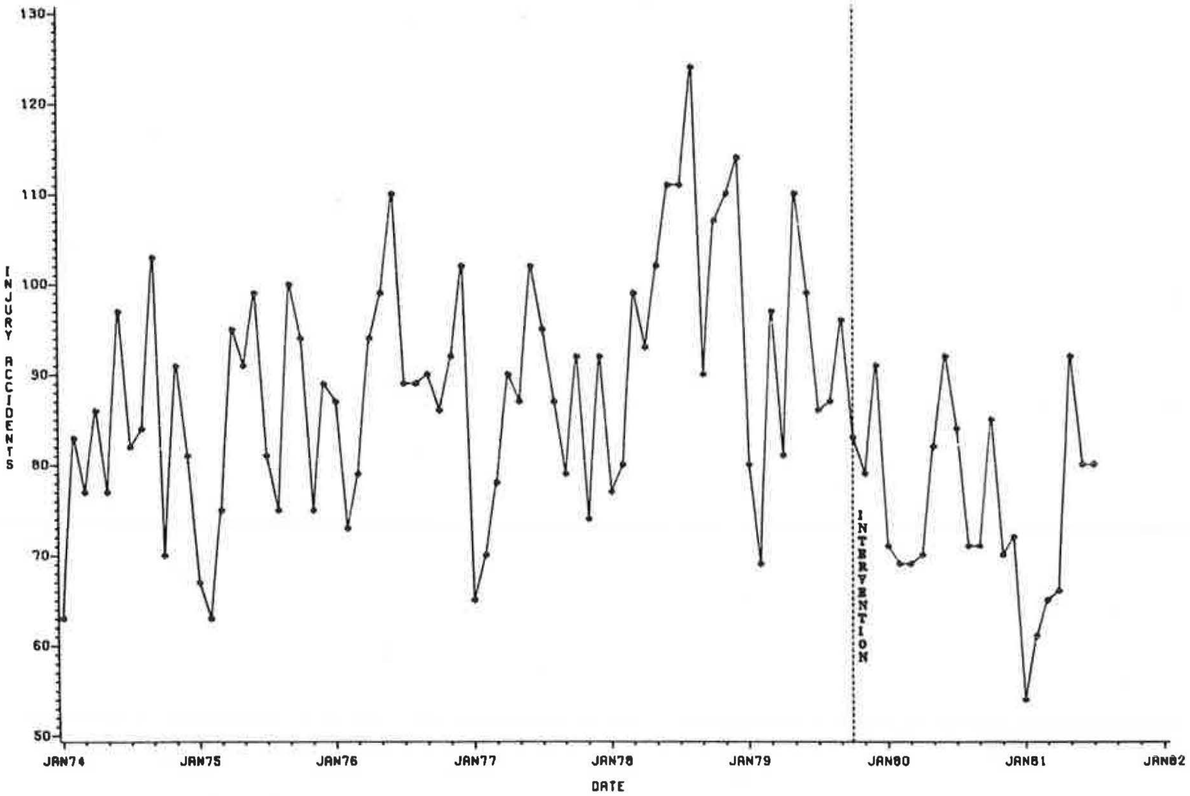


Table 2. Boise injury accident data.

	No. of Injury Accidents							
Month	1974	1975	1976	1977	1978	1979	1980	1981
January	63	67	87	65	77	89	71	54
February	83	63	73	70	80	69	69	61
March	77	75	79	78	99	97	69	65
April	86	95	94	90	93	81	70	66
May	77	91	99	87	102	110	82	92
June	97	99	110	102	111	99	92	80
July	82	81	89	95	111	86	84	80
August	84	75	89	87	124	87	71	
September	103	100	90	79	90	96	71	
October	70	94	86	92	107	83	85	
November	91	75	92	74	110	79	70	
December	81	89	102	92	114	91	72	

Figure 4. Non-STEP series (injury accidents).

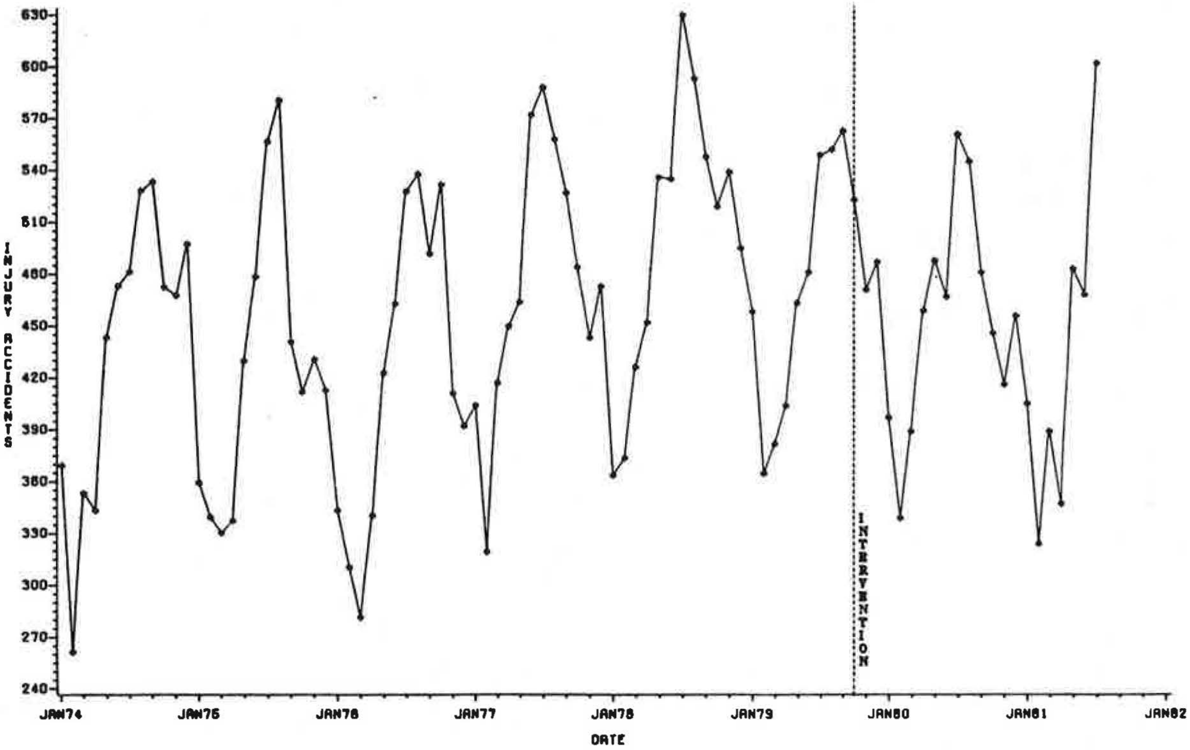


Table 3. Non-STEP injury accident data.

	No. of Injury Accidents							
Month	1974	1975	1976	1977	1978	1979	1980	1981
January	369	359	343	403	363	457	396	404
February	261	339	310	319	373	364	338	323
March	353	330	281	416	425	381	388	388
April	343	337	340	449	451	403	458	346
May	443	429	422	463	535	462	487	482
June	473	478	462	571	534	480	466	467
July	481	556	527	587	629	548	560	601
August	528	580	537	557	592	551	544	
September	533	440	491	526	547	562	480	
October	472	411	531	483	518	522	445	
November	467	430	410	442	538	470	415	
December	497	412	391	472	494	486	455	

ter estimates were significant at the $\alpha < 0.01$ level. Residual analysis revealed no model deficiencies.

Non-STEP Series

Figure 4 shows the comparison group, the non-STEP series. As before, the intervention point is referenced, but this time there is no obvious shift in level after the intervention. In fact, these data closely follow the exposure data.

Table 3 gives monthly injury accident data for non-STEP Idaho communities for the period January 1974 through July 1981. The univariate time series model for the data is

$$(1 - B)(1 - B^{12})Z_t = (1 - \overset{(0.08)}{0.69}B)(1 - \overset{(0.04)}{0.87}B^{12})\, a_t \qquad (5)$$

where

Z_t = monthly non-STEP injury accidents,
B = back-shift operator, and
a_t = noise.

Strong seasonality is obvious. No deficiencies were discovered in residual analysis.

A model similar to the Boise multivariate model was selected for this series. The model is

$$Y_t = \overset{(0.09)}{0.46}X_t - \overset{(10.5)}{8.0}I_{t-3} + [(1 - \overset{(0.09)}{0.7}B^{12})/(1 - B^{12})]\, a_t \qquad (6)$$

where

Y_t = non-STEP injury accidents for time period t,
X_t = exposure (VMT) for time period t,
I_t = presence of intervention at time period t,
B = back-shift operator, and
a_t = noise component of Y_t after explained variance is removed.

Note that the term N_t of the general model is equivalent to the expression $[(1 - 0.7B^{12})/(1 - B^{12})]a_t$.

The standard error of each parameter estimate is indicated in parentheses above the estimate. Both the exposure parameter and the seasonal moving average parameter are significant at the $\alpha < 0.01$ level. The estimate for the reduction due to I_t is not significant and so must be eliminated from the model. Residual analysis revealed no model deficiencies,

Interpretation of Findings

After implementing its STEP program, Boise sustained a reduction of 14.1 injury accidents/month. A total of 268 injury accidents were forestalled over the study period. The observed three-month delay in this reduction is entirely reasonable when one considers start-up time for public information and liaison activities. It is interesting to note that there was an immediate sharp increase in the traditional enforcement component (ticketing), but apparently this effort by itself did not achieve immediate reductions in accidents. It was not until the public information and liaison activities were under way that the maximum reductions occurred.

There was no significant reduction in injury accidents for the non-STEP group during the period of intervention in Boise. This was the expectation and is entirely logical because there was no additional effort to reduce accidents in these areas.

CONCLUSIONS

The Boise STEP achieved its objective of reducing injury accidents. It is reasonable to attribute these reductions to implementation of STEP because no such reduction was observed where STEP was not used. Increases in traditional enforcement at HALs and activity in the contextual areas both appear to be important elements of this successful program. In addition, coordination activities with other agencies, specifically the local court and the local engineering jurisdiction, facilitated accident reduction by improving communications. This allowed all agencies concerned to develop and pursue common highway safety objectives.

Cost-Effectiveness

The monthly reduction in Boise injury accidents was 14.1. This represents about a 17 percent reduction from the base period average. The cumulative reduction over the study period was 268 injury accidents. Based on the Boise base period injury severity distribution, this yielded an estimated economic cost savings of $1 600 000, an estimate calculated from National Safety Council estimating procedures. The total cost of implementation for the study period was $788 000. This yields a favorable benefit-cost ratio of 2.0. In other words, for every dollar spent $2 was saved.

REFERENCES

1. E. Hauer, F.J. Ahlin, and J.S. Bowser. Speed Enforcement and Speed Choice. Accident Analysis and Prevention, Vol. 14, No. 4, Aug. 1982, pp. 267-278.
2. E. Hauer and P. Cooper. Effectiveness of Selective Enforcement in Reducing Accidents in Metropolitan Toronto. TRB, Transportation Research Record 643, 1978, pp. 18-21.
3. C. Kohfeld and T. Likens. Media Effects on Compliance: Implications for Deterrence Models. Univ. of Missouri, Columbia, n.d.
4. O.C. Bensen. North Dakota Selective Traffic Enforcement Program. North Dakota Highway Patrol, Bismarck, 1975.
5. 1980 Census of Population and Housing: Advance Reports (Idaho). U.S. Department of Commerce, Feb. 1981.
6. Crime in the United States, 1979. U.S. Department of Justice, Sept. 24, 1980.
7. Uniform Crime Report. Idaho Department of Law Enforcement, Boise, 1974-1980 (annual).
8. R. McCleary and others. Applied Time Series Analysis for the Social Sciences. Sage Publications, Inc., Beverly Hills, CA, 1980.

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Analysis of Selective Enforcement Strategy Effects on Rural Alabama Traffic Speeds

JAMES N. HOOL, SAEED MAGHSOODLOO, ANDREW D. VEREN, AND DAVID B. BROWN

A study is described that was undertaken to examine the effects of patrol tactics on vehicle speeds, to identify the best patrol tactics of those studied, to identify general speed trends over time, and to examine the effects of an areawide selective enforcement program implemented by the Alabama State Highway Patrol. Both two- and four-lane roads were examined. Six patrol tactics were investigated—four single-vehicle tactics and two dual-vehicle tactics. All data were gathered from a radar-equipped van operated in a moving mode. Vehicle speed characteristics examined included mean speed, 85th percentile speed, and speed variance. Mean speeds were more affected by patrol tactics than were 0.85 percentiles or variances. Statistically significant reductions in average speeds were obtained with all tactics that used marked patrol vehicles. The largest reductions in average speed occurred with the stationary tactic. Significant reductions in 0.85 percentile speeds were obtained for all tactics on the four-lane road but for none of the tactics on the two-lane road. Variances were generally not affected on the four-lane road, whereas on the two-lane road they increased for five of the six tactics studied. Overall, the most effective tactic was the marked stationary vehicle. The unmarked patrol vehicle, even when issuing citations, had little, if any, effect on the speed parameters. A greater halo effect on speeds occurred on the two-lane than on the four-lane road. The general areawide selective enforcement program may have reduced mean speeds on the four-lane road but did not affect speeds on the two-lane road. No trends or cumulative effects on speeds were found during the three-month selective enforcement period.

An investigation of the short-term effects of a selective enforcement (SE) program on rural highway vehicle speeds in Alabama is described in this paper. A dual-lane highway (US-280) and a four-lane Interstate (I-85) were studied, and for each type of highway one continuous 12-mile segment of experimental highway and a 12-mile segment of matching control highway were examined. The speed limit throughout all segments studied was 55 mph. Control segments were selected based on topographic, proximity, and speed profile characteristics. Average daily traffic (ADT) on the selected roadways was as follows:

Roadway	ADT (no. of vehicles)
Two-lane experimental	6300
Two-lane control	3540
Four-lane experimental	9430
Four-lane control	9500

The formal SE program operated from October 1 to December 31, 1979, and was implemented through the Opelika Post of the Alabama State Highway Patrol. The program involved the use of $35 354 of federal funds for overtime employment of 28 officers for a total of 3721 hr. Funding was provided by NHTSA through the Alabama Office of Highway and Traffic Safety. Overtime functions during the SE period consisted of saturation enforcement along particular roadway segments, establishing roadway check stations, spot announcements on broadcasting media, and so on. The study was designed to provide information for decision making about patrol tactics to use for traffic law enforcement (1-19).

Data were collected from July through December in the following time phases: a baseline (B) phase from July 26 to September 9, a phase preceding selective enforcement (PSE) from September 10 to 30, and the SE phase. These phases were chosen as an integral part of the overall study design, which is discussed later in more detail. The B period was used to establish vehicle speed characteristics before implementation of the formal SE program and use of patrol tactics. The succeeding PSE period was used to examine the effects of the patrol tactics used before (and hence independent of) the later SE program and also to establish any trends in vehicle speed before the SE program that were unaffected by patrol tactics. Finally, the SE period was used to examine the general effect of the SE program both with and without patrol tactics.

The objectives of the investigation were

1. To determine whether the SE program had any overall effect on vehicle speeds,
2. To determine the effect on vehicle speed of each patrol tactic used in the PSE period,
3. To determine the effect on vehicle speed of each patrol tactic used in the SE period,
4. To determine the halo effect for the "single stationary marked patrol vehicle" tactic in the PSE and SE periods,
5. To compare the effects of patrol tactics used in the PSE period, and
6. To compare the effects of patrol tactics used in the SE period.

Six patrol tactics were examined for objectives 2-6; these represented combinations of single, dual, stationary, and moving patrol vehicles. The tactics used on the experimental roadway segments are discussed in detail later.

