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The Impact of Rapid Incident Detection on Freeway Accident Fatalities

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Abstract

Incident detection systems have the potential of reducing the time between the occurrence of accidents and the notification of emergency medical services, called the accident notification time. Reductions in this time, in turn, may affect the numbers of fatalities. A statistical analysis is conducted to determine the quantitative relationship between fatalities and the accident notification time on urban freeways. Using this relationship, the impact of freeway incident detection systems on fatalities is estimated. The economic benefits of fatality reduction are also derived.

KEYWORDS: Incident detection systems, Intelligent Transportation System (ITS), emergency medical service (EMS) provision

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Section 1

Introduction

Heavily congested urban highways in the United States have spurred the development of Freeway Management Systems (FMS). Among the goals of these systems is the improvement of traffic management and the facilitation of more rapid incident detection and response. Traditional methods of incident detection, relying on pedestrians, passing motorists, or patrol vehicles, involve a large element of chance that may result in long delays. The implementation of FMS incident management programs promises to reduce incident detection and response times.

FMS's consist of traffic monitoring devices, communication systems, and control centers that monitor and manage the flow of traffic. The monitoring devices, that determine the status of traffic or identify a traffic problem, may include detectors such as inductive loops, magnetometers, and ultrasonic, microwave, or infrared-based sensors. In addition, closed circuit television (CCTV) cameras may be used to visually identify the nature and extent of a traffic problem.

These devices provide inputs to an automated incident detection capability allowing incidents to be detected quickly so that appropriate actions may be taken. This capability uses incident detection algorithms to identify changes in traffic flow at various points along the highway. The systematic placement of CCTV cameras allows verification of the nature of the incident so that the authorities can take appropriate responses, such as the dispatching of emergency vehicles.

Incidents may involve vehicle breakdowns, bridge or roadway collapses, roadway obstructions such as spilled loads, or vehicular accidents. In all of these cases, the incidents may result in congestion, especially during rush hour periods. Congestion, in turn, may lead to secondary accidents caused by unexpected stops and slowdowns. Incident response time, in part, determines the level and duration of this congestion and the probability of secondary accidents. In the case of incidents involving vehicular accidents, response time is also crucial for the timely delivery of emergency medical services (EMS) to accident victims and is expected to have an impact on fatalities.

Incident detection is one aspect of incident management. Incident detection is concerned with determining that an incident has occurred, verifying its location and nature, and reporting this information to the appropriate authorities. Other aspects of incident management involve the dispatching of emergency services and the clearing of the roadway.

For incidents that specifically involve vehicular accidents, response time is the sum of the:

- ***accident notification time*** which is the time between the crash and EMS notification
- time between EMS notification and EMS arrival at the crash scene
- time between EMS arrival at the crash scene to hospital arrival

In the United States for 1990, the average accident notification time in urban areas was estimated to be 5.2 minutes. The average time between notification and EMS arrival at the crash scene was 6.2 minutes, while the average time between arrival at the crash scene to arrival at a hospital was 24.9 minutes [1, pp. 88-99].

Outcomes associated with injury trauma are time-dependent. Internal or external bleeding can be fatal and shock becomes more likely with passing time. While each of the response time components is important in determining accident outcomes (e.g., extent and impact of injuries, fatalities), it is the accident notification time that is influenced by FMS incident management programs. Initial results from Intelligent Transportation System operational tests indicate that this time could be reduced to somewhere between two to three minutes if automated incident detection methods were utilized [2, p. 26].

The purpose of this study is to determine the benefits for accident victims when the accident notification time is reduced. Specifically, we analyze the relationship of accident fatalities to the accident notification time. Although other technologies may affect this timer, automated incident detection is a currently feasible technology that is directly under the control of metropolitan transportation authorities and that can be readily implemented in the short-term.

The determinants of accident fatalities are presented in the next section. The empirical data used in this study is discussed in section 3 and in section 4 we present the statistical analysis and results. Section 5 presents the conclusions.

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1 For example, cellular car phones may encourage "good samaratin" reporting of incidents. As the availability of car phones widens, we may expect a temporal downward trend in the time to detect accidents. In addition, lTS technologies such as vehicle mayday systems promise to reduce incident detection times. But the associated technologies are less mature than FMS based automated incident detection systems, and we consequently may expect a longer time horizon before mayday systems are extensively available.

