WN 96W0000048

Reducing Accident Fatalities with Rural Mayday Systems

April 1996

William M. Evanco

Sponsor: FHWA
Dept. No.: J090

Contract No.: DTFH61-95-C00040
Project No.: 049518C10A

MITRETEK
Center for Information Systems
McLean, Virginia

Abstract

Rural mayday 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 tune. Using this relationship, the impact of rural mayday systems on fatalities is estimated. The economic benefits of fatality reduction are also derived.

KEYWORDS: Rural Mayday Systems, Intelligent Transportation System (ITS) Program Plan, emergency medical service provision

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Section 1

Introduction

The National Intelligent Transportation System (ITS) Program Plan [l] identifies rural mayday systems as a component of the Emergency Management user service bundle. Mayday systems address the concern for highway safety by facilitating requests for emergency services in the event of vehicle breakdowns or accidents. One aim of mayday systems is to improve the timely delivery of emergency medical services (EMS) by reducing the response time for rural vehicular accidents. As a result, mayday systems arc expected to have a positive impact on reducing accident fatalities.

The effectiveness of emergency response is measured by the times between the:

- Crash and EMS notification (called the ***accident notification time)***
- EMS notification and arrival of EMS at the crash scene
- EMS arrival at the crash scene and arrival at the hospital

The activities between the crash and EMS notification include the determination that an accident has occurred, the verification of the location and nature of the accident, and the reporting of this information to the appropriate authorities. Each of the time components associated with emergency response is important in determining the outcomes of an accident (e.g., extent and impact of injuries, fatalities). However, it is the accident notification time that can be most influenced by rural mayday systems'.

Today, patrol vehicles or passing motorists are the major means of accident detection in rural areas. Because of lower rural traffic densities, accident notification times are substantially greater than in urban areas. In 1990, the average rural accident notification time in the United States was 9.6 minutes compared to 5.2 minutes in urban areas [2, pp. 86-89][2]. This higher average accident notification time may contribute to the fact that rural fatalities constituted 58% of all crash-related fatalities although rural vehicle miles traveled (VMT) were only 42% of the total VMT.

Rural mayday systems are expected to substantially reduce the average accident notification time. It has been estimated that accident notification time for a mayday request can be reduced to about one minute [3]. Operational tests are currently underway in Colorado and the Puget Sound area to empirically validate these expectations [4, pp. 202-203]. However, this one minute time is an ideal that assumes both a 100% market penetration and 100% mayday service

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1 The time between notification and arrival of EMS may also be influenced by ITS technologies such as in vehicle guidance systems. However, in this study, we focus exclusively on the impact of mayday systems on fatalities.

2 These averages are taken across states as opposed to the averages weighted by state response rates reported in reference [2, pp. 86-89].

availability. An actually implemented rural mayday system will be less than ideal as discussed below.

A rural mayday system is a positional location and communication system that links:

- An in-vehicle emergency notification subsystem
- A safety answering point (SAP)
- A network of emergency response service providers

The in-vehicle emergency notification system can be initiated manually by vehicle occupants or by automated means through collision-detection or rollover-sensing devices. The emergency notification gives the vehicle location coordinates and the nature of the request. The SAP processes the received emergency notification and then forwards a service request to an emergency service provider. The emergency service provider dispatches and routes an appropriate combination of response services to the incident scene.

In contrast to metropolitan areas, which are extensively covered by terrestrial based cellular phone services, rural areas may have to rely on satellite services to provide communication links. Similarly, for location determination, a satellite system such as the Global Positioning System (GPS) is a leading candidate. Because of the potential for satellite blockage caused by terrain features, GPS may be augmented by low earth orbiting (LEO) based systems and by dead-reckoning navigation systems.

Even with backup systems in place, one or more of the rural mayday subsystems may have “blind spots” that cause communication or location failure. In such cases, accident notification could take place through traditional means via a patrol vehicle or a passing motorist. The average accident notification time, greater than the one minute time cited above, would depend on the mayday market penetration of and the effectiveness in minimizing blind spots.

The purpose of this study is to determine the benefits of rural mayday systems associated with reduced accident notification tunes. Specifically, we analyze the impact of the accident notification time on fatalities. A statistical analysis is conducted to determine the relationship between fatalities and accident notification times while controlling for a number of background variables. The analysis exploits the naturally occurring variability in fatalities and accident notification times across states.