PATROL TACTICS STUDIED

The six patrol tactics used were standard tactics commonly used by police agencies:

1. Single stationary marked patrol vehicle (SSM),
2. Single moving marked patrol vehicle (SMM),
3. Single stationary-moving marked patrol vehicle (SSMM),
4. Single moving unmarked patrol vehicle (SMU),
5. Dual moving marked/moving unmarked patrol vehicles (DMM/MU), and
6. Dual stationary-moving marked/moving unmarked patrol vehicles (DSMM/MU).

Any marked patrol vehicle used in a tactic was operated in the interior 6-mile portion of each 12-mile experimental segment used in the study. When unmarked cars were used, they were operated over the entire segment length. These were standard units operated by uniformed troopers. Some marked cars were equipped with mobile radar units. The unmarked car always operated in its standard manner. During all work with marked cars, citizens band Channel 19 was monitored and occasionally used for communication by both the patrol vehicle and a continuously moving data collection van. For each free-flowing vehicle observed from the van, 14 variables were recorded. Traffic citations were issued when necessary, and, when a car was called on an emergency, data collection was suspended. The tactics used are described below.

Single Stationary Marked Patrol Vehicle

In the SSM tactic, the marked patrol vehicle was parked for a 30-min time interval at a randomly selected milepost and was faced in a randomly selected direction (north, south, east, or west). At the end of 30 min it was moved to another location. During a typical data collection session, three stationary locations were observed. Radar was occasionally used.

Single Moving Marked Patrol Vehicle

A standard moving mode was used--i.e., a 40- to 45-mph patrol speed. On the four-lane experimental roadway (4E), the SMM operated on both the inside and outside lanes. Radar was occasionally used, but the distinction between use or no use was not made. The officer was free to issue traffic citations.

Single Stationary-Moving Marked Patrol Vehicle

The SSMM was a combination of the SSM and SMM. The vehicle was stationary for 5-min intervals at randomly selected mileposts facing randomly selected directions. Radar was occasionally used.

Single Moving Unmarked Patrol Vehicle

In the SMU tactic, an unmarked car was used in its standard operating mode. It would cruise as traffic dictated until a suspected speeding vehicle was observed traveling in the same direction. It would then verify the pace of the suspected speeding vehicle, which would then be apprehended.

Dual Moving Marked/Moving Unmarked Patrol Vehicles

One marked car using the SMM mode and one unmarked car using the SMU mode constituted the DMM/MU tactic. Both vehicles were used simultaneously.

Dual Stationary-Moving Marked/Moving Unmarked Patrol Vehicles

One marked car using the SSMM mode and one unmarked car using the SMU mode constituted the DSMM/MU tactic. Both vehicles were used simultaneously.

TYPES OF VEHICLES OBSERVED

Table 1 gives a breakdown of the number of vehicles

Table 1. Number of vehicles observed during study by road and vehicle type.

	Automobile		General Truck		18-Wheeler		Van		Other		
Roadway	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	Total
Four-lane control	2 733	59.9	566	12.4	1053	23.1	177	3.9	30	0.7	4 559
Four-lane experimental	7 305	64.1	1732	15.2	1878	16.5	416	3.7	65	0.5	11 396
Two-lane control	1 622	71.5	429	18.9	110	4.9	73	3.2	34	1.5	2 268
Two-lane experimental	4 267	69.5	1246	20.3	312	5.1	234	3.8	77	1.3	6 136
Total	15 927		3973		3353		900		206		24 359

Table 2. Study design.

Patrol Tactic	Baseline		PSE Period		SE Period	
	Two-Lane	Four-Lane	Two-Lane	Four-Lane	Two-Lane	Four-Lane
SSM			X	X	X	X
SMM			X	X	X	X
SSMM					X	X
SMU				X	X	X
DMM/MU					X	X
DSMM/MU					X	X
NPV	X	X	X	X	X	X

Note: NPV = no patrol vehicle.

observed by roadway and vehicle type. Differences between two- and four-lane roadways are evident. Higher percentages of automobiles and general trucks on two-lane roadways indicate the higher proportion of commuter and local traffic on these roads. Higher percentages of 18-wheelers on four-lane roadways indicate the larger proportion of commercial through traffic on the Interstate highway.

STUDY DESIGN

Table 2 gives the study design arranged by time phase, roadway type, and patrol tactic. An X indicates that vehicle speed (in miles per hour) and associated data (e.g., vehicle type, day of the week, time of day, etc.) were collected. Within each of the time phases (PSE and SE), the patrol tactics were randomly assigned to experimental roadway segments (i.e., two- or four-lane) and days within the first half of the period. The randomization process was then repeated for the second half of the period.

On any given day, only one patrol tactic was observed on an experimental segment and its corresponding matching control roadway segment was also observed. All observations were made between 1:00 and 4:00 p.m. During the B period, patrol tactics were not used but days for observing roadway segments were randomly selected. A given patrol tactic in the PSE period was always equivalent to that used in the SE period. However, there was no attempt to ensure that other variables, such as the day of the week, were equivalent.

Data were collected continuously over time phases B, PSE, and SE. A radar-equipped van was used to gather vehicle speed and associated data. The van was continuously moving throughout the 12-mile length of each studied segment; therefore, at various times it was either upstream or downstream of the patrol vehicles used on experimental segments.

BASELINE CONTROL VERSUS EXPERIMENTAL ROADWAY COMPARISONS

Speeds on the four-lane control segment (4C) tended to exceed those on the respective experiment segment (4E). Sample means for 4C and 4E were 61.4 and 60.4 mph, respectively. Standard deviations were 5.80 and 5.36 mph. Table 3 gives relative and cumulative relative frequencies of vehicle speeds by speed class. For each class, the cumulative relative frequency of 4E exceeded that of 4C (except for the ≥76-mph class interval).

The following table gives pth quantile speeds for 4C and 4E:

Quantile (p)	pth Quantile Speed (mph)	
	Control	Experimental
0.50	61.0	61.0
0.60	63.0	62.0
0.70	64.0	63.0
0.75	65.0	64.0
0.80	66.0	65.0
0.85	67.0	66.0
0.90	69.0	67.0
0.95	71.0	69.0

The 4C pth quantile speeds at least equaled and in all cases but one exceeded corresponding speeds for 4E. Although quantile speeds were not very different, the differences were statistically significant at a level of significance 0.01 based on the Smirnov test (20).

On 2C and 2E, sample means were 54.5 and 54.2 mph and standard deviations were 6.88 and 5.94 mph, respectively. Table 4 gives relative and cumulative relative frequency of speeds on the two-lane roadways. The 2C segment had a larger proportion of vehicles traveling below 49 mph. However, for all higher speeds, 2E had a higher proportion of vehicles traveling at or below corresponding speeds; e.g., 87.9 percent of all vehicles on 2E were traveling less than 61 mph whereas on 2C the figure was 84.7 percent.

The following table gives pth quantile speeds for two-lane segments:

Quantile (p)	pth Quantile Speed (mph)	
	Control	Experimental
0.50	55.0	54.0
0.60	56.0	56.0
0.70	58.0	57.0
0.75	59.0	58.0
0.80	60.0	59.0
0.85	61.0	60.0
0.90	62.0	61.0
0.95	65.0	64.0

The 2C pth quantile speeds equaled or exceeded cor-

Table 3. Speed frequencies on four-lane roads.

	Control Segment		Experimental Segment	
Class (mph)	Relative Frequency	Cumulative Relative Frequency	Relative Frequency	Cumulative Relative Frequency
1-45	0.3	0.3	0.6	0.6
46-48	1.0	1.3	1.2	1.8
49-51	2.5	3.8	3.1	4.9
52-54	5.1	8.9	7.2	12.1
55-57	14.9	23.8	15.9	28.0
58-60	20.5	44.3	21.5	49.5
61-63	21.2	65.5	22.9	72.4
64-66	17.3	82.8	15.2	87.6
67-69	9.4	92.2	8.1	95.7
70-72	5.0	97.2	3.1	98.8
73-75	1.2	98.4	0.8	99.6
>76	1.6	100.0	0.4	100.0

Table 4. Speed frequencies on two-lane roads.

	Control Segment		Experimental Segment	
Class (mph)	Relative Frequency	Cumulative Relative Frequency	Relative Frequency	Cumulative Relative Frequency
1-45	8.2	8.2	6.6	6.6
46-48	7.7	15.9	7.3	13.9
49-51	13.3	29.2	17.4	31.3
52-54	17.7	46.9	19.5	50.8
55-57	21.4	68.3	22.8	73.6
58-60	16.4	84.7	14.3	87.9
61-63	8.7	93.4	6.8	94.7
64-66	3.5	96.9	3.5	98.2
67-69	1.7	98.6	1.0	99.2
70-72	0.9	99.6	0.7	99.9
73-75	0.2	99.7	0.1	100.0
>76	0.3	100.0	0.0	100.0

responding speeds for 2E. Speed differences were statistically significant at a 0.05 level of significance.

RESULTS AND DISCUSSION

Three vehicle speed characteristics were analyzed: mean speed, 0.85 quantile speed, and speed variance. Data for all vehicle types were collectively analyzed. For various subsets of data, the Lilliefors test (20) was used to test for normality. Due to large sample sizes, the tests indicated nonnormality for most subsets, although a visual test of normality appeared to be reasonable. Therefore, parametric statistical tests based on the normality assumption were used. Analyses are discussed one by one by specific objective.

Overall Effect of SE Program on Speed

Objective 1 was to determine whether the SE program had any overall effect on speeds. To obtain an evaluation independent of the patrol tactics studied, only roads 2C and 4C were evaluated. Two approaches were taken. For each control road and vehicle speed characteristic, the following analyses were performed:

1. A linear regression equation regressing vehicle speed characteristics on time was derived by using data over the entire study period (i.e., B, PSE, and SE periods) in order to assess any trend effects.
2. Sample data for the combined B and PSE periods were compared with SE period data to test for significant differences.

Hypotheses of zero slope parameters were tested for fitted equations. At the 0.05 level of significance, all slope hypotheses were accepted. Based on trend analysis, there were no significant speed trends that could be attributed to the SE program.

The t-test was used in one-sided tests of hypotheses conducted on differences between means before and during the SE program. Before and during speed variances were compared by using the two-sided F-test. An adaptation of the median test (20) was used to test differences in 0.85 quantiles. Hypothesis test results are summarized below:

Road	Parameter	Sample Statistic	Level of Significance
4C	Means	t = -1.75	0.05
	0.85 quantiles	T = 0.0005	
	Variances	F = 1.091	0.05
2C	Means	t = -0.342	
	0.85 quantiles	T = 0.0003	
	Variances	F = 1.202	0.01

The alternative hypothesis for means and quantiles tests was that the SE period speed was lower than the before speed.

Table 5 gives summary values for roads 2C, 4C, 2E, and 4E. The text table above indicates a significant reduction in the mean speed on 4C and variance on 2C but an increase in variance on 4C. Thus, it could be concluded that the overall selective enforcement program had only limited success in reducing speeds.

Effect on Speed of Patrol Tactics in PSE Period

Objective 2 was to determine the effect on speed of each patrol tactic used in the PSE period. Hypothesis tests comparing B-period speeds with PSE-period speeds were conducted. Calculations were similar to those for objective 1 tests except that PSE experimental road data were adjusted by using corresponding control road data. Adjustments were made to account for any possible shift in speed characteristic means between the B and PSE periods. The adjustment factors (albeit small) were based on data from roads 2C and 4C during the B and PSE periods. Table 6 gives (adjusted) speed summary data for the PSE period.

Twelve hypothesis tests were conducted, one for each combination of road, patrol tactic, and speed characteristic. For mean and 0.85 quantile tests, the alternative hypothesis was that the speed was lower during the PSE period than during the B period. Variance tests were two-sided.

Highly significant reductions in mean speeds were indicated for both tactics on 2E and 4E. Estimated percentage reductions for the four road-tactic combinations were as follows:

Road-Tactic Combination	Reduction in Mean Speed (%)
4E, SSM	2.9
4E, SMM	1.0
2E, SSM	4.6
2E, SMM	3.9

The only significant reduction in 0.85 quantile (from 60.0 to 58.2 mph) was for the SMM patrol tactic on road 2E. The conclusion drawn was that patrol tactics were effective in reducing mean speeds

Table 5. Summary speed data for objective 1 by road and time phase.

Road	Time Frame	No. of Observations	Speed Data (mph) Mean	0.85 Quantile	Standard Deviation
4C	B	1 065	61.4	67.0	5.80
	PSE	1 346	61.6	67.0	5.50
	B+PSE	2 411	61.5	67.0	5.63
	SE	2 148	61.2	67.0	5.88
4E	B	1 093	60.4	66.0	5.36
	PSE	2 354	59.9	65.0	5.45
	SE	7 949	59.1	64.0	5.34
2C	B	1 128	54.5	61.0	6.88
	PSE	392	53.5	60.0	7.10
	B+PSE	1 520	54.2	60.0	
	SE	748	54.1	60.0	6.34
2E	B	944	54.2	60.0	5.94
	PSE	1 267	51.9	58.0	6.29
	SE	3 925	52.4	58.0	6.51
Total		24 359			

Table 6. Adjusted summary speed data for objective 2 by tactic.

Road	Tactic	No. of Observations	Speed Data (mph) Mean	0.85 Quantile	Standard Deviation
4E	SSM	1059	59.6	65.8	5.59
	SMM	818	59.8	64.8	5.19
2E	SSM	590	52.0	58.2	6.44
	SMM	677	52.1	58.2	6.22

during the PSE period but that they had little effect on 0.85 quantile speeds and variances.

Effect on Speed of Patrol Tactics in SE Period

Objective 3 was to determine the effect on speed of each patrol tactic in the SE period. Procedures and statistical tests were the same as for objective 2. A total of 36 tests were conducted, one for each combination of road, patrol tactic, and speed characteristic. Table 7 gives relevant speed summary data.

Significant reductions in mean speeds resulted for all patrol tactics except SMU on 4E. The percentage reductions are given below:

Road	Tactic	Reduction in Mean Speed (%)
4E	SSM	2.6
	SMM	1.5
	SSMM	2.3
	DSMM/MU	2.5
	DMM/MU	1.5
2E	SSM	3.3
	SMM	3.5
	SMU	2.6
	SSMM	2.4
	DSMM/MU	2.2
	DMM/MU	1.3

Significant 0.85 quantile reductions of 1.8 mph, or 2.7 percent, were obtained on 4E for all tactics except SMU, which increased. On 2E, however, only tactic DSMM/MU resulted in a significantly lower 0.85 quantile. Variances were mostly unaffected on 4E except under DSMM/MU, for which a decrease was observed. Variances increased on 2E for all patrol tactics except DSMM/MU. Thus, the patrol tactics used in the SE period clearly had a significant effect on speed.

Table 7. Adjusted summary speed data for objective 3 by tactic.

Road	Tactic	No. of Observations	Speed Data (mph) Mean	0.85 Quantile	Standard Deviation
4E	SSM	1378	58.8	64.2	5.13
	SMM	1674	59.5	64.2	5.33
	SMU	1161	60.5	66.2	5.68
	SSMM	1011	59.0	64.2	5.39
	DSMM/MU	1228	58.9	64.2	5.01
	DMM/MU	1497	59.5	64.2	5.38
2E	SSM	571	52.4	58.4	6.78
	SMM	612	52.3	59.4	6.95
	SMU	731	52.8	59.4	6.65
	SSMM	581	52.9	58.4	6.45
	DSMM/MU	816	53.0	58.4	5.77
	DMM/MU	614	53.5	59.4	6.80

Halo Effect for SSM Tactic in PSE and SE Periods

Objective 4 was to determine the halo effect for the SSM tactic in the PSE and SE periods. The halo effect refers to speed reduction as a function of distance from the patrol vehicle (PV). Subsets of vehicle speeds recorded at the PV location and at approximately 1-mile intervals in either direction from the PV were created. Vehicle locations were accurate to within 0.5 mile. Vehicle direction was also noted: primary direction refers to vehicles traveling in the same direction that the PV faced and secondary direction to vehicles traveling in the opposite direction.