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Section 2

Determinants of Fatalities

The number of fatalities can be viewed as a function of the demand for mobility, driver characteristics, non-driving behavior patterns, and access to EMS. Variables representing these factors are discussed below. These variables are introduced to determine the independent effect of accident notification time on fatalities.

2.1 Vehicle Miles Traveled

The number of highway fatalities depends upon the number of highway accidents. Highway accident numbers, in turn, are related to the demand for mobility as measured by the vehicle miles traveled (VMT) Since accident data is not as well reported as fatality data, we express the number of highway fatalities directly in terms of the VMT. VMT is expected to have a positive sign in the empirical estimation.

2.2 Mean Vehicle Speed

Driving speed is another aspect of the demand for mobility. Higher speeds on the highways increase the exposure of motorists to highway accident risk. Moreover, accidents tend to be more severe at higher speeds, leading to more fatalities. The mean vehicle speed is expected to have a positive sign in the empirical estimation.

2.3 Alcohol Consumption

Non-driving behaviors such as alcohol or drug consumption are expected to influence the fatality rate. In 1990, about fifty percent of all fatal crashes were alcohol related. The National Highway Traffic Safety Administration (NHTSA) defines a fatal traffic crash as alcohol-related for blood alcohol concentration levels of .01% or higher [1, p. 22]. We use the per capita consumption of distilled spirits as the measure of alcohol consumption. This variable is expected to enter the empirical estimation of fatalities with a positive sign.

2.4 Driver Age Distribution

Driver characteristics are also determinants of fatality rates. For example, younger drivers appear to engage in more risky driving. In 1990, drivers under the age of 21 experienced the highest fatal crash involvement rate per vehicle mile driven. Similarly, drivers of age 65 and greater experienced higher fatality rates per vehicle mile than the 21 to 64 year old age group. As a measure of the risk factor associated with the age distribution of the driving population, we take the fraction of VMT generated by drivers under the age of 21 and over the age of 65. We expect the number of fatalities to vary positively with this fraction.

2.5 Accident Notification Time

Access to EMS is expected to affect accident fatality rates. The components of response time discussed in the introduction are not all equivalent with respect to their impacts on accident fatalities. The time period before the arrival of EMS may be particularly important in determining fatalities. During this period, accident victims receive little or no first aid and unattended injuries may lead to death. In the United States in 1990, accident notification time constituted about forty-five percent of the time period before arrival of EMS. We expect fatalities to vary positively with accident notification time.

2.6 Personal Income Per Capita

Both the timeliness and quality of emergency medical care is an important factor influencing accident fatalities. The proximity and density of EMS facilities near highways may affect the time between accident notification and the arrival of emergency services. Well-equipped emergency response vehicles, the availability of medical evacuation helicopters, and well-trained EMS personnel also impact the provision of medical services to accident victims prior to hospital arrival. Additionally, the availability and quality of hospital emergency trauma units are factors influencing the treatment of accident victims.

These factors, relating to the timeliness and quality of emergency medical services, may be influenced by per capita income. More affluent communities are generally more willing and able to invest in these services to a greater degree. Moreover, per capita income may influence the provision of post-trauma medical care to accident victims. The availability of health insurance and the capability of more affluent individuals to demand better medical cam may also have an impact on fatalities.

For the reasons cited above, we expect accident fatalities to vary negatively with personal income per capita.

2.7 Other Variables

Other variables were considered for this analysis but were excluded because either they proved to be statistically insignificant or were highly correlated with the variables discussed above. For example, the average educational attainment by state was highly correlated with the personal income per capita variable.

Additional emergency response variables such as the time between EMS notification and arrival at the crash scene, and the time between crash scene arrival and arrival at the hospital were not included because they proved to be insignificant or inconclusive. For example, the effect on fatalities of the time between crash scene arrival and hospital arrival is expected to be complex.

EMS services arriviing at the crash scene may involve vehicles and personnel that can provide either advanced life support (ALS) or only basic life support (BLS). The availability of only BLS at an accident scene may limit the possibilities for on-the-scene medical cam and encourage the more rapid movement of injured victims to hospitals which may increase fatalities. Statewide data is not collected regarding the type of EMS service dispatched to an accident scene, so we were unable to include a variable in the analysis that directly captures the "quality" of EMS.