In the next section, the determinants of rural accident fatalities are presented. 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.

Section 2

Determinants of Fatalities

The number of fatalities is determined by the demand for driving, driver characteristics, non-driving behavior patterns, and access to EMS. The purpose for introducing variables other than the accident notification time is to control for those factors that may have some correlation with the accident notification time and, hence, affect the estimate of its coefficient. Variables representing these determinants are discussed below.

2.1 Vehicle Miles Traveled

An obvious measure for the demand for driving is the vehicle miles traveled (VMT). The VMT, viewed as an exposure to risk, is a determinant of the number of vehicular accidents. In turn, the number of vehicular accidents is a detenninant of highway fatalities. Since accident data is less reliable because of incomplete reporting, we can eliminate the number of accidents as an intermediate variable and directly relate the number of highway fatalities to the VMT.

Rural accidents occur on a variety of roadways and the roadway type may influence the probability of accidents and associated fatalities. We identify four types of rural roadways-interstates, arterials, connectors, and locals. Mean vehicle speed, which is a determinant of highway fatalities, differs among these rural roadways. Partial data [5, p. 195] averaged over the states indicates that mean speeds on rural interstates are the highest (60.4 mph), followed by rural arterials (56.4 mph), and then rural collectors (54.3 mph). Although no mean speed data is available for local roads, we expect the mean speed on local roads to be substantially less than for the other types of roads. In addition, there are differences in the quality of the roadways. Interstates are limited access roadways built to high quality standards. At the other extreme, local roads may include partially paved, gravel, and unpaved roads. Both speed and roadway quality will contribute to accidents and fatalities. To account for the different characteristics of these roadways, we use the numbers of VMT on rural interstate highways, arterial and connector roads, and local roadways as explanatory variables. These variables are expected to enter the empirical estimation of fatalities with a positive sign.

2.2 Alcohol Consumption

Non-driving behaviors such as alcohol or drug consumption are determinants of the fatality rate. In 1990, about fifty percent of all fatal crashes were identified as alcohol- related [2, p. 22]. The National Highway Traffic Safety Administration (NHTSA) defines a fatal traffic crash as alcohol-related for blood alcohol concentration levels of .01% or higher. We use the statewide per capita consumption of distilled spirits as a measure of alcohol consumption. This variable is expected to enter the fatality equation with a positive sign.

2.3 Driver Age Distribution

Driver characteristics may also influence fatality rates. For example, younger drivers appear to engage in more risky driving. In 1990, drivers under the age of 2 1 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 use 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.

2.4 Accident Notification Time

Access to EMS is expected to influence accident fatality rates. The components of accident response time discussed in the introduction are not all equivalent in their impacts on accident fatalities. The time period before the arrival of EMS may be particularly important in affecting the number of fatalities. During this period, accident victims receive little or no first aid and unattended injuries may lead to death. In 1990, accident notification time averaged about 46% of the time between the accident occurrence and EMS arrival. We expect fatalities to vary positively with the accident notification time.

2.5 Personal Income Per Capita

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

These factors, relating to the timeliness and quality of emergency medical services, may be influenced by mean per capita income. Affluent localities are more willing and able to invest in these services. In addition, 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 care may also affect the number of fatalities.

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

Section 3

Empirical Data

Summary statistics for the variables in the rural crash fatality model ate shown in Table 3-1. The data are for individual states in the United States during 1990.

Fatality data was obtained from the Fatal Accident Reporting System [2]. An individual involved in a motor vehicle crash dying within thirty days of the crash is regarded as a fatality [2, p. 196]. The individual may be in the **vehicle** or may be a pedestrian or bicyclist. In this study, we focus on fatalities resulting from accidents in rural areas on interstates, arterial roads, connector roads, and local roads. There were a total of 25,761 of these fatalities in 1990.