The halo effect was examined from four perspectives:

1. Only vehicles traveling in the primary direction were examined.
2. Vehicles traveling in the secondary direction were considered.
3. Speeds were combined for both directions by their absolute distance from the PV--i.e., relative to the PV direction.
4. Speeds were combined by their relative distance from the PV--i.e., either approaching or departing.

The effects of the PV on mean speed are evident in Figures 1-4. Points on the right side of Figures 1 and 4 and on the left side of Figure 2 represent vehicles that have passed the PV. Similar effects in both the primary and secondary lanes are indicated from Figures 1 and 2, with perhaps greater influence in the primary lane. The general effect is speed reduction nearest the PV.

For 4E, the mean speed decreased approximately 0.15 mph/mile from 5 miles to 1 mile upstream, then dropped sharply within 0.5 mile of the PV. Mean speeds increased an average of 0.7 mph/mile after vehicles passed the PV and the halo effect diminished after approximately 3 miles downstream. Mean speeds at 4 and 5 miles downstream continued to increase above the rather stable approach level, which perhaps indicates an effort by some motorists to compensate for the temporary speed reduction.

A different effect occurred on 2E. The mean speed gradually decreased as traffic approached the PV from 5 miles upstream, then increased very gradually from 1 to 5 miles downstream. At 5 miles downstream, the mean speed was still lower than any of the five upstream mean values. The halo effect was at least 5 miles on the downstream side and about 3 to 4 miles on the upstream side. Motorists were much more cautious on 2E, perhaps due to a much shorter visibility span and lower traffic volumes.

Effects on the 0.85 quantiles were similar to effects on the means. No clear-cut effect on speed variability could be determined, however. On 4E, variability appeared to be slightly more stable downstream but not significantly. There was a moderate lowering of variance on 2E after vehicles passed the PV, particularly at the 2- and 3-mile points.

Comparison of Patrol Tactic Effects on Speeds in PSE Period

Objective 5 was to compare patrol tactic effects on speeds in the PSE period. Relative differences between patrol tactic effects were sought by comparing all patrol tactics. The 2C and 4C data were used to make adjustments to 2E and 4E data. Adjustments were made to account for natural day-to-day fluctuations in speeds during the PSE period and were based on a computed daily index that gave the overall PSE speed mean for a particular day. Table 8 gives a summary of adjusted data.

Six statistical tests were conducted, three for each experimental road. Tests were for differences (SSM versus SMM) in means, 0.85 quantiles, and vari-

Figure 1. Mean spot speed: vehicles traveling in primary direction.

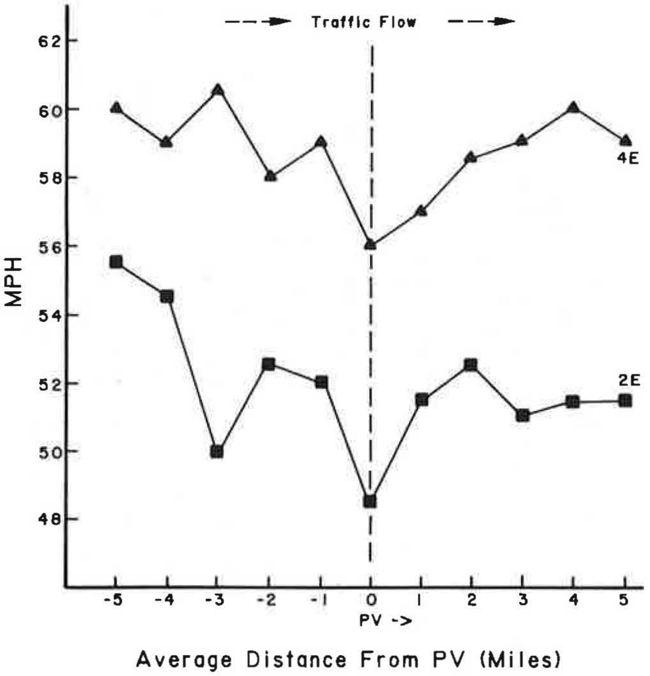

Figure 2. Mean spot speed: vehicles traveling in secondary direction.

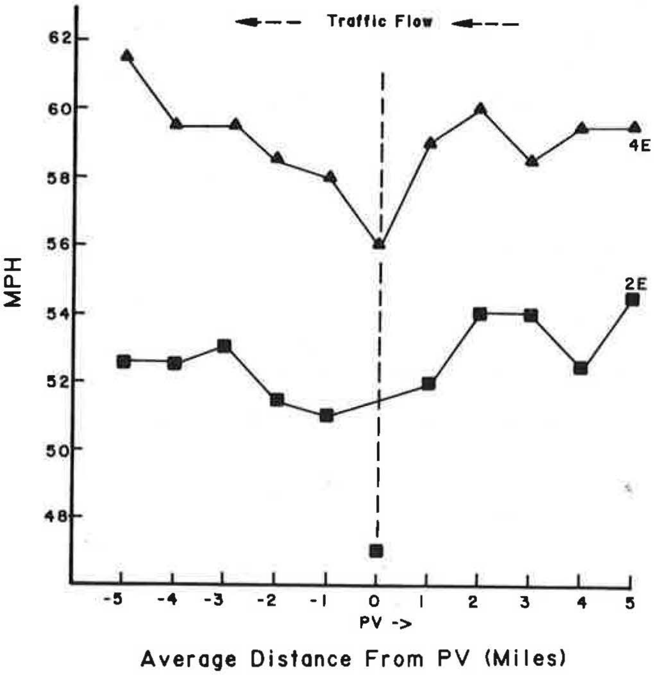

Figure 3. Mean spot speed by absolute distance from PV: all vehicles.

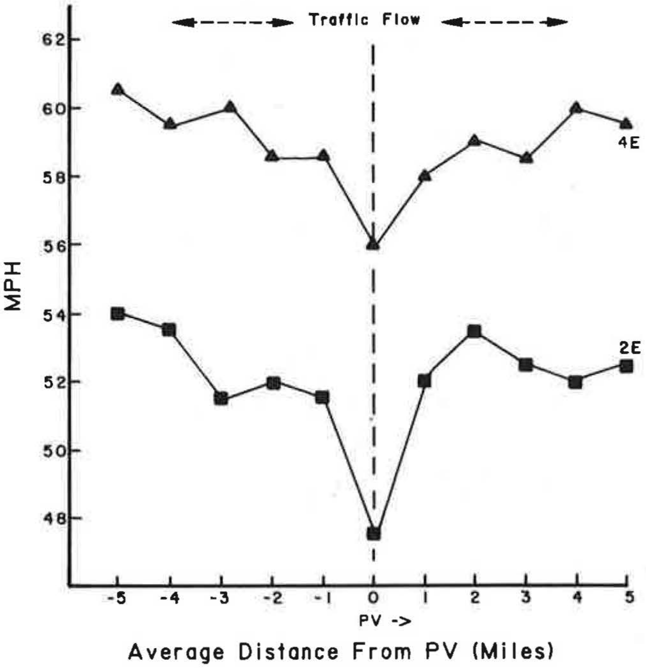

Figure 4. Mean spot speed by relative distance from PV.

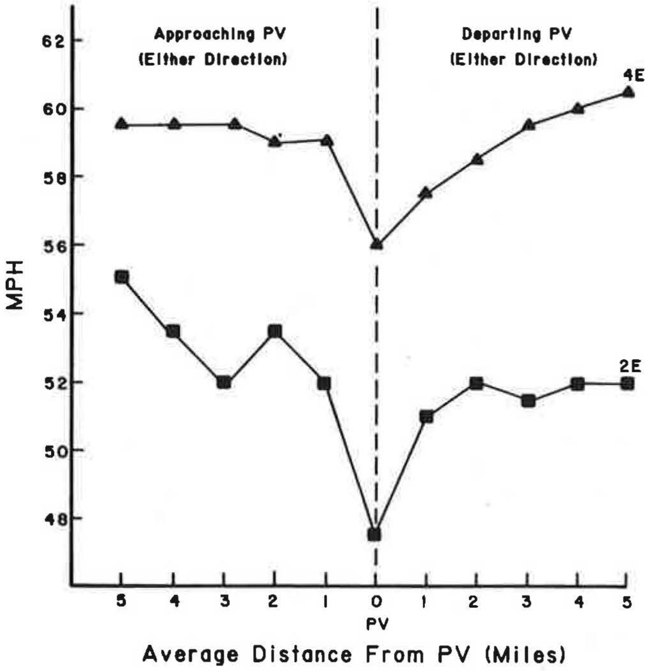

Table 8. Adjusted summary speed data for objective 5 by tactic.

Road	Tactic	No. of Obser-vations	Speed Data (mph) Mean	0.85 Quantile	Standard Deviation
4E	SSM	1059	60.0	65.8	5.63
	SMM	818	60.2	65.6	5.21
2E	SSM	590	51.94	58.3	6.41
	SMM	677	51.86	57.9	6.18

Table 9. Adjusted summary speed data for objective 6 by tactic.

Road	Tactic	No. of Obser-vations	Speed Data (mph) Mean	0.85 Quantile	Standard Deviation
4E	SSM	1378	58.4	63.4	5.15
	SMM	1674	59.2	64.5	5.32
	SMU	1161	60.3	66.0	5.76
	SSMM	1011	58.8	64.2	5.41
	DSMM/MU	1228	58.5	63.6	4.99
	DMM/MU	1497	59.7	64.5	5.40
2E	SSM	571	51.4	57.9	6.65
	SMM	612	52.9	60.0	7.04
	SMU	731	52.8	59.0	6.65
	SSMM	581	52.6	58.1	6.42
	DSMM/MU	816	52.3	57.4	5.70
	DMM/MU	614	52.5	58.7	6.64

Table 10. Effectiveness of patrol tactics ranked by speed.

Road	Rank	Mean	0.85 Quantile	Standard Deviation
4E	1	SSM	SSM	DSMM/MU
	2	DSMM/MU	DSMM/MU	SSM
	3	SSMM	SSMM	SMM
	4	SMM	SMM	DMM/MU
	5	DMM/MU	DMM/MU	SSMM
	6	SMU	SMU	SMU
2E	1	SSM	DSMM/MU	DSMM/MU
	2	DSMM/MU	SSM	SSMM
	3	DMM/MU	SSMM	DMM/MU
	4	SSMM	DMM/MU	SSM
	5	SMU	SMU	SMU
	6	SMM	SMM	SMM

ances. The only significant differences were on 4E, where the 0.85 quantile and variance were lower for SMM. Thus, generally no significant differences in speed due to patrol tactics were found during the PSE period.

Comparison of Patrol Tactic Effects on Speeds in SE Period

Objective 6 was to compare patrol tactic effects on speeds in the SE period. Speeds were adjusted in the same way as for objective 5. Table 9 gives a summary of adjusted results. All six patrol tactics were tested for significant differences between at least two. Means, 0.85 quantiles, and variances for each road were tested. The one-factor analysis of variance was used for means. The quantile differences test was used for 0.85 quantiles, and Cochran's test for homogeneity of variances was used for variances.

Significant differences were indicated for all speeds on 2E and 4E. A postanalysis of variance comparison (ANOVA) of means on 4E, using Scheffe's method, yielded the following contrast results at the 0.05 level of significance:

```
(SSM)     (DSMM/MU)      (SSMM)     (SMM)     (DMM/MU)     (SMU)
 X̄1        X̄5             X̄4         X̄2        X̄6            X̄3
58.4      58.5           58.8       59.2      59.7          60.3
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                         ----------------
                                    ---------------
                                              ------------------
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Means underlined by the same line are considered not significantly different. Thus, means for SSM, DSMM/MU, and SSMM were not significantly different, but SSM and DSMM/MU had lower means than SMM, DMM/MU, or SMU. The same post-ANOVA analysis for 2E gave the following results:

```
(SSM)     (DSMM/MU)      (DMM/MU)      (SSMM)     (SMU)      (SMM)
 X̄1        X̄5             X̄6            X̄4         X̄3         X̄2
51.4      52.3           52.5          52.6       52.8       52.9
--------------------------------------------
          ------------------------------------------------------
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Only the mean for SSM was significantly lower than means for both SMU and SMM.

Table 10 ranks patrol tactics for effectiveness by speed sample means, 0.85 quantiles, and standard deviations by their effectiveness, where a lower sample value was considered more effective. SSM and DSMM/MU gave the best results overall. Of the four single-vehicle patrol tactics, SSM was superior in reducing mean speed and 0.85 quantiles on both roads. SSM and SSMM were not significantly different in mean speeds on either road but were significantly lower than SMU on 4E.

SMM and SMU did not do well on a comparative basis. This is reinforced when one considers the two dual-vehicle tactics. Mean speeds were not significantly lower under DMM/MU than under either SMM or SMU alone. In fact, on 4E, SMM ranked above DMM/MU for all speeds. DSMM/MU was relatively effective but not in comparison with SSMM. Thus, addition of the unmarked vehicle to the stationary-moving mode had little or no effect on reducing speed parameters.

CONCLUSIONS

The following conclusions were inferred from the analyses:

1. The general areawide SE program may have reduced mean speeds on the Interstate road studied but did not affect speeds on the two-lane road.
2. Mean speeds were more affected by the patrol tactics studied than were 0.85 quantiles or variances. Reductions in mean speeds that were significant, although small in absolute value, were obtained with stationary, moving, and stationary-moving tactics. Reductions in 0.85 quantiles were smaller. Variances were not affected on the four-lane road but increased with five of six tactics on the two-lane road.
3. The most effective tactic on four-lane roads was the stationary mode. Average reductions in mean speed over the experimental segments were estimated to be 1.6 mph, or 2.6 percent, and in 0.85 quantile 1.8 mph, or 2.7 percent. This tactic was significantly better than the moving or unmarked tactic.
4. Results were less consistent on the two-lane segment, perhaps because of greater variability in speed data. In a direct comparison of all tactics, however, the stationary mode was superior to the moving and unmarked modes.
5. The unmarked tactic, either by itself or in combination with another vehicle, had little, if any, effect on speeds.

6. There was no significant difference between the stationary and the stationary-moving modes.
7. A greater halo effect occurred on the two-lane road than on the four-lane road. This effect extended from 3 to 4 miles upstream to at least 5 miles downstream from a stationary PV on the two-lane road. On the Interstate segment, vehicle speeds were affected, to a lesser extent, from 2 miles upstream to 3 miles downstream from the PV; speeds even increased from 3 to 5 miles downstream as motorists apparently attempted to make up lost ground.

