Analysis of State Department of Transportation Safety Expenditures and Highway Safety

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A review of the FHWA annual *Highway Statistics* report indicates that variations in motor vehicle traffic fatality and injury rates, as well as safety and administrative expenditures, are quite significant among the state departments of transportation (SDOTs), even for those in states with similar regional, physical size, population, and other socioeconomic characteristics. The extent of the causal relationships that may exist between highway fatality or injury rates and SDOT upper-management structures, percent budgetary allocations, traffic variables, and network pavement conditions is examined and evaluated. The statistical test of significance and variance component analysis were used to quantify the magnitudes of these relationships. The findings indicated that (a) the states with the lowest highway fatality rates suffered from the highest injury rates and vice versa, (b) increases in the annual average daily traffic per km and in expenditures on safety were both significantly associated with reductions in fatality rates, and (c) no common pattern could be found among the SDOTs in the allocation of budgetary funds between the competing activities of safety and administration. Areas for further research are recommended.

The recent shift in emphasis from primarily federal financial support of transportation infrastructures to greater local and private-sector self-sufficiency has created an enormous challenge for state departments of transportation (SDOTs). The combined effects of deteriorating infrastructures, increasing needs for system expansion in areas experiencing growth, and the rising costs of project implementation at all levels require financial resources that will have to come from a variety of sources. Improving the allocation efficiency of the limited resources of SDOTs may be a key factor in meeting the challenge. This paper aims to analyze SDOT budgetary allocations for safety and administration and highway fatalities.

The minimization of road traffic accidents has always been a top priority of the U.S. Department of Transportation and SDOTs. Despite this strong emphasis, however, roughly one-half million people have lost their lives on U.S. highways over the last decade or so (*1*). Motor vehicles kill more Americans from ages 1 to 34 than any other source of injury or disease (*2*), and the cost of highway collisions for the year 1986 alone was estimated by the National Safety Council to be $57.8 billion (*3*).

Road accident injuries are often measured in relation to the total miles traveled. This indicator, the number of fatalities per 100 million miles of travel, has been reduced significantly over the years to, for example, 1.91 in 1991, compared with 3.5 in 1980. However, when viewed from a public health perspective, which uses deaths per 100,000 population, the reduction is less significant: 16.5 fatalities per 100,000 population in 1991 compared with 23 fatalities per 100,000 population in 1980.

Despite the overall improvement in road safety, however, there has been a growing concern in recent years that both federal and state administration of highway safety-related projects may suffer from serious shortcomings (*4*). Safety expenditures have been demonstrated to be unsystematic (*5*), based on inadequate data and evaluation procedures (*6–8*), and often allocated to projects with questionable safety effectiveness (*9*).

To complicate the matter further, the approach to decision making in the SDOTs has also begun a process of change due to several important and complex factors. These include a significant increase in the public's concern for social and environmental issues, a significant and sudden decline in financial resources, rapid increases in costs, the emergence of new technologies and tools (*10–12*), and strategies for change (*13*).

A review of *Highway Statistics*, the annual report published by FHWA, indicates that motor vehicle traffic fatality and injury rates (fatalities or injuries per 100 million vehicle miles) vary significantly from state to state (*1*). The 1991 fatality rate, for example, varies from a low of 1.16 in Connecticut to a high of 2.83 in Nevada, a 244 percent difference. The rate for personal injuries differs from 82.6 in Vermont to 260.30 in New York, a difference of 315 percent. Several socioeconomic, environmental, and geographical factors affect these highway safety statistics significantly. What may also have a pronounced effect on highway safety, however, is the distribution and allocation of budgetary resources among the competing capital, maintenance service, and safety-related activities of SDOTs. It is generally agreed that highway safety performance is closely correlated with safety expenditures, especially if those expenditures are made on safety-related activities with proven records of effectiveness (*14*).

Again, a review of FHWA's *Highway Statistics* shows that variations in expenditures on safety and administration are quite significant among SDOTs. For example, when viewed in terms of the percentages of the total SDOT budget, expenditures on safety and administration differ from state to state by as much as 15 and 9 times, respectively.