We also examined an urban community hospital density variable, the logic being that close proximity to hospitals may affect accident fatality rates. But this variable proved to be insignificant. As discussed above, the per capita income variable was introduced as a proxy to capture possible qualitative differences in the provision of EMS relating both to the timeliness and the quality of medical care.

Section 3

Empirical Data

Summary statistics for the variables in the fatality model are shown in table 1. The data are for individual states in the United States in 1990. Fatality data were obtained from the Fatal Accident Reporting System [1]. An individual involved in a motor vehicle crash dying within thirty days of the accident is regarded as a fatality. The individual may be in an involved vehicle or may be a pedestrian or bicyclist. In the statistical analysis, we focus on fatalities resulting from accidents on urban interstates since these roadways are prime candidates for FMS implementations of automated incident detection systems. There were a total of 2331 fatalities on the approximately 11,500 miles of urban interstates in 1990. The mean number of fatalities is 43.8 ranging from zero in Vermont to 380 in California.

Table 3-1. Summary Statistics

Variable	Mean	Standard Deviation	Minimum	Maximum
Number of Fatalities	43.8	65.7	0	380
Vehicle Miles Traveled (in millions)	5459	8142	159	51287
Mean Vehicle Speed (mph)	58.7	2.3	50.7	62.3
Alcohol Consumption Per Capita (gallons)	.84	.34	.42	1.99
Driver Age Distribution	.11	.02	.08	.16
Accident Detection Time (minutes)	5.2	2.5	1.44	15.2
Personal Income Per Capita (in dollars)	17888	2893	12830	25395

Data on vehicle miles traveled was obtained from the Highway Statistics report for 1990 [3]. The VMT ranges from 159 million miles in Wyoming to 51,287 million miles in California. The total VMT traveled on urban interstates is estimated to be 278,404 million miles, yielding a mean fatality rate of about .84 fatalities per 100 million miles of interstate travel.

Vehicle speed data was also obtained from the Highway Statistics report for 1990 [3]. The mean vehicle speed factors in congestion during the rush hours as well as any other unpredictable delays resulting from incidents. Across the states, mean vehicle speeds range from 50.7 mph in Vermont to 62.3 mph in New York with a national average of 58.7.

The data on alcohol consumption was obtained from reference [4]. Per capita alcohol consumption of distilled spirits ranges from .42 gallons per year in West Virginia to 1.99 gallons per year in New Hampshire with an average of .84.

The driver age distribution was obtained from reference [5] while the average annual miles per driver was obtained from reference [6]. The driver age distribution as measured by the fraction of VMT generated by drivers under the age of 21 and over the age of 65 averages 11% across the state data with a low of 7.6% in Georgia and a high of 16% in Rhode Island.

The accident notification time data was obtained from the Fatal Accident Reporting System [1, p. 86] North Carolina and Virginia did not report accident notification times in 1990 and were consequently excluded from the statistical analysis. The remaining states varied in their reporting rates from 2.42% in California (69 cases) to 100% in Vermont (3 cases). The average over the remaining states was 5.2 minutes for the accident notification time with a minimum of 1.44 minutes and a maximum of 15.2 minutes. The accident notification time is computed as the difference between the time the accident occurs and the time that an EMS was notified. Both of these times (in particular, the time that an accident occurs) are subject to error. However, as Brodsky [7] points out, a lack of precision in individual measurements tends to average out in a larger sample so that aggregate results may be trustworthy even though individual observations may have inaccuracies.

Personal income data was obtained from reference [8]. Personal income per capita averaged $17,888 across the nation and ranged from $12,830 in Mississippi to $25,395 in Connecticut.