REFERENCES

1. J.S. Baker. Effect of Enforcement on Vehicle Speeds. HRB, Bull. 91, 1954, pp. 33-38.
2. A.B. Calica, R.F. Crowther, and R.P. Shumate. Enforcement Effect on Traffic Accident Generation. Department of Police Administration, Indiana Univ., Bloomington, 1963.
3. Operation 101 Final Report: Phase I--Background and Accident Analysis. California Highway Patrol, Sacramento, 1966.
4. W.J. Conover. Practical Nonparametric Statistics. Wiley, New York, 1971.
5. F.M. Council. A Study of the Immediate Effect of Enforcement on Vehicular Speeds. Highway Safety Research Center, Univ. of North Carolina, Chapel Hill, 1970.
6. F.M. Council. Police Traffic Services. Highway Safety Research Center, Univ. of North Carolina, Chapel Hill, 1971.
7. C.B. Ferster and B.F. Skinner. Schedules of Reinforcement. Appleton-Century-Crofts, Inc., New York, 1957.
8. W.J. Huffman, J.L. Payne, A.E. Florio, and J.T. Henry. The Effectiveness of an Emphasis Patrol by the Illinois State Highway Patrol in a District on a Selected Highway. Traffic Safety, Vol. 5, 1961, pp. 17-29.
9. W.W. Hunter and H.L. Bundy. A Study of the Effects of the Speed Zone Check Concept. Highway Safety Research Center, Univ. of North Carolina, Chapel Hill, 1975.
10. P. Johnson, T.M. Klein, and P.S. Levy. Effect of the 55-MPH Speed Limit Law on Fatal Crashes in Texas. NHTSA, 1976.
11. K.B. Joscelyn, T.H. Bryan, and D.M. Goldenbaum. A Study of the Effects of Law Enforcement on Traffic Flow Behavior. Institute for Research in Public Safety, Indiana Univ., Bloomington, 1971.
12. W.L. Merte. 1976 Traffic Speed Trends Report. Federal Highway Bulletin, March 19, 1976.
13. R.M. Michaels. The Effects of Enforcement on Traffic Behavior. Public Roads, Vol. 31, 1960, pp. 109-113.
14. C.T. Morgan. Introduction to Psychology. McGraw-Hill, New York, 1961.
15. N.C. Munn, L.D. Fernald, and P.S. Fernald. Introduction to Psychology. Houghton Mifflin Co., Boston, 1965.
16. J.L. Recht. Traffic Fatalities Increase in January. Traffic Safety, Vol. 75, 1975, pp. 28-33.
17. D.W. Reinfurt, D.N. Levine, and W.D. Johnson. Radar as a Speed Deterrent: An Evaluation. Highway Safety Research Center, Univ. of North Carolina, Chapel Hill, 1973.
18. R.P. Shumate. Effect of Increased Patrol on Accidents, Division, and Speed. Traffic Institute, Northwestern Univ., Evanston, IL, Res. Project R13, 1956.
19. R.P. Shumate. The Long Range Effect on Driving Speeds. Field Service Division, International Assn. of Chiefs of Police, Inc., Gaithersburg, MD, Project 533, 1954.
20. R.D. Smith. The Effect of Enforcement on Driving Behavior. Field Service Division, International Assn. of Chiefs of Police, Inc., Gaithersburg, MD, 1962.

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Evaluation of the Bonneville County, Idaho, DUI Accident Prevention Program

DAVID R. AMICK AND PATRICIA B. MARSHALL

The results of an impact evaluation of the first 15 months of an accident prevention program in Bonneville County, Idaho, are presented. Project Safety is a comprehensive driving under the influence (DUI) program implemented in Bonneville County in October 1979. It provided an integrated systems approach to the drinking-driver problem by the enhancement of treatment, sentencing and parole, and rehabilitation processes. DUI enforcement teams were added to the Bonneville County Sheriff's Office and the Idaho Falls Police Department. A public information component was also developed. Specific personnel were assigned system liaison responsibilities. A before-and-after analysis, which included two comparison locations, used an alcohol proxy measure (nighttime fatal and injury accidents occurring between 8:00 p.m. and 5:00 a.m.) to identify reductions in alcohol-related accidents. There was a reduction of 4.6 alcohol proxy accidents/month (a total of 64) during the study period. Reductions did not occur in comparison counties in the alcohol measure, although the direction of daytime accident trends was similar for all counties studied. State alcohol proxy accidents remained stable during the program period. An estimated $1 million in fatal and injury accident costs was avoided during the program period compared with actual total project costs of $312 471. The $1 million accident cost estimate excludes probable reductions in property-damage-only accidents.

The results of an impact evaluation of the first 15 months of the Bonneville County, Idaho, Project Safety program, implemented October 1, 1979, are presented in this paper. The program was designed to reduce alcohol-related motor-vehicle accidents in the county. The results of this study will contribute to the growing body of literature concerning the design, implementation, and effectiveness of alcohol-related countermeasures. The methodology adopted was designed to determine the following:

1. Has there been a measurable reduction in alcohol-related accidents that can be correlated with the implementation of Project Safety?
2. Is there reasonable evidence to indicate that such reductions can be attributed to Project Safety?
3. What are the cost savings in accident reduction due to Project Safety?

REVIEW OF LITERATURE

Identifying effective methods for preventing alcohol-related motor-vehicle accidents has been a matter of public concern since the U.S. Department of Transportation (DOT) made public evidence that showed that greatly increased crash risk was strongly associated with drinking while driving, even when only moderate drinking was involved (1). Since that time, numerous local and national projects have been implemented in an attempt to curb the drinking-driver problem. Almost all of these efforts were supported with federal funding. The types of countermeasures studied centered primarily on special enforcement campaigns.

The Alcohol Safety Action Projects (ASAPs) funded by DOT and operated during the early 1970s in 35 cities, counties, and states were the largest efforts by far. These programs used a traditional enforcement concept to provide special enforcement directed at the drinking driver and to improve judicial and treatment system capabilities to efficiently process arrested drivers. "The concept in operation represented a major overhaul of the entire enforcement system, and it was therefore of a magnitude and duration that is unique in the history of highway safety" (2, p. 4).

The ASAPs easily demonstrated success in increasing intermediate effectiveness indicators such as driving under the influence (DUI) arrests and agency enforcement levels. Cost-effectiveness was also easily demonstrated through the use of improved management techniques, specialized training, and more accurate devices for testing alcohol concentration. However, "no project reached levels of arrests at which deterrence or a clear reduction in accidents could be traced definitely to the enforcement countermeasure" (2, p. 6).

Moderate successes were reported in reducing the arrest ratio for social drinkers, as opposed to heavy or problem drinkers, through education and treatment components of the ASAPs. Special surveys for a few specific public information projects produced findings that demonstrated a clear relation between exposure to campaign activities and changes in knowledge and attitude. Analysts of the national ASAP program concluded that public information efforts should be significant components of future projects.

Although evaluations conducted at local levels failed to reveal conclusive results concerning the effectiveness of the ASAP concept, a final evaluation conducted by DOT did present enough data and analyses that it could be credibly argued that "some programs including increased certainty of a legal penalty under American law could, in the short run, produce declines in drinking and driving and in associated casualties" (3, p. 84).

Other attempts to measure the effectiveness of enforcement-centered projects have been characterized by methodological weaknesses. Some of the stronger research designs still provide little conclusive evidence because of study weaknesses. In the Stockton, California, Increased DUI Enforcement Program (4), there was a decrease in blood alcohol concentrations and reported collisions during the program period. Yet control-group comparisons yielded ambiguous results and preprogram data were limited. The Fatal Accident Reduction Through Enforcement (FARE) program also reported reduced fatalities in 44 of 47 project locations (5). Again, research results were not completely convincing because of the lack of control sites.

Studies of nonenforcement components of alcohol countermeasures have produced little knowledge about the relation between education, treatment, and probation and alcohol-related accidents. The Tennessee DUI Probation Follow-Up Demonstration Project reported that probation, rehabilitation, or their combination had no significant impact on rearrest or accident rates (6). A study of education programs under the Sacramento, California, Comprehensive Driving Under the Influence of Alcohol Offender Treatment Demonstration Project (7) showed a significant reduction in DUI recidivism due to the education of first-offense drunk drivers. The education programs had no effect on accident involvement.

In general, it is commonly believed that alcohol countermeasures can be expected to produce reductions in alcohol-related accidents if sites are selected that actually have alcohol-related accident problems and if the population of the area is large enough to provide measurable reduction indicators. It is more likely to be successful if the countermeasure is more comprehensive in nature, involving enforcement and public information components as well as treatment, education, and sanctions. Recent findings that only suggest accident reduction are expected to be strengthened by continued, careful project implementation and evaluation.

PROJECT SAFETY

Project Safety provides an integrated systems approach to the drinking and driving problem in Bonneville County through coordination of prevention and education programs, DUI enforcement, sentencing and parole processes, and rehabilitation programs.

Planning for Project Safety began in the spring of 1979 in response to the Idaho Health Systems Agency plan, which called for a reduction in alcohol-related accidents. The plan further called for the initiation of a demonstration project to reduce alcohol-related traffic fatalities.

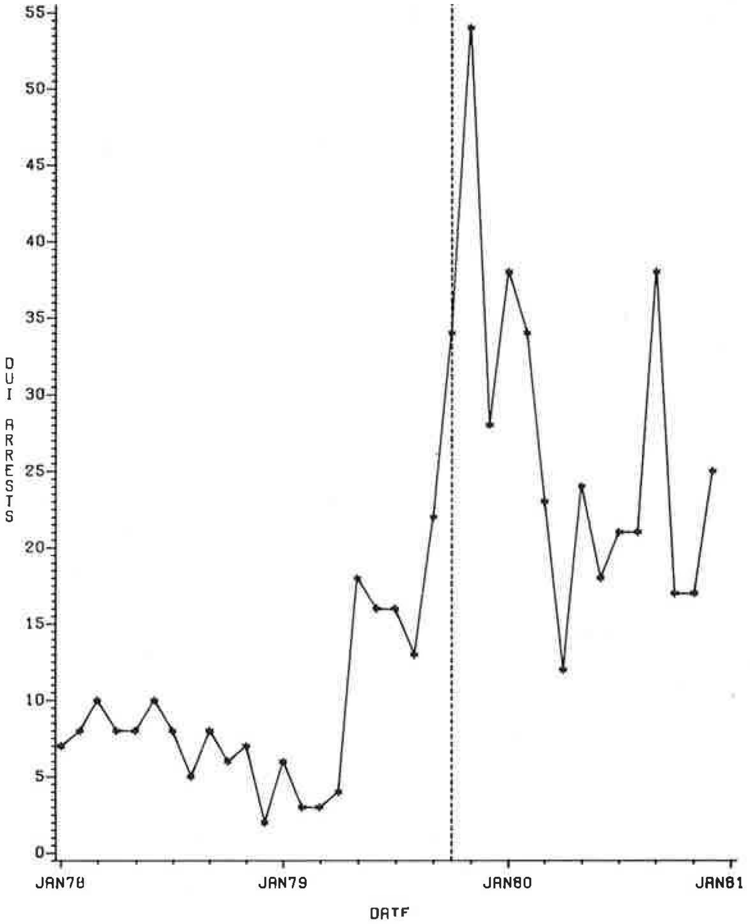
In the 1979 Idaho Highway Safety Plan, by use of an alcohol proxy measure, Bonneville County was ranked number one among all Idaho counties in 1978 alcohol-related accidents. Fortunately, Bonneville County had an alcohol abuse planning group and this group was challenged to seek a solution to the problem. The Combined Alcohol Rehabilitation and Education Services (CARES) policy committee contacted the Idaho Office of Highway Safety, requesting funds to implement a project to reduce alcohol-related accidents.

The resulting project created a new DUI Selective Traffic Enforcement Project (STEP) in both the Idaho Falls Police Department and the Bonneville County Sheriff's Office, a new probation and parole component within the county judicial system, and a new county staff position for a prevention-education specialist who would implement a public information campaign about the project. The program officially began on October 1, 1979.

The county already had well-established services for alcohol education and rehabilitation. However, these needed to be linked with the courts and enforcement in a more purposeful approach in order to control the alcohol traffic safety problem. With the addition of new staff, this was accomplished.

In the enforcement area, a two-man DUI STEP was created in both the Bonneville County Sheriff's Office and the Idaho Falls Police Department. Each STEP team worked shifts and geographic areas that were rated high in alcohol involvement. The patrols worked at night and during the early morning hours. The patrol officers were trained in DUI apprehension. Additional patrol vehicles, a direct breath-testing instrument, and video equipment were purchased for use on the project. Both law-enforcement agencies were located in the same building and were able to use the equipment effectively.

Figure 1. Bonneville County DUI arrests: 1978-1980.



There was a significant increase in DUI arrests for both law-enforcement agencies after initiation of the project. This was the first time either had specifically emphasized DUI detection and arrest. This increase was especially noticeable in the county, which historically had made few DUI arrests. Figures 1-3 show the changes in DUI arrest levels at the beginning of and during the program. It should be noted that much of the discussion about the alcohol problem resulted in increased arrest activity even before the implementation of the program on October 1, 1979, especially in the Bonneville County Sheriff's office.

The number of specialists providing presentence and probation services for DUI offenders was increased from two to five. The DUI specialists provided the link between the enforcement and judicial system and the alcohol-treatment system. Feedback was provided to the court on the status of sentences involving these services. At the beginning of the project, the Alcohol Rehabilitation Association (ARA) provided in-patient and intermediate-care alcohol services. The Idaho Department of Health and Welfare provided outpatient and educational services.

Available records showed that a 50 percent increase in the referral of DUI offenders to treatment occurred during the first 12 months of Project Safety. There were 399 people referred to treatment in the 12 months preceding Project Safety compared with 600 people referred in the first 12 months of the project. An additional 124 people were referred to treatment during the last three months of 1980. This evaluation covers the first 15 months of Project Safety.

The final component was a public information program to educate the public about Project Safety and the problem of drinking and driving in the community. A prevention-education specialist was hired to carry out this task. Activities initiated by this person included daily reports by several local radio stations, profiles of citizens arrested for DUI, a "this could be you" type of program, interviews about Project Safety on local television stations, news releases, booths at community events, and presentations at the junior high and high schools.

During the first six months of the project, the media were supportive and provided considerable coverage. As Project Safety continued, the type of high-exposure media coverage experienced at the beginning of the project was more difficult to obtain. A comparison shows that in the first fiscal project year, FY 1979/80, there was considerably more media activity than in project year FY 1980/81. In FY 1979/80, there were 7 television stories or interviews, 6 newspaper stories, and 10 radio interviews plus daily spot announcements over five AM/FM radio stations; in FY 1980/81, there were 2 television stories and 3 newspaper stories plus weekly spot announcements over 2 radio stations.

METHODOLOGY

Accident Measures

All of the accident data used in this study were retrieved from the central traffic accident data base maintained by the Idaho DOT. All state jurisdictions are required to provide copies of accident re-

Figure 2. Idaho Falls DUI arrests: 1978-1980.

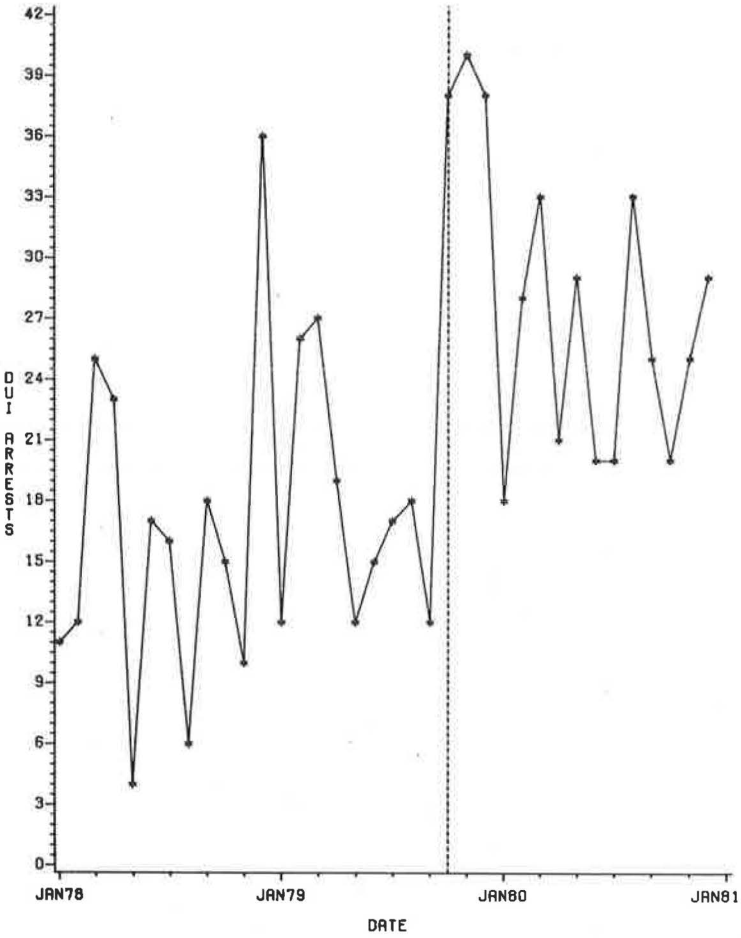
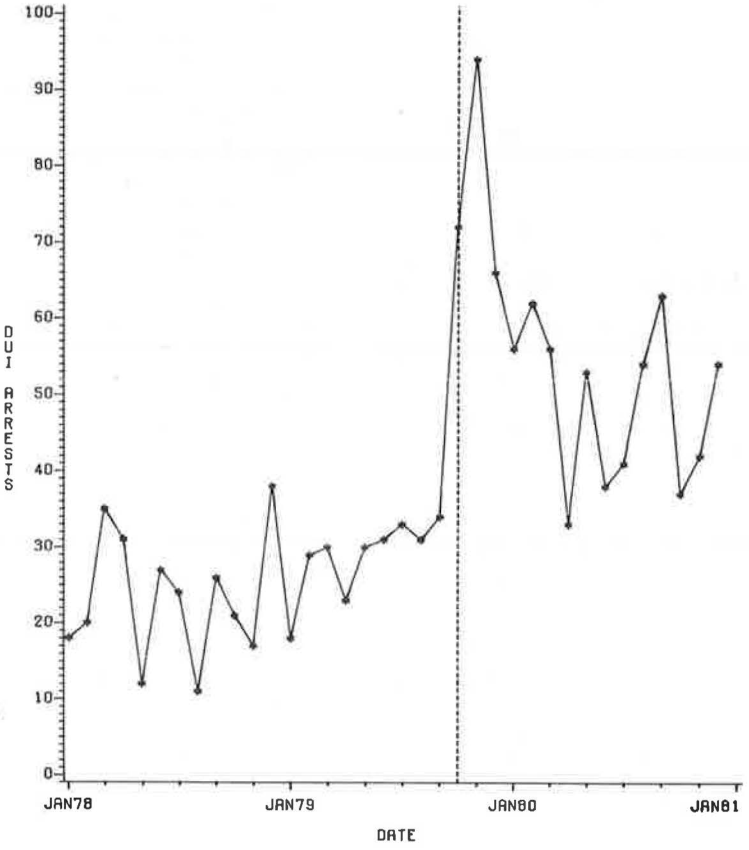


Figure 3. Total Project Safety DUI arrests: 1978-1980.



ports to be entered in this data base. An historical examination of the data used in this study provided no evidence to indicate significant reporting problems for fatal or injury accidents during the period under study.