In light of these statistics and the accelerated rate of change in SDOT organizational structures and policy decisions for meeting the changing socioeconomic environment and adapting to the requirements of the Intermodal Surface Transportation Efficiency Act of 1991, several logical questions deserve attention:

1. To what extent do factors of organizational structure, traffic, network condition, and expenditures on safety and SDOT administration affect roadway safety?

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2. Are differences in budgetary allocations on safety and administration statistically significant for the states with the lowest and highest fatality rates?

3. Are SDOT expenditures on highway safety made in relation to certain physical, geographical, traffic, or SDOT organizational structures?

This paper attempts to provide answers to these questions.

FINDINGS

The data for the 50 states, taken from the FHWA's annual *Highway Statistics* (*1*), include the following: population of driving age (age 16 years and over); numbers of licensed drivers (per 1,000 total resident population), registered vehicles, and vehicle miles of travel; annual average daily traffic (AADT) per mile; volume service flow ratio (V/SF; percentage of total mileage with V/SF > 0.7); present serviceability rating PSR ≥ 3.5 to 5.0; computed as percentage of total urban and rural road mileages; expenditures on highway law enforcement and safety and on administration/miscellaneous (as percentage of total expenditures); and fatality and injury rates (per 100 million vehicle miles of travel). Tables 1 and 2 present these data for the 15 states with the lowest and highest fatality rates, respectively.

The organizational structures of SDOTs, taken from a research report by Koushki et al. (*15*), were also added to the data list. The state-level mean statistics of the data are presented in Table 3.

Factors Affecting Road Safety

In this section the extent to which factors of SDOT upper-management organizational structure, traffic, network condition, expenditures on safety, and expenditures on SDOT administration affect fatality and injury rates are examined.

In their 1991 study of SDOT management information systems, Koushki et al. (*15*) also found that among the 50 SDOTs there were six types of upper-management organizational structures. These organizational types were used to examine the potential relationship that may exist between the upper-management decision-making structure and highway fatality and injury rates. Forty-two states comprised three organizational types, Types 2, 3, and 4. The other three organizational types, which represented those of eight states, were excluded from the analysis because of insufficient sample size (less than five) in each category.

Interesting and important points were revealed (Figure 1). First, the analysis showed that states with the highest fatality rates (13 states) experienced the lowest injury rates, and those with the lowest fatality rates suffered from the highest injury rates (21 states). The remaining eight states were somewhere in between these two extremes, with fatality and injury rates approximating the overall mean rates for the 50 states. It seems that achieving reductions in both the fatality and injury rates simultaneously are similar to performing tasks that are mutually exclusive. The reason is that in severe accidents, individuals who may be saved from death end up with injuries, unless accidents can be prevented from happening altogether.

Second, states with SDOTs with the Type 2 organizational structure experienced the highest fatality rates (2.195; standard deviation, 0.457) and the lowest injury rates (134.0; standard deviation, 27.13). States with SDOTs with the Type 4 organizational structure were the opposite: they had the lowest fatality rates (1.766; standard deviation, 0.450) and the highest injury rates (154.7; standard deviation, 46.13). States with SDOTs with the Type 3 organizational structure were in the middle [fatality rate, 1.97 (standard deviation, 0.295); injury rate, 141.8 (standard deviation, 33.76)]. The results of a statistical test of significance indicated that the difference in the mean fatality rates for states with SDOTs with the Type 2 organizational structure and those with SDOTs with the Type 4 organizational structure were statistically significant at the 99 percent level of significance ($\alpha = 0.01$).

Why do states with SDOTs with the Type 4 organizational structure have the lowest rates of fatalities in the nation? The only apparent difference between the two upper-management organizational hierarchies (Figure 1) is the absence of a group of board or commission members in the decision-making hierarchy. This may mean (a) a shorter chain in the upper level of the decision-making process,

TABLE 1 Traffic, Travel, and Budgetary Allocations for 15 States with Lowest Fatality Rates[a]