Section 4

Statistical Analysis and Results

The number of fatalities, NF, is the dependent variable in the statistical analysis. Our interest centers on the effect of the explanatory variables discussed above on the number of fatalities. Since the number of fatalities assumes non-negative integer values across the state data, an ordinary least squares regression analysis, which requires a continuous dependent variable, is inappropriate. Instead, we propose a Poisson regression model which represents a count of events, such as the occurrence of fatalities. The number of fatalities then is a random variable with a Poisson distribution given by:

$$\text{Prob}(NF_i=r) = \exp(-\phi_i)\frac{(\phi_i)^r}{r!}$$

where ϕ_i is a parameter representing the expected number of fatalities for state i. The expected number of fatalities is a function of VMT, mean vehicle speed (MVS), alcohol consumption (ALC), young/aged driver VMT fraction (YAD), accident notification time (ANT), and income per capita (IPC). For estimation purposes, the relationship is expressed in logarithmic form:

$$\ln(\phi_i) = a_0 + a_1*\ln(VMT_i) + a_2*\ln(MVS_i) + a_3*\ln(AC_i) + a_4*\ln(YAD_i)$$

$$+ a_5*\ln(ANTi) + a_6*\ln(IPC_i) \qquad (1)$$

where "ln" is the natural logarithm, a_0, a_1, ..., a_6 are parameters to be estimated. The logarithmic form of the functional relationship forces the expected number of fatalities, ϕ_i, to be positive, permits non-linear relationships, and allows us to interpret the coefficients as elasticities. The relationship between the actual number of fatalities and the expected number of fatalities is given by:

$$\ln(NFi) = \ln(\phi_i) + \varepsilon_i \qquad (2)$$

where ε_i is the difference between the logarithms of the actual number of fatalities and the expected number. Substituting (1) into (2) yields:

$$\ln(NFi) = a_0 + a_1*\ln(VMT_i) + a_2*\ln(MVS_i) + a_3*\ln(ALC_i) + a_4*\ln(YAD_i)$$

$$+ a_5*\ln(ANTi) + a_6*\ln(IPC_i) + \varepsilon_i \qquad (3)$$

The results of the Poisson estimation are shown in table 2.

Table 4-1. Analysis Results

Variables	Parameter Estimates	Standard Errors
Constant	-2.47	3.81
VMT	1.06	.03
MVS	2.33	.62
ALC	.64	.13
YAD	.53	.16
ANT	.27	.07
IPC	-1.17	.26

The coefficient of determination, R^2, associated with the estimation is .95, meaning that 95% of the variation in fatalities is explained by the independent variables. All of the coefficients enter with the expected signs. Vehicle miles traveled, mean vehicle speed, alcohol consumption per capita, the young driver VMT fraction, and the accident notification time all enter with positive signs, while income per capita enters with a negative sign. All of the coefficients are within the 1% level of significance. The large coefficient associated with mean vehicle speed (MVS) may reflect the fact that accidents involving fatalities are less likely to occur in congested traffic when the speeds are low.

For purposes of comparison, a univariate Poisson regression was conducted yielding:

$$\ln(NF_i/VMT_i) = -5.13 + .19*\ln(ANT_i) \tag{4}$$

The coefficient for the ANT term in equation (3) is 42% higher than that for equation (4). Thus the use of a univariate analysis as epitomized by equation (4) yields a coefficient estimate that is biased downward and, hence, a smaller impact of accident notification time on fatality reduction.

4.1 Impact of Rapid Accident Notification on Lives Saved

From equation (3), a change ΔANT in the accident notification time results in a change in the number of fatalities ΔNF given by:

$$\frac{\Delta NF}{NF} = .27*\frac{\Delta ANT}{ANT} \tag{5}$$

If the accident notification time in 1990 were reduced from 5.2 minutes nationally to 3 minutes by the use of an FMS incident detection program, then 246 lives would have been saved annually, an 11% reduction in fatalities. If the accident notification time were reduced to 2 minutes, 356 lives would be expected to be saved annually, a 15% reduction in fatalities.

Although the fatality model discussed above was obtained based on data from urban interstate highways, it can be used to estimate the reduction of fatalities if incident detection programs were implemented on urban freeways and expressways. There were 178 1 fatalities on urban freeways and expressways in 1990. If the accident notification time in 1990 were reduced to 3 minutes, then 203 of these lives would have been saved, while a reduction to 2 minutes would save 296 lives. The results of implementing a nationwide incident detection program on urban interstates, freeways, and expressways is summarized in table 3.