Several types of data might serve as indicators of alcohol-related accidents. Police accident reports provide information about drivers' alcohol consumption levels when breath tests or blood tests are administered. Although such data are generally reliable, alcohol tests are actually administered rarely. In Idaho in 1980, only 2 percent of all drivers involved in accidents were given an alcohol test.

Another indicator of alcohol involvement is the item "had been drinking" under the category of "driver contributing circumstance" on the accident report form. This item is marked at the discretion of the officer even if a citation is not issued or if a test is not administered. This item is also infrequently checked (8.5 percent of all drivers in 1980). Officers are generally hesitant to indicate alcohol involvement without concrete evidence. A great deal of bias is also introduced because the tendency to mark "had been drinking" varies from officer to officer depending on training, experience, and personal values.

The major weakness of these indicators as effectiveness measures is their dependence on the officer's experience. It is likely that introduction of patrol officers trained in DUI enforcement will cause an upward shift in the frequency of alcohol testing and an increase in the observation of drinking behavior.

An alcohol proxy measure was developed to determine shifts in accidents believed to be alcohol related. The proxy used in this study differs from the alcohol proxy typically used in the NHTSA Fatal Accident Reporting System (FARS)--i.e., nighttime single-vehicle fatal accidents occurring between 8:00 p.m. and 4:00 a.m. (8). The proxy measure used in FARS would not be a feasible indicator of alcohol-related accidents in Idaho because there are only 330 yearly fatalities recorded statewide. Fatal-accident frequencies for counties or cities on a monthly basis are simply too small to be used for trend analysis.

The proxy measure used in this study includes all nighttime fatal and injury accidents occurring between 8:00 p.m. and 5:00 a.m. Accidents occurring on private property are excluded. An analysis of Idaho statewide accidents showed that accidents occurring during these hours normally involved a greater percentage of total drivers being given drinking tests (5.0 percent). Such accidents are also more frequently described by the officer as involving alcohol at some level. In fact, "had been drinking" and "inattention" are the most frequently cited driver contributing circumstances for nighttime accidents. For 23 percent of the drivers, "had been drinking" was noted. "Inattentive driving" was also noted on the accident report for 23 percent (inattentive driving is thought by Idaho traffic safety officials to be frequently related to alcohol).

The alcohol proxy just described is not to be interpreted as the actual number of alcohol-related accidents in any area. Instead, it should be used only as an indicator that is likely to shift if actual alcohol-related accidents are being affected.

A major weakness of the alcohol proxy is that it does not include all alcohol-related accidents because property-damage accidents are excluded due to unreliable reporting. It will therefore be difficult to estimate the complete impact of a DUI program by using the proxy measure.

Design

The evaluation design used here relies on a before-and-after analysis to measure the impact of Project Safety. In addition, two comparison counties in Idaho were selected to provide information about changes in proxy accident trends that occurred during Project Safety but in counties that did not have DUI prevention programs.

It was critical to determine the effect of generally reduced travel and other unmeasured exposure factors on alcohol proxy accidents. It was possible that proxy accidents that occurred at night, even though they were believed to be largely alcohol related, might be seriously affected by the same variables as daytime accidents. If it were found that daytime accident trends were generally not related to alcohol proxy accident trends, it would counter suggestions that accident reductions in the project location were caused by unmeasured exposure variables. Thus, data were also collected in comparison counties and in Bonneville County on daytime fatal and injury accidents (5:00 a.m. to 8:00 p.m.) to suggest overall accident patterns that could have affected proxy accidents differently in each county.

In a further attempt to verify overall accident trends and their relation to proxy accidents, statewide injury accidents were used to help corroborate relations found in the project county and the comparison counties. It was believed that this additional step was needed because comparison sites were not randomly selected before program implementation. Thus, even though similarity between comparison sites and the project county was a serious selection criterion, important differences could have been overlooked by the researchers. Overall statewide data could help suggest normal accident trends.

Comparison Counties and State Data

The researchers attempted to identify counties as similar as possible to Bonneville County. Factors considered significant in selecting sites were population, rural or urban composition, geography, problem size, and existence of DUI prevention programs. The two comparison counties selected were Bannock and Twin Falls.

Bonneville, Bannock, and Twin Falls Counties are similar in population, as indicated below:

County	Population		Increase (%)
	1970	1980	
Bonneville	52 457	65 980	26.0
Bannock	52 200	65 421	25.0
Twin Falls	41 807	52 927	27 0

According to 1980 census data (9), all three counties experienced approximately the same percentage growth in population since 1970.

Each of the study counties contains one major population center that is largely surrounded by very small rural communities and open farming country. All three have similar open-farmland geographic characteristics typical of eastern and southern Idaho. Another important common characteristic is that the major population center of each county is bypassed by one major Interstate highway. The accident frequencies for these counties are also similar.

All counties have similar estimates of vehicle miles of travel (VMT), as indicated in the following table (these estimates exclude local roads because knowledge of local-road VMT could affect the direction or magnitude of the percentage change from year to year):

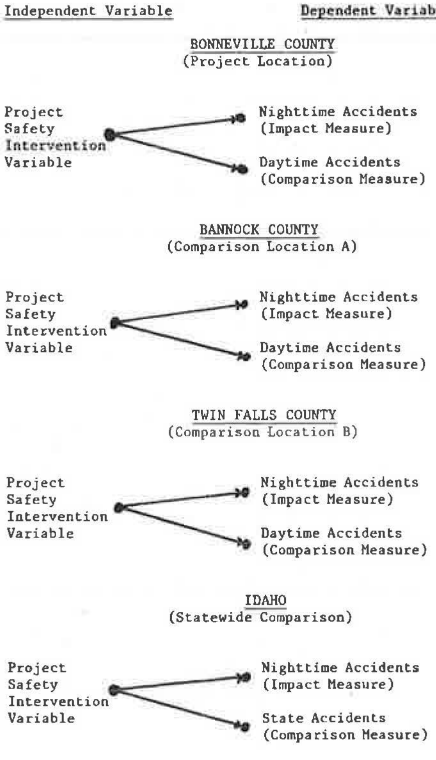
	VMT (000 000s)		
County	1979	1980	Change (%)
Bonneville	317	312	-1.5
Bannock	332	329	-0.9
Twin Falls	212	214	+0.9

There are differences among comparison counties in their abilities to address the problem of the drinking driver. Bannock County has traditionally had an alcohol-treatment program. However, there was no specific concentration on DUI enforcement and officer training in Bannock County, and there was no increase in DUI enforcement personnel levels during the Project Safety program. In fact, DUI arrests in Bannock County were 14 percent less in 1980 than in 1979.

It should be kept in mind that Bonneville County also has traditionally had a treatment program. This evaluation was conducted to measure the impact of an enhanced alcohol accident prevention program. Bannock County can be considered as not having a program of the type evaluated here because it does not have enforcement, public information, and coordination components comparable to those of the Bonneville County program.

The existence of a Bannock County treatment program prompted the inclusion of Twin Falls County, the third comparison group. Twin Falls County does not have a treatment or DUI enforcement program. DUI arrests remained stable from 1979 to 1980 in Twin Falls County. In addition, Twin Falls County does not experience the possible spillover effects of the public information component of Project Safety. Bannock County receives some of the same television and radio information received in Bonneville County. The Twin Falls site was needed to control for alcohol education information released through Project Safety. This precaution was taken even though public information without enforcement has never been shown to have a direct effect on accident occurrence.

Figure 4. Analysis procedure.



Statewide data were collected in two forms: (a) state fatal and injury accidents and (b) nighttime fatal and injury accidents. All counties where active STEPs were in operation were omitted from statewide data. Nighttime hours were defined in the same fashion as project and comparison group data. Figure 4 shows the design approach used in this study.

In all cases, monthly data covered the period from January 1975 to December 1980. The Project Safety intervention was introduced in October 1979.

Analysis Technique

The Box-Jenkins time series approach (10) was used to determine the time series parameters and transfer function estimates for the data. The advantage of using the Box-Jenkins approach is that it allows the researcher to account for and describe characteristics of the data attributable to seasonality or trend or both as well as characteristics of the data that are correlated with individual or multiple independent variables. The time series model for each of the relations to be examined in this study can generally be mathematically depicted as follows:

$$Y_t = W_o I_t + N_t \tag{1}$$

where

Y_t = monthly alcohol proxy accidents at time period t;
W_o = impact of Project Safety, i.e., average monthly change in Y_t;
I_t = Project Safety intervention variable at time period t (when $t < 58$, $I_t = 0$; otherwise, $I_t = 1$);
N_t = noise series, some function of normal independently distributed error.

The transfer function parameter (W_o) may be interpreted as the average monthly change in accidents during the presence of Project Safety. N_t represents the noise portion of the model for Y_t. N_t contains seasonality, trend, and other time series characteristics of Y_t. The final model will also include reasonable, identifiable delays in program impact that may occur when a program is just beginning.

The t-test statistic was used to determine whether or not W_o was different from zero. Significance was tested at the 95 percent confidence level.

Hypotheses

The following research hypotheses were tested.

1. There will be a significant reduction in nighttime injury accidents in Bonneville County during the time Project Safety is in effect:

$$W_o(1) < 0 \tag{2}$$

where $W_o(1)$ is the average monthly change in nighttime injury accidents in Bonneville County.

2. Reductions in nighttime injury accidents in Bonneville County will be greater than possible reductions in nighttime injury accidents in Bannock County, comparison location A, during the program period:

$$W_o(1) < W_o(2) \tag{3}$$

where $W_o(2)$ is the average monthly change in nighttime accidents in Bannock County during the program period.

Figure 5. Bonneville County alcohol proxy accidents.

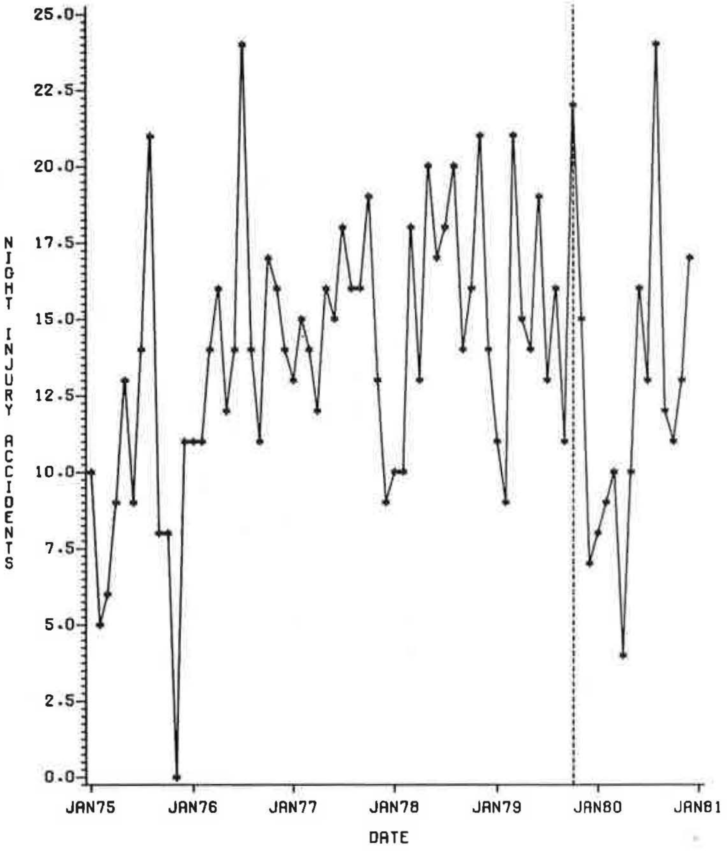


Figure 6. Bannock County alcohol proxy accidents.

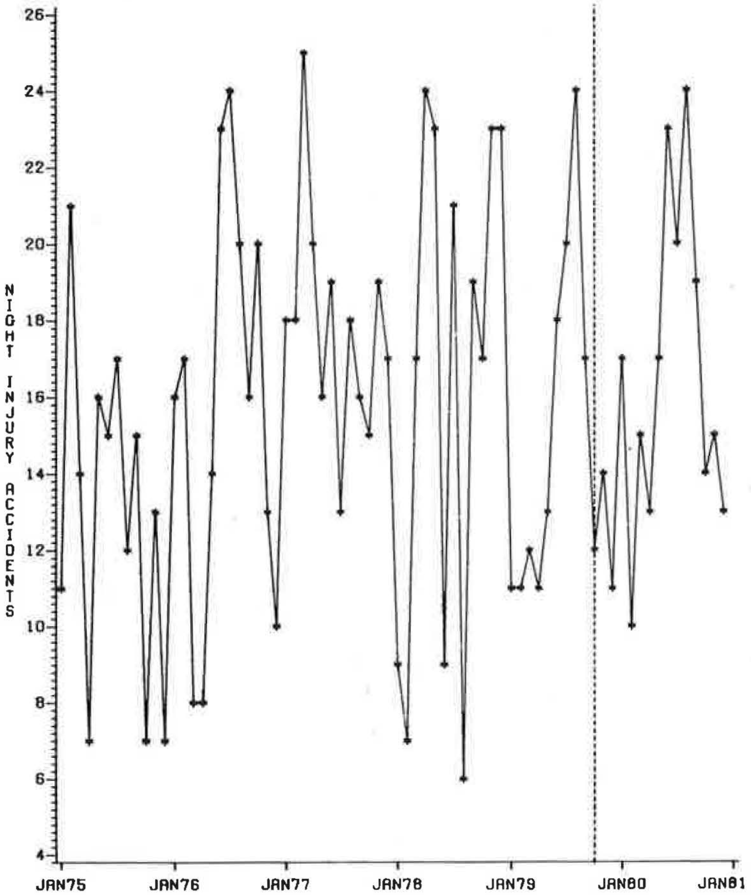


Figure 7. Twin Falls County alcohol proxy accidents.