Rank/State	Fatality Rate[b]	AADT/ Km	% of Hwys. with $\frac{V}{SF} > 0.7$	VKT (10^6)	Expenditures (% of Total) Safety	Admini.
1. Connecticut	0.721	2252	0.80	42871	3.3	2.8
2. Massachusetts	0.739	2307	0.59	74924	7.5	11.7
3. Rhode Island	0.764	1989	0.51	11515	4.9	3.9
4. New Jersey	0.820	2944	1.30	95455	4.2	4.8
5. Minnesota	0.839	516	0.18	63199	5.3	5.0
6. New Hampshire	0.894	1137	0.78	15995	9.1	18.7
7. Washington	0.913	989	0.15	74783	6.8	6.5
8. Delaware	0.944	2075	1.10	10821	8.2	11.6
9. Virginia	0.957	1528	0.50	98369	5.0	8.0
10. North Dakota	0.981	117	0.00	9581	4.2	5.3
11. Hawaii	1.031	3378	1.60	13110	1.2	6.4
12. Maryland	1.044	2428	1.10	66572	9.9	6.1
13. Illinois	1.050	1068	0.03	137542	5.5	6.7
14. Maine	1.068	898	0.97	19077	7.8	4.6
14. Michigan	1.068	1186	0.41	131915	9.2	9.4
15. Wisconsin	1.087	701	0.20	73187	4.2	5.4

[a] Source: Ref. (1)
[b] Fatality per 100 million vehicle-kilometers of travel

TABLE 2 Traffic, Travel, and Budgetary Allocations for 15 States with Highest Fatality Rates[a]

Rank/State		Fatality Rate[b]	AADT/ Km	% of Hwys. with $\frac{V}{SF} > 0.7$	VKT (10^6)	Expenditures (% of Total) Safety	Admini.
1.	Nevada	1.76	393	0.10	16921	9.0	5.0
2.	Mississippi	1.75	584	0.12	40084	5.6	4.2
3.	New Mexico	1.74	509	0.02	27004	4.4	10.7
4.	Arkansas	1.72	484	0.05	35314	6.1	3.3
5.	Alabama	1.61	806	0.25	69108	5.8	7.7
5.	West Virginia	1.61	784	0.62	25802	1.7	7.4
6.	South Carolina	1.60	915	0.56	55474	9.4	8.0
7.	Idaho	1.59	282	0.01	16612	6.4	7.3
8.	Alaska	1.56	506	0.28	6474	4.7	6.6
9.	Louisiana	1.53	1009	0.10	55883	8.8	4.7
10.	Montana	1.50	200	0.00	13386	6.1	3.7
11.	Kentucky	1.46	860	0.76	56693	6.1	5.6
11.	Tennessee	1.46	948	0.11	76100	4.8	6.6
12.	Arizona	1.45	1075	0.05	56236	4.0	4.7
13.	Florida	1.35	1766	0.14	182708	6.9	4.2
14.	South Dakota	1.32	137	0.00	10805	5.0	8.1
15.	Iowa	1.32	348	0.08	37062	6.1	6.6

[a] Source: Ref. (1).
[b] Fatality per 100 million vehicle-kilometers of travel.

(b) a potential reduction in conflicts of interest among the policy makers in upper management, (c) potential variations in the organizational hierarchies of middle management, and (d) none of the above. It may mean, however, that the apparent existence of this relationship is basically a chance phenomenon.

The effects of traffic flow variables on highway safety were examined by analyzing the effects of factors such as AADT per mile and the percentage of the roadway network with a V/SF ratio > 0.7 (an indicator of congestion level and travel speed) on highway fatality and injury rates. An increase in traffic volume was generally accompanied by a decrease in traffic fatalities and, at the same time, with an increase in traffic injuries (Figure 2). This finding is in accordance with the expectations. Increases in traffic volume cause reductions in travel speed. Accidents occurring at lower travel speeds will likely be less severe (injurious rather than fatal). Results of a statistical test of significance indicated that the difference in the mean fatality rates for the states with AADT per km < 1250 and those with AADT per km > 1250 was statistically significant at the 95 percent level of significance ($\alpha = 0.05$).

An analysis of the V/SF ratio and its relationship to highway fatality and injury rates indicated that although the same general trend as that for AADT existed between V/SF ratios and traffic fatality and injury rates, the point elasticities of fatality and injury rates (defined as the slope of the curve at a given point) were much less pronounced compared with those of AADT per mile. The test of significance also failed to demonstrate the existence of any statistical significance in the differences in the mean rates of fatalities and injuries with regard to the V/SF ratio variable.