Table 3-1. Summary Statistics

Variable	Mean	Standard Deviation	Minimum	Maximum
Number of Fatalities	515	434.3	20	2,125
Interstate Vehicle Miles Traveled (in millions)	4,003	3,051	0	14,732
Arterial and Connector Vehicle Miles Traveled (in millions)	11,460	8,836	698	38,778
Local Vehicle Miles Traveled (in millions)	1,948	1,402	72	6,066
Alcohol Consumption Per Capita (gallons)	.84	.34	.42	1.99
Driver Age Distribution	.11	.02	.08	.16
Incident Detection Time (minutes)	9.6	3.8	2.9	19.8
Personal Income Per Capita (in dollars)	17,888	2,893	12,830	25,395

Rural VMT data was obtained from reference [5]. The rural interstate VMT ranges from zero miles in Delaware to 14,732 million miles in California with a mean of 4,003 million miles. Rural arterial and connector VMT ranges from 698 million miles in Rhode Island to 38,778 million miles in Texas with a mean of 11,460 million miles. Finally, rural local VMT ranges from 72 million miles in Rhode Island to 6,006 million miles in Ohio with a mean of 1,948 million miles.

The data on alcohol consumption was obtained from reference [6]. 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 a nationwide average of .84.

The driver age distribution was obtained from reference [7] while reference [8] provided the average annual miles per driver. 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 nation with a low of 7.6% in Georgia to a high of 16% in Rhode Island.

The accident notification time data was obtained from the Fatal Accident Reporting System [2, p. 88]. North Carolina and Virginia did not report accident notification times in 1990 and were consequently excluded from the model estimation. The remaining states varied in their reporting rates from .66% in California (12 cases) to 96.5% in Maryland (278 cases) The accident notification time averaged across the remaining states was 9.6 minutes with a minimum of 2.9 minutes in Connecticut and a maximum of 19.8 minutes in Nevada. The accident notification time is computed as the difference between the time the accident occurs and the time that an EMS provider was notified. Both of these times (in particular, the time that an accident occurs) are subject to error. However, as Brodsky [9] 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. In addition, a lack of precision should not be confused with bias. We may reasonably expect any errors in the measurement of accident notification times to be uncorrelated with fatalities at the state level.

Personal income data was obtained from reference [l0]. 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, ordinary least squares regression analysis is inappropriate, since it requires a continuous dependent variable. Instead, we use a Poisson regression model which is useful when the dependent variable (i.e., the number of fatalities) represents a count of events. The number of fatalities then is a random variable with a Poisson distribution given by:

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

where ϕ_i is a parameter representing the expected number of fatalities for state i. The expected number of fatalities is expressed as a function of VMT on rural interstates (VMTI), the VMT on rural arterials and connectors (VMTAC), the VMT on rural local roads (VMTL), alcohol consumption (ALC), young and aged driver VMT fraction (YAD), accident notification time (ANT), and income per capita (IPC). The relationship is expressed in logarithmic form as:

$$\ln(\phi_i) = a_0 + a_1*\ln(VMTI_i) + a_2*\ln(VMTAC_i) + a_3*\ln(VMTL_i)$$

$$+ a_4*\ln(ALC_i) + a_5*\ln(YAD_i) + a_6*\ln(ANTi) + a_7*\ln(IPC_i) \qquad (1)$$

where "ln" is the natural logarithm and a_0 , a_1, ..., a_7 are parameters to be empirically estimated. The logarithmic form forces the expected number of fatalities, ϕ_i, to be positive, permits the consideration of non-linear relationships between fatalities and the explanatory variables, 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:

$$\ln(NFi) = a_0 + a_1*\ln(VMTI_i) + a_2*\ln(VMTAC_i) + a_3*\ln(VMTL_i)$$

$$+ a_4*\ln(ALC_i) + a_5*\ln(YAD_i) + a_6*\ln(ANTi) + a_7*\ln(IPC_i) + \varepsilon_i \qquad (3)$$

The results of the empirical estimation of the parameter values are shown in Table 4-1.

Table 4-1. Analysis Results

Variable	Parameter Estimate	Standard Error
Constant	5.27	.66
VMTI	.48	.03
VMTAC	.62	.03
VMTL	.03	.02
ALC	.32	.03
YAD	.11	.05
ANT	.14	.03
IPC	-.93	.07

The coefficient of determination, R^2, indicating the goodness of fit, is .97. Thus, 97% of the variation in fatalities is explained by the independent variables. All of the coefficients enter with the expected signs. The three major types of VMT, alcohol consumption per capita, the young/aged driver VMT fraction, and the accident notification time all enter with positive signs, while the mean income per capita enters with a negative sign. All of the coefficients are within the 1% level of significance with the exception of the young/old drivers ratio which enters at the 5% level of significance and the local VMT which enters at the 10% level of significance.