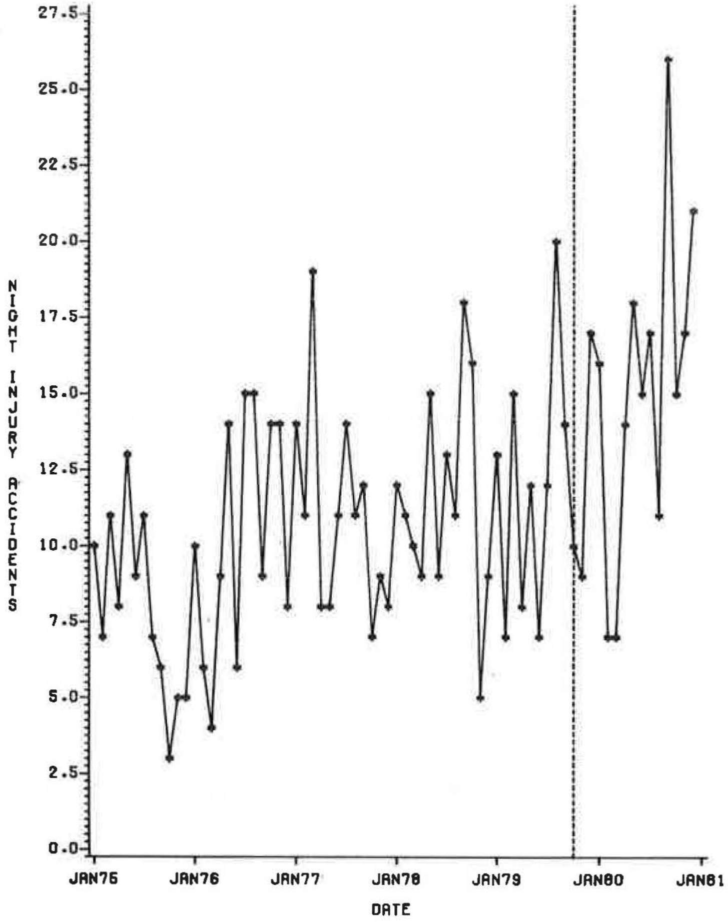


Figure 8. Data sets subjected to time series analysis by use of intervention variable.

STATE ALCOHOL PROXY ACCIDENTS

Transfer function = -0.71
t-statistic = -0.06
Delay time = 1 month
Significance = No
Generalized model:

$$Y_t = -0.71\ I_{t-1} + [1 - 0.63B)(1 - 0.67B^{12})]/[(1 - B)(1 - B^{12})]\ a_t$$

STATE INJURY ACCIDENTS

Transfer function = -18.0
t-statistic = -0.57
Delay time = 1 month
Significance = No
Generalized model:

$$Y_t = -18.0\ I_{t-1} + [(1 - 0.52B)(1 - 0.60B^{12})]/[(1 - B)(1 - B^{12})]\ a_t$$

BONNEVILLE COUNTY DAYTIME ACCIDENTS

Transfer function = -7.8
t-statistic = -3.39
Delay time = 1 month
Significance = Yes
Generalized model:

$$Y_t = -7.8\ I_{t-1} + [(1 - 0.28B^{12})/(1 - B^{12})]\ a_t$$

BANNOCK COUNTY DAYTIME INJURY ACCIDENTS

Transfer function = -6.5
t-statistic = -2.41
Delay time = 1 month
Significance = Yes
Generalized model:

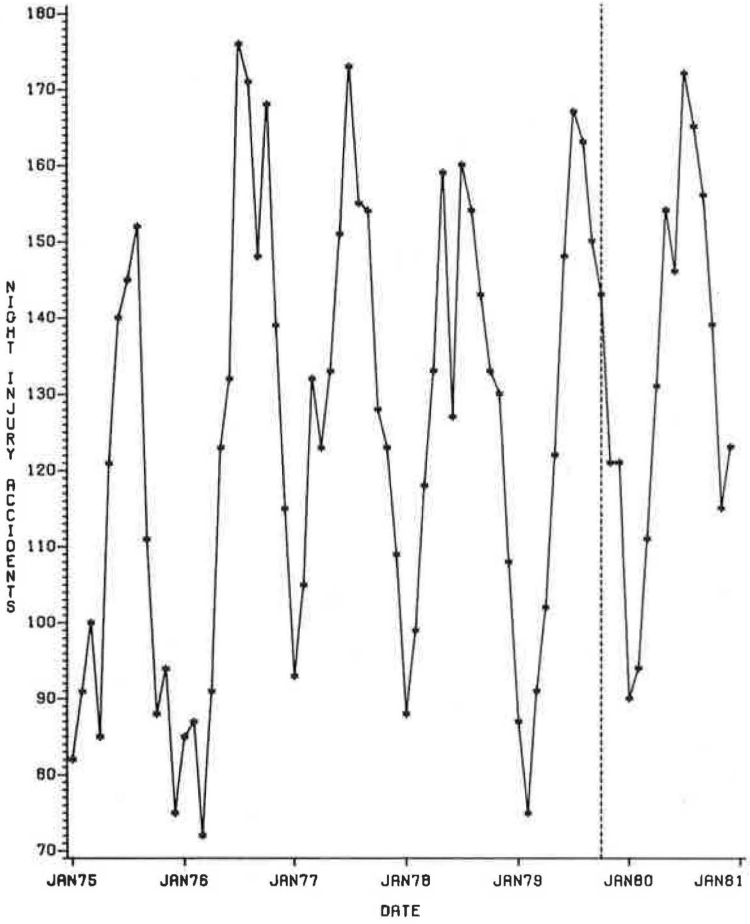
$$Y_t = -6.5\ I_{t-1} + [(1 - 0.60B^{12})/1 - B^{12})]\ a_t$$

TWIN FALLS COUNTY DAYTIME INJURY ACCIDENTS

Transfer function = -6.0
t-statistic = -1.18
Delay time = 1 month
Significance = No
Generalized model:

$$Y_t = -6.0\ I_{t-1} + [(1 - 0.61B)/(1 - B)]\ a_t$$

Figure 9. State alcohol proxy accidents.



3. Reductions in nighttime injury accidents in Bonneville County will be greater than possible reductions in nighttime injury accidents in Twin Falls County, comparison location B, during the program period:

$$W_o(1) < W_o(3) \tag{4}$$

where $W_o(3)$ is the average monthly change in nighttime injury accidents in Twin Falls County during the program period.

The relations between the Project Safety intervention variable and county daytime and statewide measures were examined to help explain relations found between Project Safety and nighttime accidents in the project and comparison locations.

RESULTS

Findings

Figure 5 shows nighttime injury accidents for the project location, Bonneville County. The time series represents monthly accidents that occurred between January 1975 and December 1980. Project Safety was implemented in October 1979.

The mathematical time series (intervention) model for the data is presented below:

$$Y_t = -\overset{(2.2)}{4.6}\, I_{t-1} + \{[(1 - \overset{(0.07)}{0.87}B)(1 - \overset{(0.10)}{0.62}B^{12})]/[(1 - B)(1 - B^{12})]\}\, a_t \tag{5}$$

where

Y_t = monthly nighttime injury accidents in Bonneville County in time period t;
I_t = intervention effect in time period t;
B = back-shift operator;
a_t = white noise component of Y_t after the transfer function (-4.6), moving average $(1 - 0.87B)$, seasonal moving average $(1 - 0.62B^{12})$, regular difference $(1 - B)$, and seasonal difference $(1 - B^{12})$ components have been removed from Y_t; and

$$N_t = \{[(1 - 0.87B)(1 - 0.62B^{12})]/[(1 - B)(1 - B^{12})]\}\, a_t$$

The standard errors for each of the parameter estimates are displayed in parentheses above the estimates. A delay period of one month was identified, as indicated by the term I_{t-1}. All parameter estimates were significant at the $\alpha = 0.05$ level. The t-statistic for the transfer function parameter was -2.09.

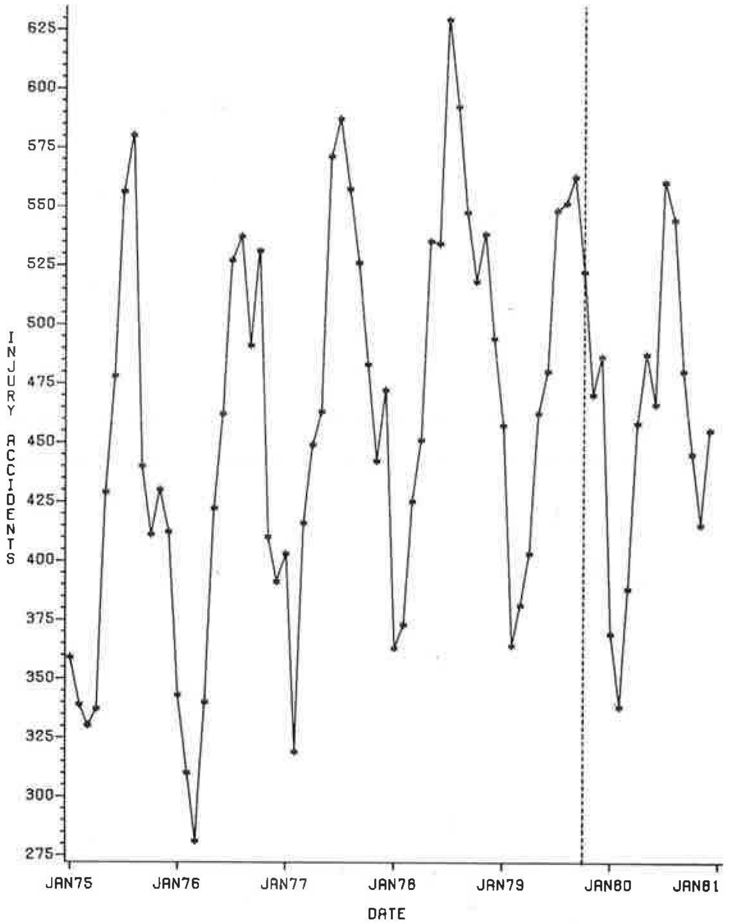
A time series (intervention) model was developed for comparison location A, Bannock County, and comparison location B, Twin Falls County. Figure 6 shows monthly nighttime injury accidents for Bannock County that occurred between January 1975 and December 1980. The Project Safety intervention variable was used in the analyses. A one-month delay period was introduced for all comparison locations to be consistent with the Bonneville County model.

The mathematical time series (intervention) model for Bannock County nighttime injury accidents is as follows:

$$X_t = \overset{(1.79)}{0.64}\, I_t + [(1 - \overset{(0.12)}{0.65}B^{12})/(1 - B^{12})]\, a_t \tag{6}$$

where X_t is monthly nighttime injury accidents in Bannock County in time period t.

Figure 10. State injury accidents.



The seasonal moving average parameter was significant at the $\alpha = 0.05$ level. The t-statistic (0.36) for the transfer function parameter was not significant.

Figure 7 presents the monthly time series data for Twin Falls County nighttime injury accidents. The mathematical time series (intervention) model for Twin Falls County nighttime injury accidents is presented below:

$$Z_t = \overset{(1.2)}{4.5}\, I_t + N_t \qquad (7)$$

where

Z_t = monthly nighttime injury accidents in Twin Falls County in time period t and

$N_t = a_t$.

The transfer function parameter was found to be significant at the $\alpha = 0.05$ level ($t = 3.75$). Seasonal and automobile correlation components in the time series were not significant and therefore were not included in the model.

The sets of data shown in Figure 8 were subjected to the same time series (intervention) analysis as the project and comparison locations by using the Project Safety intervention variable. As with the previous comparison data, a one-month delay time was forced into these models to ensure similar time-period comparison. Graphs of these data sets are shown in Figures 9-13.

Interpretation of Findings

The results indicated a significant reduction in nighttime injury accidents in the project location, Bonneville County, during Project Safety implementation. Significant reductions began occurring in November 1979. The average monthly reduction from the preintervention level was 4.6 accidents/month. An effort was made to rule out the possibility that the above reductions resulted from some factor other than Project Safety by examining similar counties that did not have a comprehensive alcohol program.

Reductions in nighttime injury accidents did not occur in comparison location A, Bannock County, or in comparison location B, Twin Falls County. In fact, changes in accident frequencies in the comparison groups did not resemble reductions in the project location, Bonneville County, in direction or magnitude. Bannock County nighttime injury accidents remained stable during the implementation of Project Safety. Twin Falls County actually experienced a significant increase in nighttime accidents during the project period. The increase in nighttime accidents in Twin Falls County was 4.5 accidents/month.

It was possible that alcohol proxy accidents could have been reduced due to statewide travel and other factors. However, it was found that alcohol proxy accidents did not vary in the same way as daytime injury accidents during the project period. State alcohol proxy accidents remained essentially

Figure 11. Bonneville County daytime injury accidents.

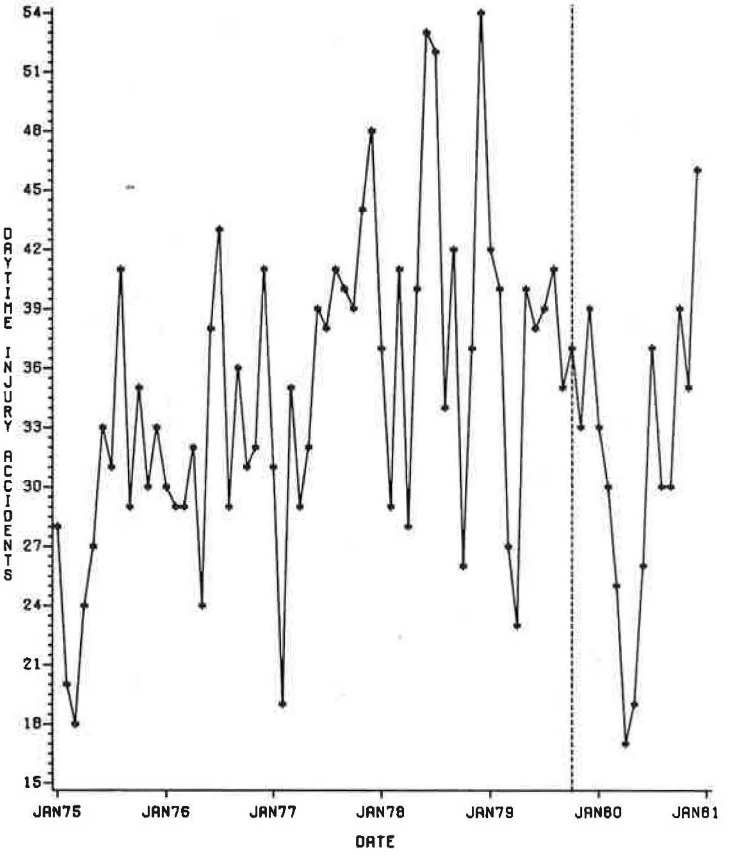


Figure 12. Bannock County daytime injury accidents.