TABLE 3 State-Level Mean Values of Data

Variable Name	Mean Value	Std. Dev.	Minimum	Maximum
Pop. of Driving Age (1000)	3865.30	4250.80	338.0	22988.0
Licensed Drivers (per 1000 Residents)	682.70	51.40	558.0	812.0
Registered Vehicles (1000)	3763	3914	247.0	22253.0
Vehicle-Kilometers of Travel (10^6)	69835	72967	6474	415341
Annual Ave. Daily Traffic per Kilometer	1054	763	117	3378
% V/SF Ratio > 0.7	0.36	0.38	00.0	1.6
% PSR ≥ (3.5 - 5.0)	3.45	1.71	0.9	9.1
Safety Exp. ($1000)	80703.00	125491.00	4401.0	861451.0
Adm. Exp. ($1000)	81324.00	91302.00	8946.0	506511.0
Fatality Rate	1.22	0.28	0.72	1.76
Injury Rate	88.8	23.8	51.3	161.7

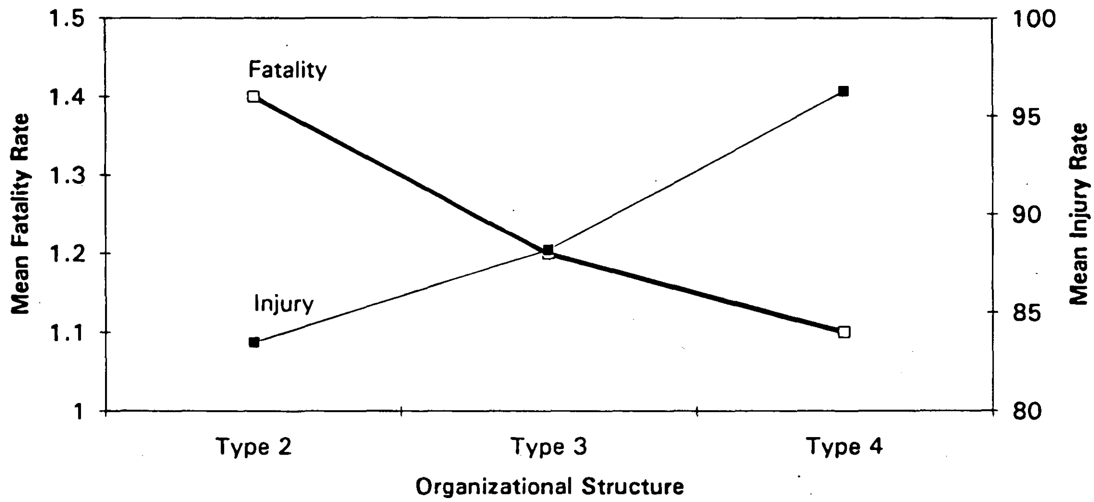

FIGURE 1 Upper-management organizational structure and highway fatality and injury rates.

The effects of network conditions on the mean rate of highway fatalities and injuries was examined by using the (PSRs) for the highway network. Only those sections of the network with PSRs of 3.5 to 5.0 (good or excellent), computed as a percentage of the total urban and rural road mileage, were considered in the analysis. The result indicated that as the percentage of highway mileage with high PSRs increased, the fatality rates also increased, whereas the injury rates decreased. This increase in fatality rates may again be caused by a likely increase in travel speed when pavement conditions on a highway network are improved. Higher travel speeds consequently affect the severity of accidents (*16*).

The increase in the fatality rates and the decrease in the injury rates, however, were not strongly correlated with the increase in the percentage of highway mileage with good pavement conditions (r_{xy} = 0.199 and −0.131 for fatality and injury rates, respectively). The test of significance also quantified this lack of a strong relationship when no statistically significant difference was found to exist between the mean fatality or injury rates for the states with the lowest and those with the highest percentages of highway mileage with PSRs of 3.5 to 5.0.