Table 4-2. Impact of Accident Notification Time on Lives Saved

	Fatalities	Notification Time: 3 mins.		Notification Time: 2 mins.	
	(1990)	Lives Saved	% Change	Lives Saved	% Change
Urban Interstates	2331	246	10.5	356	15.3
Urban Freeways and Expressways	1781	203	11.4	296	16.6
Totals	4112	449	10.9	652	15.9

4.2 Economic Benefits of Rapid Incident Detection

Given the impact of rapid incident detection on lives saved, we can infer the net economic benefits that would accrue if incident detection systems were fully implemented on the nation's urban interstates, freeways, and expressways. Miller [9] conducted a comprehensive study of the costs associated with roadway accidents and fatalities. Monetary costs where defmed to include costs for medical and emergency services, productivity and workplace losses, and administrative and legal fees. In addition, Miller estimated the monetary value of lost quality of life--the value people place on avoiding pain, suffering, and loss of life--resulting from crash related injuries and deaths. For costs distributed over multiple years, a 4% discount rate was used. For non-fatal injuries, these cost estimates were classified according to injury severity as measured by the maximum abbreviated injury scale (MAIS). The MAIS classifies injuries as minor, moderate, serious, severe, or critical.

Assuming that the most life threatening injuries are in the serious, severe, or critical categories, we weighted the AIS cost estimates for these categories in proportion to their occurrences and computed mean costs per injury in 1990 dollars. The monetary cost associated with a non-fatal injury victim was estimated at $111,870. On the other hand, the monetary cost associated with a fatality was estimated to be $708,235. The comprehensive costs, which additionally include the costs associated with the loss of quality of life were $560,018 for each injury and $2,634,551 for each fatality also in 1990 dollars. Thus, incident management systems show a net monetary benefit of $596,365 and a net comprehensive benefit of $2,074,533 for each fatality that is reduced.

The net benefits accruing from a fully implemented incident detection program across the nation's urban interstates, freeways, and expressways is shown in table 4. For an accident notification time of three minutes, the monetary benefits are about $268 million per year while the comprehensive benefits are about $93 1 million per year. With a detection time of two minutes, the monetary benefits are about $389 million per year while the comprehensive benefits come in at about $1.352 billion per year.

Table 4-3. Net Benefits From Rapid Incident Detection (in $'s)

	Notification Time: 3 mins.		Notification Time: 2 mins.	
	Monetary	Comprehensive	Monetary	Comprehensive
Urban Interstates	146,705,800	510,335,100	**2 12,305,900**	738,533,700
Urban Freeways and Expressways	121,062,100	421,130,200	176,524,000	614,061,800
Totals	267,767,900	931,465,300	388,829,900	1,352,595,500

4.3 Applicability to Subsequent Years

In order to demonstrate the applicability of equation (4), which was estimated on the basis of 1990 data, to subsequent years, we used equation (4) to predict the number of fatalities by state for 1992. The numbers of predicted fatalities were then compared to the actual 1992 fatalities. The correlation between actual and predicted fatalities across the states was .92. The predicted national totals were 1966 fatalities compared to 1865 actual number of fatalities, a difference of about five percent or two fatalities per state. The difference between predicted and actual fatalities might be explained, in part, by improvements in vehicle safety (e.g., airbags) or in highway improvements that contribute to safety. Since the statistical analysis presented in this study was cross-sectional (i.e., states were the units of observation), temporal trends in safety that reduce fatality could not be taken into account

The average accident notification time in 1992 was 4.28 minutes representing an 18% reduction from the 5.2 minute average of 1990. Using equation (5), 91 of the total of 466 fatalities (i.e., 2331-1865) that were reduced are attributable to temporal changes in the average accident notification time.

Section 5

Conclusion

The above analysis has demonstrated that the accident notification time is a determinant of the number of fatalities for urban interstate highway accidents. Other explanatory variables were introduced into the analysis to allow us to identify the independent effect of the accident notification time on fatalities. The explanatory variables were shown to account for a substantial portion of the variation in the numbers of fatalities on urban interstates.

The important relationship derived from this analysis is the elasticity of freeway fatalities with respect to the accident notification time. This dependency is a function of underlying human physiology and the response of the human body to delays in treatment after an accident. Trauma associated with vehicular accidents may involve external or internal bleeding and associated shock. Consequently, success in the treatment of trauma is very much time-dependent. We do not expect that the response of the human body to trauma will change much over the forseeable future. Therefore, we feel confident in applying the elasticity relationship to years other than the one analyzed in this study.

The analysis showed that the implementation of FMS incident detection programs holds the promise of substantially reducing the accident notification time and, hence, the fatalities resulting from highway accidents.

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