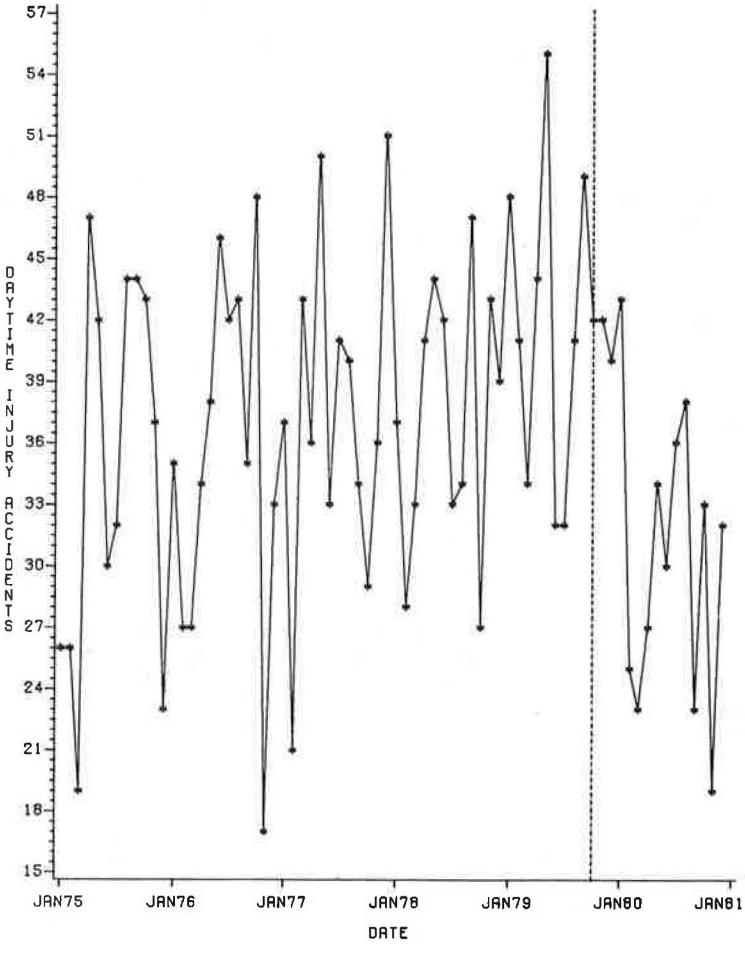
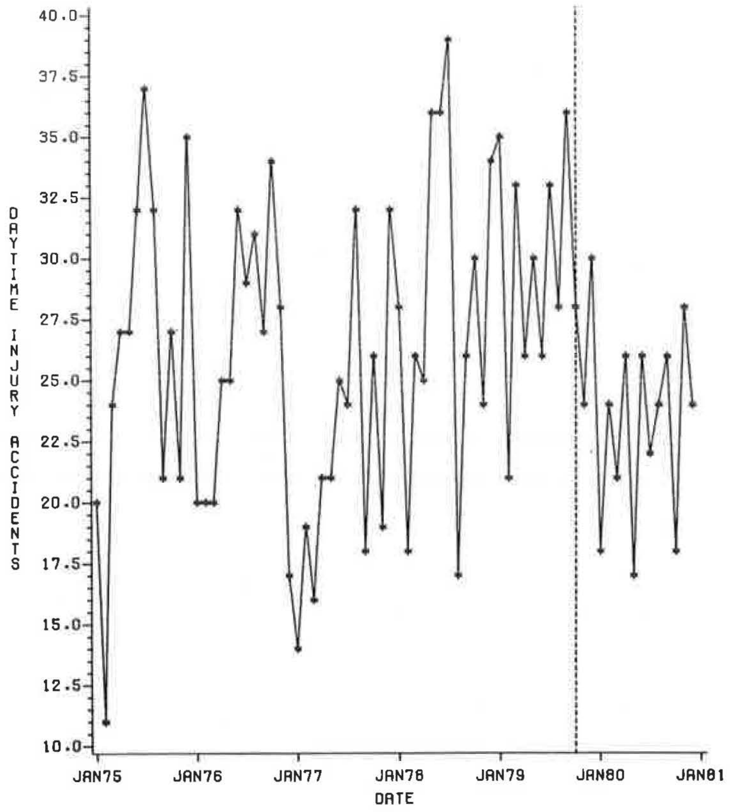


Figure 13. Twin Falls County daytime injury accidents.



stable during the program period. State injury accidents decreased only slightly during the program period.

Daytime injury accidents in Bannock County decreased significantly by a monthly average of 6.5 accidents. Twin Falls County also experienced a reduction in daytime injury accidents of 6.0 accidents/month, although this reduction was not significant at the 0.05 level. Bonneville County experienced a significant daytime accident reduction also (an average of 7.8 accidents/month).

Reductions in daytime injury accidents in the study counties do not appear to be reflected to any great degree in state injury accidents. A good deal of research remains to be done to determine the reason for this apparent difference. Other counties included in the state measure used here are generally quite different from the study counties in population, size, and geographic makeup. Decreases in the study counties must have been offset by increases in other counties. No explanation can be offered here.

In general, the study counties did experience reductions in daytime accidents that appear to be unrelated to trends in alcohol proxy accidents. Alcohol proxy accidents may be less likely to be affected by exposure variables because night driving is less likely to include long-distance trips, especially if drinking is involved. The stable or increasing pattern of alcohol proxy accidents statewide and in the comparison counties could be partly explained by a weaker relation to exposure factors.

CONCLUSIONS

The Project Safety DUI prevention program was implemented to reduce alcohol-related traffic accidents in Bonneville County through enhancement of the alcohol-treatment, enforcement, education, and public-information efforts of the county and city governments. The program resulted in substantial increases in DUI enforcement, public-information, and treatment activities. An estimated average reduction of 4.6 nighttime fatal and injury accidents/month occurred during the study period (64 total accidents). Reductions began occurring one month after the start of the program. A comparison with the two other similar counties showed that the above reduction was unique to Bonneville County during the program study period.

Although a monthly reduction of 4.6 fatal and injury nighttime accidents may not appear important, it must be remembered that it makes up a 39 percent average monthly reduction in the alcohol proxy measure in comparison with the appropriate 12 months before Project Safety. Over a 12-month period, it represents 55 accidents. By way of comparison, 55 accidents represents 9 percent of all 1979 injury accidents in Bonneville County (607). This study did not estimate probable reductions in property-damage-only or private-property accidents.

It is estimated that a total of 64 accidents were prevented during the study period. The total cost of the project for that same period amounted to $312 471. The estimated cost of the accidents that were prevented is $1 million. The benefit/cost ratio for Project Safety was approximately 3.2. Given the size of the accident problem in Bonneville County and the scope of the DUI accident prevention program, Project Safety was found to be cost effective.

REFERENCES

1. Alcohol and Highway Safety. U.S. Department of Transportation, 1968.
2. Results of National Alcohol Safety Action Projects. NHTSA, 1979.
3. H.R. Lawrence. Deterrence of the Dri Driver: An International Survey. NHTSA,

4. J. House and others. Increased DUI Enforcement Program: Stockton, California. U.S. Department of Transportation, draft rept., 1979.
5. R. Voas, M. Ruzecke, and R. Youngs. Fatal Accident Reduction Through Enforcement: The Implementation of a Quick Reaction Nationwide Safety Program. NHTSA, 1976.
6. R.T. Holden and others. Tennessee DUI Probation Follow-Up Demonstration Project. NHTSA, 1981.
7. R.E. Reis, Jr. The Traffic Safety Impact of Education Programs for First Offense Drunk Drivers: An Interim Analysis. Presented at National Safety Council Symposium on Traffic Safety Effectiveness Evaluation Projects, Rosemont, IL, May 19-21, 1981.
8. Traffic Fatal Accident and Fatality Data Collected on FARS for the Year 1980. In Fatal Accident Reporting System 1980, U.S. Department of Transportation, 1980.
9. 1980 Census of Population and Housing: Advance Reports (Idaho). U.S. Department of Commerce, Feb. 1981.
10. R. McCleary and others. Applied Time Series Analysis for the Social Sciences. Sage Publications, Inc., Beverly Hills, CA, 1980.

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Field Study of Rail-Highway Grade-Crossing Crash Sites

J.W. HALL

The results of a study undertaken to determine whether an acceptable level of safety has been achieved at the 845 public rail-highway grade crossings in New Mexico are presented. Field studies were conducted at 57 rail-highway grade crossings where one or more accidents had occurred during a 30-month period. With few exceptions, these crossings were found to have adequate design and operational features. Of the sites studied, 35 percent had active traffic-control devices installed after the accident. The project also examined the existing grade-crossing inventory data to determine their accuracy. The study found numerous errors in the inventory file: Principal deficiencies related to highway volumes and advance signs and markings. Evaluation of the data for a limited time period following improvements found an apparently significant reduction in crash experience, which was achieved at a cost of $35 000/accident. The researchers recommend correction of the few deficiencies found in the field study, upgrading of sites that do not meet relevant signing and marking standards, updating of the inventory, and more extensive use of the crossing identification number on accident report forms.

Traffic accidents that occur at the intersection of a rail line and a street or highway are one of the enigmas of highway safety. Available statistics indicate that such accidents are both rare and severe. Their rarity is indicated by the fact that, on an annual basis, at the approximately 220 000 public rail-highway grade crossings in this country there are a total of 11 100 accidents, or an average of 0.05 accident/public crossing/year (1). The severity statistics are also not surprising; the result of several 200-ton locomotives pulling a 5000-ton string of freight cars and striking a 1.5-ton car or pickup is not difficult to predict. What is perhaps surprising is that such a collision does not always result in a fatality. National data indicate that 11 percent of the collisions between trains and highway vehicles result in fatalities and that many of the remainder produce occupant injuries. Although they account for less than 0.1 percent of nationwide traffic accidents, collisions with trains result in approximately 2 percent of the highway fatalities.

In one sense, the grade crossing is just like any other highway intersection where two flows of traffic intersect. However, the generally low train volumes create a situation in which the approaching driver knows that a train may be at the crossing but does not expect one to be there while he or she is actually at the crossing. In an attempt to improve safety at these locations, a variety of static and active traffic control devices can be used to warn approaching motorists and to regulate vehicle traffic when a train is near the crossing. Flashing lights or gates are preferred treatments, but they are expensive, and limited funds for improvement restrict the number of locations that can be treated with these devices.

Through mechanisms with varying degrees of formality, safety improvements at rail-highway grade crossings must compete for funding with a variety of other highway programs that range from spot improvements to new construction. Numerous studies have documented the highly favorable measures of cost-effectiveness for some of these other types of remedial actions. However, once the most hazardous grade crossings have been improved, it is difficult to show a comparable level of cost-effectiveness for the remaining crossings. In fact, it is valid to inquire whether a point of diminishing returns has been reached in grade-crossing safety (2). The objective of this study was to determine whether New Mexico and the three principal railroads that operate within it have, through their previous improvement programs, reached the maximum practical level of safety at rail-highway grade crossings.

Although New Mexico is the fifth largest state in land area, it has only 1960 miles of Class I and Class II rail line, barely 1 percent of the mileage in the entire country. The state has 845 public rail-highway crossings, approximately 0.4 percent of the nationwide total. Accident statistics based on police reports for the 1961-1980 period show that the state averaged 32.5 train-involved accidents/year. Annual fatal and injury accidents averaged 4 and 10, respectively. Although there was a small annual increase in accident experience during this period, the increase is apparently less than the growth of either rail or highway volumes. A 1979 tabulation of grade-crossing accidents and incidents reported to FRA by the railroads shows that New Mexico had 0.24 percent of the nationwide accidents, 0.96 percent of the fatalities, and 0.37 percent of the injuries. Although it is risky to draw strong conclusions from this data base, it appears that the state has fewer but more severe accidents than might be expected in view of its relative share in the number of crossings.

In a typical year, less than 4 percent of New Mexico's public grade crossings have an accident.

As a result, the New Mexico State Highway Department uses a hazard index to help in establishing priorities for countermeasure implementation. The index is a modified version of the New Hampshire method, which includes sight distance, train speed, and accident history parameters in addition to the standard parameters of highway and railroad traffic volumes and a traffic-control-device factor. Like most hazard index methodologies, this procedure calculates a relative value and makes no clear distinction between safe and hazardous. Because the index does not predict accidents, it cannot be used in traditional forms of benefit-cost analysis (3). It may be useful for setting priorities among potential grade-crossing improvements, but it is of minimal value in allocating funds among competing safety programs.

In recent years, the Highway Department, using this index and input from a diagnostic team, undertook a vigorous program of grade-crossing improvements. At approximately 11 percent of the crossings, active devices (costing, on the average, $60 000) were installed, and, at many others, signs and markings were installed or upgraded. Despite these improvements, there was an average of 32 accidents/year for the 1978-1980 period, which was almost identical to the experience in the preceding 17 years. At this point, responsible highway officials began to question the results of their efforts and to seek a more thorough analysis of the consequences of their program.

STUDY PROCEDURES

To achieve the objectives of this project, a research plan involving computer analysis of National Railroad Grade Crossing Inventory data and a field study of accident sites was developed and implemented. Combined input from both data sources provided a means of evaluating the accuracy of the national inventory.

Data for the initial inventory were collected by the railroads and the New Mexico State Highway Department in 1974. The inventory contains 78 data items for each public grade crossing in the state. With the notable exception of sight distance, the inventory contains information on most of the relevant physical and operational features at rail-highway grade crossings. The seven-digit crossing number provides a means of relating the inventory information to other data bases, such as the FRA accident file. At the time of the study, the established mechanism for updating inventory information had been used extensively by the railroads but sparingly by the Highway Department.

Several basic crossing characteristics are summarized in Table 1. Traffic volumes at the crossings are generally low; only 19 percent have average daily traffic (ADT) in excess of 1000 vehicles. The comparatively minor nature of many of the roads is supported by their functional classification (57 percent are classified as other local roads) and the fact that only half the roadways were paved. The busiest rail line has 46 trains/day. The average crossing has 1.46 tracks.

Table 1. Characteristics of New Mexico grade crossings.

Characteristic	Low	High	Avg	Median
ADT (no. of vehicles)	5	27 000	1040	100
Trucks (%)	0	93	8.2	5
Daily trains				
Day	0	23	5	3
Night	0	23	4	2
Train speed (mph)	0	90	42	49
Number of tracks				
Main	0	3	0.90	1
Other	0	7	0.56	0

The inventory provides extensive information on the type of warning device at the crossing. FRA classifies these according to a hierarchy from no devices (1) to gates (8), characterizing the crossing protection level by the highest level of warning device. Table 2 summarizes the highest warning level for nine categories of traffic volume. Crossbucks are the predominant form of traffic-control device, accounting for the highest level of protection at 68 percent of the crossings. Active devices are in use at 29 percent of the crossings. For those crossings with estimated ADT of 1250 or more, 73 percent had active devices. In general, higher levels of protection are provided at crossings with higher traffic volumes. A separate analysis showed a rank order correlation of +0.57 between traffic volume and protection level, which is highly significant for the sample size. The correlation between number of trains per day and highest level of protection is +0.37, which is also statistically significant.

In addition to signs and active devices at the crossings, the inventory contains information on the use of pavement markings and advance-warning signs. The railroad advance-warning sign (W10-1) was reported at only 168 (20 percent) of the crossings. Because the sign is placed several hundred feet in advance of the crossing, its presence may not have been detected by technicians conducting an inventory from the tracks. The inventory data indicate that 61 (7 percent) of the crossings had standard pavement markings prescribed for railroad crossings. More specifically, 57 sites had the RR symbol on the pavement, and 45 provided a stopline.

The inventory data were analyzed by using correlation techniques to determine relations among the several variables. This analysis showed that, where

Table 2. Highest warning level used at crossings by volume of vehicle traffic.

	No. of Crossings Using Device						
Traffic Volume	None	STOP	X-Buck	Wigwag[a]	Light	Gate	Total
<100	11	2	394	5	7	12	431
100-200	0	1	62	0	9	10	82
200-400	2	1	41	2	14	15	75
400-625	4	0	20	1	11	9	45
625-1250	1	1	20	0	26	18	66
1250-2500	0	0	15	2	21	19	57
2500-5000	0	0	9	0	12	19	40
5000-10 000	0	0	8	0	8	14	30
>10 000	0	0	7	0	3	9	19
Total	18	5	576	10	111	125	845

[a] Includes bells and highway traffic signals.

Table 3. Average rail-highway crossing characteristics.