An analysis of the impacts of SDOT expenditures on safety on highway fatality and injury rates revealed that as the level of expenditures on safety increased, fatality rates decreased and injury rates increased (Figure 3). The point elasticities of the fatality rates (slope of the fatality curve), however, decreased as the level of expenditures on safety increased. The analysis showed that the reduction in the fatality rate was most elastic with safety expenditures in the range of $30 million or less. Expenditures in the range of $50 million to $100 million on highway safety had the second highest effect on reducing fatality rates. Results of a statistical test of significance also showed that a significant difference in fatality rates existed between the SDOTs that annually spent $50 million or less and

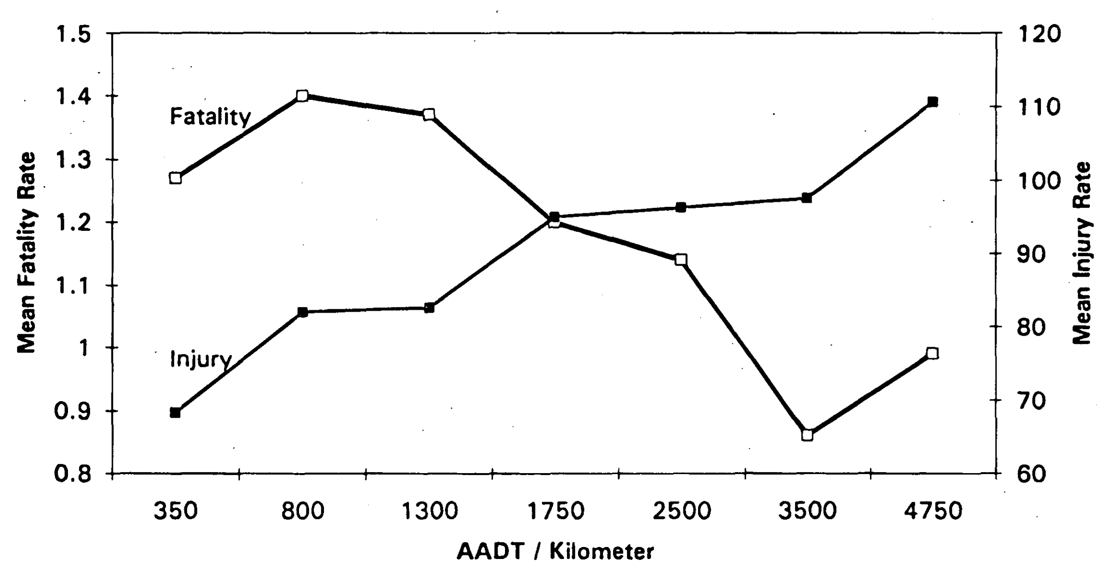

FIGURE 2 AADT per kilometer and highway fatality and injury rates.