Characteristic	Accident Crossings	Nonaccident Crossings
Highway ADT	2200[a]	960
Trucks (%)	7.9	8.2
Number of daytime trains	8.0[a]	4.7
Number of nighttime trains	7.0[a]	3.9
Total number of trains	15.0[a]	8.6
Train speed (max mph)	50.2[a]	41.9
Number of highway lanes	1.98[a]	1.75
Number of main tracks	1.12[a]	0.88
Number of other tracks	0.37	0.58[b]
Total number of tracks	1.49	1.46
Warning device class[c]	5.98[a]	4.86
Number of crossbucks	0.57	0.92[b]
Number of STOP signs	0.12	0.03
Number of other signs	0.05	0.04
Number of bells	0.61[a]	0.30
Number of flashers	1.45[a]	0.62
Number of traffic signals	0.11	0.01
Number of gates (red/white)	0.54[a]	0.20

[a] Significantly higher at the accident sites at $\alpha = 0.05$.
[b] Significantly higher at the non-accident sites at $\alpha = 0.05$.
[c] From no warning (1) to gates (8).

traffic volumes are higher (principally in urban areas), there tend to be fewer main tracks, more other tracks, and lower train speeds. Crossings with higher train volumes tend to have more main tracks and higher speeds. Sites with higher train speeds generally have more main tracks and a higher level of protection, whereas the number of highway lanes and other tracks is typically lower. In addition, the protection level was generally higher for crossings with more highway lanes, main tracks, and other tracks. None of these correlations is particularly surprising. They basically show that more important crossings--as reflected by higher volumes (trains and vehicles), speeds, and number of tracks--are better protected.

FIELD STUDIES

Although the inventory contains a substantial amount of information, it is not comprehensive with respect to some highway parameters, such as alignment and sight distance, which may be significant in causing accidents. In addition, because the highway data in the inventory had not been updated on a periodic basis, the accuracy of some inventory information was questionable. In an attempt to address these issues, field studies were made at 57 grade crossings at which there had been 67 train accidents during a 30-month period ending in December 1979. During the review and analysis of data on grade-crossing accidents, discrepancies were noted in the number and location of accidents contained in the Highway Department and FRA record systems.

The field measurements and observations were designed to verify and supplement the inventory data. Observations were used to check inventory data on such things as traffic-control devices, number of tracks, advance-warning devices, and the presence of nearby intersections. Measurements were made of roadway alignment, crossing profile, and control-device placement as well as approach and AASHTO Type III sight distance. The techniques for making these measurements are described in the research report (4). Supplementary information on the operational characteristics of the crossings was provided by the Highway Department and the railroads.

DATA ANALYSIS

The seven-digit crossing number, an integral part of the inventory system, should permit comparison between crossings that have experienced train-vehicle collisions and those where there were no such accidents during the study period. The usual failure of the investigating officer to include this number on the accident report complicates the process of determining the actual crossing number of the accident sites. With the assistance of the Highway Department files and through the field studies, it was possible to make a reliable determination of the crossing number of the accident sites. Then it was a rather straightforward process to compare the inventory characteristics of crossings where accidents had occurred and those where accidents had not occurred.

Table 3 compares the 1980 inventory information for the two categories of crossings. The crossings that experienced accidents are clearly more active: They have twice the train and highway volume of public crossings that did not have accidents during the study period. They also have significantly more highway lanes and main tracks and significantly fewer other tracks. Maximum typical train speeds are also significantly higher. The protection level is higher at the crossings where there were accidents, as evidenced by the significantly larger number of bells, flashers, and red-white gates.

By using the protection factor coefficients used in the New Hampshire hazard index (i.e., 1.0 for signs, 0.6 for flashing lights, and 0.1 for gates), the average protection coefficients were found to be 0.62 for the crossings with accidents and 0.82 for the crossings without accidents. The values are significantly different, verifying what is implied in Table 3--that is, that better protection is provided at the crossings where accidents occurred. The New Hampshire index for all public crossings averaged 2640. For crossings with accidents, the index averaged 9030, which is significantly higher than the index of 2180 for the crossings without accidents. This finding indicates that, as a group, the crossings with accidents, despite their higher protection levels, are more hazardous than the much larger set of crossings where accidents did not occur during the study period.

Another item of concern with respect to the inventory is the accuracy of the data it contains. The basic inventory data were collected in 1974. As grade-crossing improvements are made, the railroad submits an updated inventory form to the Highway Department, which in turn modifies the highway data (if necessary) and forwards the information to FRA. Of the crossings studied in this research, 25 (45 percent) were updated since the original data collection, mostly in response to improvement in traffic-control devices.

The accuracy of the physical information at the site was established by comparing the inventory with the conditions actually observed in the field. Of the crossings studied in this research, 42 (74 percent) exhibited physical conditions in the field that differed from those listed in the inventory. By far the most prominent error in the inventory is its failure to document the actual presence of the railroad advance-warning sign (W10-1). At nearly half the accident sites, the inventory indicated that this sign was not present when in fact it was placed on one or both approaches. Because the original inventory data were collected by a team moving along the track rather than on the highway, it is reasonable to expect that this sign could be easily overlooked. The next most common errors involved the failure to note the presence of pavement markings, specifically the RR symbol and stoplines. It is quite possible that the markings, which have a relatively short lifetime, were not in place when the inventory was initially conducted.

Table 4. Alignment characteristics at accident sites.

Characteristic	Mean	Min	Max
Curvature			
150 ft[a, b]	0.48	-15.51	21.27
50 ft[a, b]	-0.26	-15.42	24.11
Average	0.11	-13.90	18.63
Modified[c]	-0.38	-10.00	10.00
Absolute[d]	1.40	0	18.63
Gradient			
150 ft[a]	0.34	-5.00	7.60
50 ft[a]	1.47	-2.80	7.20
Average	0.91	-2.40	5.75
Approach profile[e]	3.17	-1.94	10.78
Departure profile[e]	-3.06	-9.80	2.84
Superelevation			
150 ft[a]	1.71	-3.00	7.20
50 ft[a]	1.96	-3.30	8.80

[a] Distance in advance of the rail tracks.
[b] Curves to the left were assigned positive algebraic signs.
[c] Truncated to values between -10° and +10°.
[d] Absolute value of the average curvature.
[e] Established from level readings at the rail and 50 ft on either side. "Approach" is the direction of the vehicle involved in the accident.

Table 5. General characteristics at accident sites.

Characteristic	Sites (%)
Land use	
Commercial	46
Farming	45
Residential	9
Level of development	
Heavy	28
Moderate	40
Light	15
Undeveloped	17
Type of area	
Rural	40
Suburban	3
Town	57
General approach alignment	
Horizontal	
Tangent	70
Curve left	14
Curve right	16
Vertical	
Level	72
Upgrade	19
Downgrade	9
Protective devices that need physical maintenance	30
Sites with official, nonrailroad traffic-control devices	43

According to the inventory guidelines, a nearby intersecting highway is one within 75 ft of the crossing. This characteristic, which is not likely to change much over time, is improperly coded for 8 (14 percent) of the sites. These and other major error categories and the number of crossing sites (of the 57 sites studied) at which errors were noted are given below:

Category	No. of Sites Where Error Was Noted
RR advance-warning sign	27
RR symbol (pavement marking)	21
Stopline (pavement marking)	16
Nearby intersecting highway	8
Red and white gates	7
Bells	5
Passing zone markings	4
Number of train tracks	3
Number of highway lanes	3
Miscellaneous	10

Miscellaneous includes the presence of flashing lights, crossbucks, STOP signs, other (exempt) signs, and crossing surface characteristics.

Table 6. Placement of official railroad traffic control devices.

Device	No. of Sites	Distance from Rail (ft)			
		Avg	Min	Max	MUTCD
Gates	29	12.8	9	17	10 min
Flashers	41	15.6	10	40	10 min
Crossbuck[a]	58	16.7	10	51	6-50
Stopline	25	24.3	14	91	15
RR symbol	28	207	48	568	Variable
Begin no passing zone	18	278	84	769	Variable
RR advance warning sign	37	296	28	769	100-750

[a] Includes crossbucks on active devices.

The Highway Department was able to provide traffic volume data for eight study sites on their roadway system, but reliable traffic volumes for other roads were not available. On the state highway system, current volumes ranged from 66 to 650 percent of the values included in the inventory. The current average highway volume is 121 percent of the average volume values from the inventory. Only two of the state highway sites for which new volume data were available had been updated, both in response to the installation of gates.

The three railroads that owned the crossings at the study sites provided information on their current operating conditions. In general, the railroads have been conscientious in submitting updated information for crossings where traffic-control devices had been changed. However, the updated information they had submitted through the established channels in early 1981 was not reflected in the inventory file used for this research.

The railroads reported changes in the number of daily trains at 26 crossings. These volume changes were equally divided between increases and decreases. Actual current daily volumes ranged from 47 to 180 percent of the inventory values, and there would be a corresponding effect on the value of the hazard index calculated for these crossings. In one case, daily train movements increased from 36 to 57; in two others, the increase was from 46 to 64. Other changes in this parameter were considerably smaller. It must be noted that some deviation in daily train volume is expected, and it would be unreasonable to expect any inventory to specify precisely a value in which there is such inherent variation. Train speed, which is an important input to sight distance calculations, was incorrect in the inventory data for 18 crossings. The current speeds reported by the railroads were generally lower than those shown in the inventory.

ANALYSIS OF FIELD SITE DATA

Measurements of the roadway alignment in the direction traveled by the highway vehicle involved in the accident are summarized in Table 4. The roads were basically tangent; 80 percent had a curvature of 0°. Several of the sites with high curvature (>10°) were actually near intersections where the vehicle made a turn just before colliding with a train. Although the presence of nearby highway intersections may affect the safety of a crossing, it is quite possible that roadway curvature is not a proper measure to use to indicate this influence.

As expected, the approach gradient on the highway was generally positive (at 72 percent of the sites). The average value of +1.47 percent, measured at a point 50 ft in advance of the tracks, is significantly greater than zero. A level and rod were used to establish the profile (average gradient) over the 50-ft sections immediately before and beyond the tracks. These measurements probably give the truest reflection of the sudden elevation change experienced by a vehicle traversing the crossing. The average values of these grades (3.1 percent) were virtually identical for the approach and departure sides of the track, although their algebraic signs, of course, differed.

Evaluation was made of the adequacy of sight distance for motorists approaching the track as well as for those who are legally stopped at the crossing. It was found that 19 crossings (33 percent) had sight distance deficiencies in one or more of the quadrants. This statistic may overstate the seriousness of the problem, however, because 14 of these crossings are controlled by active devices (flashing lights or gates) that can be seen by approaching motorists. The presence of these devices significantly reduces the importance of sight distance along the tracks.

Some general characteristics of the sites are summarized in Table 5. Land use was found to be predominantly commercial and farming and nearly equally divided between these two categories. Although nearly 60 percent of the sites were in urban areas, less than 30 percent had heavily developed land adjacent to the crossing. The general alignment characteristics of the road over a 0.25-mile approach in the direction traveled by the vehicle involved in the crash are generally similar to those measured at 50 and 150 ft before the crossing. Specifically, 70 percent were tangent and more than 70 percent were level. Upgrades were found twice as frequently on the approaches as downgrades.

Official railroad crossing traffic control devices were positioned by measuring distances from the nearest rail. The Manual on Uniform Traffic Control Devices (MUTCD) permits some leeway in the longitudinal placement of flashers, crossbucks, and other devices. Actual placement is determined on the basis of factors such as alignment and vehicle speed. Table 6 summarizes information on the actual longitudinal placement of official railroad traffic control devices at the study sites and also identifies, for comparison purposes, the standards from the MUTCD. Almost all of the devices appear to be placed in accord with the standards.

CROSSING IMPROVEMENTS

Beginning in 1976, the Highway Department initiated an aggressive program of rail-highway grade-crossing safety improvements. Since that time, numerous crossings have been treated with static devices and 98 were improved with flashing lights or gates. Among the sites with major improvements, accidents occurred at 23 during the 30-month study period. At 3 of these crossings, accidents occurred after the installation of gates; the remaining 20 were improved an average of 14 months after the accident. In several cases, it appears that the improvement was planned but not implemented before the date of the crossing accident. The apparent role of accident experience in the selection of crossings for improvements would seriously bias a traditional before-and-after study of countermeasure effectiveness.

Because most of these improvements in traffic control devices are reflected in the inventory, the current inventory data do not properly indicate the crossing conditions at the time of the accident. There was no indication that other physical factors, such as alignment or sight distance, were changed between the time of the accident and the field study.

At the completion of this study in 1981, it was difficult to assess the effect of these improvements. Between 1961 and 1976, statewide annual accidents averaged 33. Linear regression analysis of the data for this period showed an average increase of 0.76 accident/year. During the late 1970s, while improvements were being implemented, accidents averaged 31/year. The 95 percent prediction limits for 1980 accident experience were 41.6 ± 13.6, and the actual number of accidents (31) is within this range. The similar limits for 1981 accident experience are 42.3 ± 13.9, whereas the actual accident experience was 22, the lowest value in more than 20 years. The most recent data suggest a significant downturn in train accidents despite increases in highway and train volumes, and it is logical to attribute the change to the crossing improvement program.

If the costs of all grade-crossing improvements in New Mexico between 1976 and 1980 are amortized over a 20-year lifetime, the annual improvement cost is approximately $700 000. Assuming the apparent reduction of 20 accidents/year, as suggested by the predicted and observed values for 1981, the cost of eliminating one accident through grade-crossing improvements is $35 000. Although data for one or two more years are needed to verify these findings, it appears that grade-crossing improvements may be more cost effective than previously thought.

CONCLUSIONS

Although traffic accidents involving trains account for only 0.06 percent of highway accidents in New Mexico, rail-highway grade crossings have received considerable attention in recent highway safety improvement programs. A computerized study of crossings where accidents occurred showed that they have substantially higher volumes of train and vehicle traffic than a set of nonaccident crossings and, despite their higher protection level, their hazard indices are also higher. Field studies of accident sites found no consistent pattern of highway deficiencies that might contribute to accidents, although several sites exhibited adverse alignment or poor sight distance. The location of warning and traffic-control devices at these sites was in compliance with existing standards. Inventory data for the crossings were often in error. The principal deficiency was errors in the highway information. For a variety of reasons, including the number of parameters included in the inventory data base, the timeliness of the data, the failure to update in response to new signs and markings, and the poor quality of volume data on local roads, it can be stated with reasonable certainty that the inventory has at least one error or omission for each public crossing. Probably the most important omission is the failure in many cases to include the street name at the crossing. Along one major railroad in the state, less than half the crossings show a street name or highway number for the intersecting roadway. This, of course, makes it difficult to match inventory and accident data. Significant errors in highway and train volumes were also found in the inventory. An FRA report (5) shows that problems with the inventory are not unique to New Mexico.

Data for the year following completion of the extensive crossing improvement program show a significant reduction in accident experience. This preliminary information suggests that the reduction is being achieved at a cost of $35 000/accident, a value that may be appropriate for those accidents that have a severity index of 0.5.

It is difficult to conclude with certainty whether or not an acceptable level of safety at grade crossings has been achieved in New Mexico. Accident experience has decreased in the past few years at these locations. However, the Transportation Systems Center (TSC) accident prediction models (6), which rely in part on inventory data, suggest that there is still room for improvement. Although 39 of the sites studied in this research were in the top 100 according to the TSC models, 61 other crossings with an annual expected accident experience of 0.07-0.25 have not had a recent accident. According to a more traditional index, these 100 crossings are more hazardous than the sites studied in this project. Furthermore, because at 37 of the top 100 sites crossbucks are the highest level of protection, it would appear that continued attention to the problems of grade-crossing safety in New Mexico may be warranted.

REFERENCES

1. Rail-Highway Crossing Accident/Incident and Inventory Bulletin: Number 2. FRA, 1980.
2. Rail Crossing Safety: At What Price. General Accounting Office, Rept. CED-78-83, 1978.
3. E. Farr. Rail-Highway Crossing Resource Allocation Model. FRA, Rept. FRA-RRS-81-01, 1981.
4. J. Hall. Rail-Highway Grade Crossing Safety. FHWA, Rept. FHWA-NMDOT-81-2, 1981.
5. B. Tustin. Investigation of Anomalous Rail-Highway Crossings. FRA, 1981.
6. P. Mengert. Rail-Highway Crossing Hazard Prediction Research Results. FRA, Rept. FRA-RRS-80-02, 1980.

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