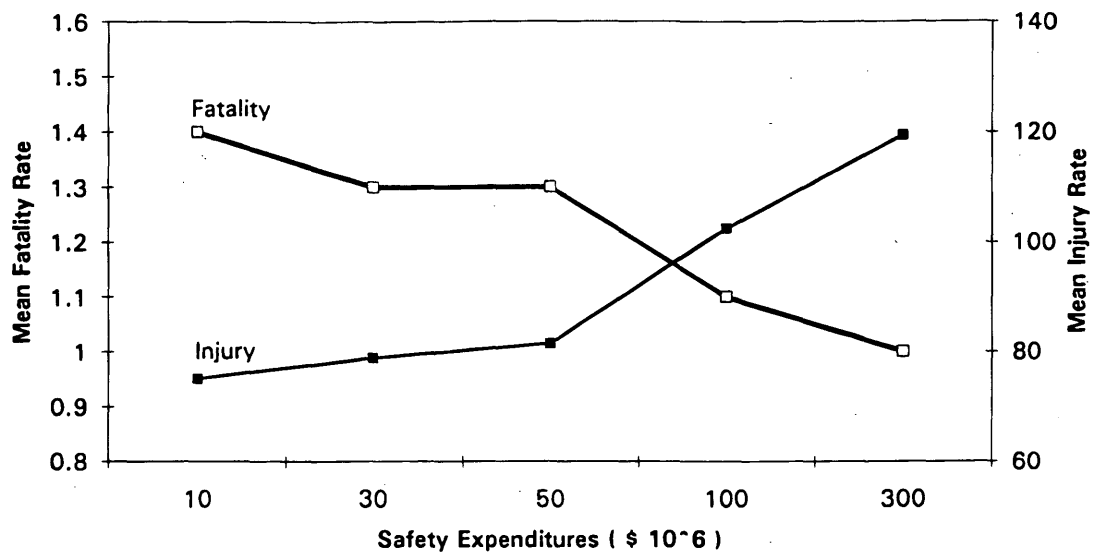

FIGURE 3 Safety expenditures and highway fatality and injury rates.

those that spent $100 million or more on highway safety. The reductions in the fatality rates for the states that spent $100 million or more on safety-related projects were significant at the 95 percent level of significance ($\alpha = 0.05$).

The level of expenditures on SDOT administration, on the other hand, produced no tangible reductions in highway fatality rates. The difference in fatality rates for states that spent $70 million or less and those that spent $100 million or more on administration was not statistically significant, even at the 80 percent significance level. It may therefore be safe to conclude that expenditures on highway safety have a much more pronounced impact on the reduction of highway fatalities than do expenditures on SDOT administration.

However, to assume that safety expenditures alone could improve road safety may also be premature. For example, to examine one point, it was hypothesized that the top 10 states with the lowest fatality rates spent significantly larger percentages of their total annual budgets on highway safety than the bottom 10 states with the highest rates of highway fatalities. The answer was a surprising no. The difference in the mean percentage of expenditures on highway safety for the two groups of states was not statistically significant even at the 30 percent significance level (the computed z value was 0.36, indicating only a 28 percent chance of significance). The reason for this was because of the problem associated with data aggregation. When safety expenditures are aggregated for 10 states (in each group), the largest portion of variations in these expenditures (the within-group variations) is lost to the aggregation process. What remains, the between-group variations, is only a small portion of the total variations (*17,18*). A glance through the data in Tables 1 and 2 confirms this statement.

How, then, do SDOTs distribute their limited budgetary funds among their competing capital, maintenance, administrative, and safety activities? Are the expenditures on highway safety, for example, made in relation to certain physical, geographical, traffic, or the upper-management hierarchy structures of SDOTs?

An exhaustive number of search, sort, and classification procedures failed to demonstrate the existence of any significant pattern in the distribution of budgetary funds among the competing activities by the 50 SDOTs. Among the 15 states with the lowest fatality rates, for example, the allocation of safety expenditures (as a percentage of the state's total budget) ranged from a low of 1.2 percent to a high of 9.9 percent, a difference of 725 percent. Similarly, among the 15 states with the worst highway fatality rates, expenditures on safety ranged between 1.7 and 9.4 percents, a difference of more than 450 percent. Enormously large variations in the physical size, geographical locations, traffic characteristics, and network pavement conditions were also observed among the states within either the group with the lowest fatality rates or the group with the highest fatality rates.

Variance Component Analysis

To determine the relative contributions of organizational structures, traffic, network conditions, expenditures on safety, and expenditures on SDOT administration (independent variables) to variations in fatality and injury rates (dependent variables), the variance component analysis method was used.

This statistical technique estimates the contribution that each of the independent variables makes to the overall variability in the dependent variable. The maximum likelihood procedure is used to compute the estimates of the variance components. The procedure iterates until the log-likelihood objective function converges. The objective function is $l_n\,(|V|)$, where

$$V = \sigma_0^2 + \sum_{i=1}^{n} \sigma_i^2 \chi_i \chi_i'$$

where

σ_0^2 = residual variance,
n = number of random variables in the model,
σ_i^2 = variance components, and
X_i = part of the design matrix for the random effect of variable i.

The results of the analysis, as presented in Table 4, indicate that the variances in the fatality and injury rates attributable to the factor of AADT per mile are by far larger than those attributable to the

TABLE 4 Maximum Likelihood Variance Component Estimates

Independent Variable	Relative Contribution to Dependent Variable Variance	
	Fatality Rates[a]	Injury Rates[b]
AADT per kilometer	174.631	1008.425
V/SF Ratio	34.257	194.673
Present Serviceability Rating, PSR	--	170.817
Safety Expenditures	7.946	--
Administrative Expenditures	2.471	--

[a] No. of iterations = 8,
[b] No. of iterations = 2.

V/SF ratio, PSR, expenditures on, safety, and expenditures on SDOT administration. The factor of traffic volume (which dictates the travel speed) seems to be the most important variable affecting highway fatality and injury rates. It seems that heavy volumes of traffic, as the AADT per mile indicates, are the main reason behind the high safety performances (low fatality rates) of the small, densely populated states of the Northeast in general and New England in particular. It is also noteworthy that the relative contribution of expenditures on safety to variations in the fatality rates is more than 3 times that of expenditures on SDOT administration.

CONCLUSIONS

The purpose of the present study was to examine the impacts and to evaluate the extent of causal relationships existing between SDOT management structures, traffic variables, network conditions, and budgetary allocations for safety and administration and highway fatality and injury rates. The study's findings indicated that attempts to achieve a reduction in both the highway fatality and injury rates simultaneously are similar to performing tasks that are mutually exclusive. Any successful attempt at saving a life will add one to the list of injuries, unless the accident can be prevented from happening altogether. States that experienced the lowest rates of fatalities suffered from the highest rates of injuries.

States without a board or commission in their upper-management organizational structures experienced the lowest rates of highway fatalities (and the highest injury rates, as was the pattern). Likely reasons may include a shorter link in the decision-making process or a possible reduction in the conflicts of interests among the members of upper management. Chance, however, may be the most likely answer for the existence of this relationship.

Traffic volume, as represented by the AADT per mile, demonstrated the strongest negative association with highway fatality rates. An increase in AADT per mile was accompanied by a significant (statistically) decrease in fatality rates and a significant increase in injury rates. The influence of the V/SF ratio on highway fatality and injury rates, although similar to that of AADT per mile, was less pronounced than that of AADT per mile. PSR, which represents network pavement conditions, was also positively correlated with fatality rates and was negatively correlated with injury rates, but to a much lesser extent.

Analysis of the impact of the level of expenditures on highway safety indicated that increases in safety expenditures resulted in a significant reduction in fatality rates. Increases in the levels of expenditure on SDOT administration, on the other hand, produced no tangible reductions in fatality rates.

Exhaustive search, sort, and classification attempts failed to highlight the existence of any patterns among the 50 states with regard to the expenditure of budgetary funds between the competing activities of safety and administrative.

The application of variance component analysis, performed to determine the relative contribution of the causal factors to variances in the fatality and injury rates, further supported the findings presented earlier.

From the study it can be concluded that although expenditures on highway safety could significantly reduce highway fatalities (which expenditures on administration do not), safety expenditures alone may not be enough to achieve the level of highway safety desired by SDOT management. Highway safety, as a literature search and the data in this paper indicate, seems to be affected by a host of socioeconomic, political, physical, and geographical variables. Factors such as the sparseness of the population and activities both within and between urban areas; lengths of trips; the daytime or nighttime distributions of trips; the percent distributions of inter- and intracity travel; enforcement policies concerning alcohol, drug, and seat-belt use; congestion levels and frequencies; speed limits and speed limit enforcement policies; the homogeneity and age compositions of drivers and the road-user population; the level of road-user education and awareness; and the compliance of road users with traffic rules and regulations may all have significant effects on highway safety, especially at the regional or state levels.

Research is urgently needed to take a microscopic look at the factors that make the small states of the Northeast in general and New England in particular experience the lowest rates of highway fatalities in the nation. Is it because these states are densely populated? Do their small sizes cause intercity trips to be short in length and time? Is it because they have more homogeneous driver populations or stiffer penalties for driving under the influence of drugs and alcohol? Or is it because of a more appropriate distribution of budgetary funds between safety and SDOT administration?

Is it not feasible for the states that share similar regional, physical size, population, and other socioeconomic characteristics to gain from the experiences of those in the same region with the best safety records? Many more logical and unanswered questions may also be posed.

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