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

$$\frac{\Delta NF}{NF} = .14 * \frac{\Delta ANT}{ANT} \qquad (4)$$

The coefficient value of .14 is interpreted as the *elasticity* of fatalities with respect to the accident notification time.

4.1 Applicability to Subsequent Years

In order to demonstrate the applicability of equation (3), which was estimated on the basis of 1990 data, to subsequent years, we used the equation 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 the actual and predicted 1992 fatalities across the states was .98. The predicted national totals were 24,059 fatalities compared to 22,749 actual number of fatalities, a difference of about 5.8%. The difference between predicted and actual fatalities might be explained, in part, by improvements in vehicle safety (e.g., airbags) or in highway improvements contributing 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 the fatalities were not taken into account.

The average accident notification time in 1992 was 8.9 minutes representing a 7.3% reduction from the 9.6 minute average of 1990. Using equation (4), 246 of the total of 1310 fatalities (i.e., 24059-22749) that were reduced between 1990 and 1992 are attributable to temporal changes in the average accident notification time.

4.2 Impact of Rural Mayday Systems on Fatality Reduction

As discussed previously, the impact of a rural mayday system depends upon the level of market penetration and the mayday service availability. Given market penetration, M ($0 \leq M \leq 1$), and service availability, S ($0 \leq S \leq 1$), the mean accident notification time is given by:

$$ANT = f(M)*(1-M) + f(M)*M*(1-S) + 1.0*M*S \qquad (5)$$

The function f(M) represents the accident notification time for vehicles not equipped with mayday devices when the market penetration is M. In 1990, with market penetration equal to zero, f(M=O) equaled 9.6 minutes. As market penetration increases, we expect the accident notification time for vehicles not equipped with mayday devices to decrease (i.e., $f'(M)<0$)[3]. Passing motorists equipped with mayday might report accidents, thus reducing the accident notification time for accidents involving unequipped vehicles. The probability of this occurrence increases as the market penetration increases.

The first term in equation (5) represents the contribution to the mean accident notification time of vehicles not equipped with mayday devices. The second term is the contribution by mayday equipped vehicles that are not able to receive service because of blockage. The final term represents the contribution of mayday equipped vehicles that successfully receive mayday service (i.e., an accident notification time of one minute).

For the purpose of the following analysis, we assume a 100% market penetration (i.e., M=l). Three cases of service availability are considered, namely: 60%, 80%, and 100%. Thus, the relatively pessimistic assumption of a 60% (i.e., S=.6) service availability[4] implies that 40% of rural accidents would occur in blocked areas with communication and/or location failure.

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3 We may also expect a secular decrease in the mean accident response time independent of rural mayday market share as cellular phone coverage reaches into rural areas.

4 A recent study indicated that a mayday system based exclusively on cellular coverage of the roadway would offer a 67% service availability [3].

In such cases, we further assume that the mean accident notification time would be 9.6 minutes (i.e., f(M)=9.6 for all M). This is a relatively pessimistic assumption in that we do not account for the possibility that a mayday equipped motorist may encounter an accident and report it through his system. For the three service level scenarios, the results in terms of the reduction of 1990 fatalities are shown in Table 4-2. Because of the assumptions made above, these are conservative estimates that represent lower bounds for fatality reduction.

Assuming a 60% service availability, the mean accident notification time is reduced from 9.6 minutes to 4.44 minutes resulting in an expected 1727 lives saved annually, a 6.7% reduction in fatalities. If the service availability were increased to 80%, the accident notification time would be 2.72 minutes, leading to 2394 lives saved annually, a 9.3% reduction in fatalities. Finally, assuming a 100% service availability, yields 3069 lives saved per year, an 11.9% reduction in fatalities.

Table 4-2. Fatality Reduction (for M=l)

Service Availability	Mean Accident Detection Time (mins)	Fatality Reduction
60%	4.44	1727
80%	2.72	2394
100%	1.00	3069

4.3 Economic Benefits of Rural Mayday Systems

Given the impact of mayday systems on lives saved, we can infer the net economic benefits if these systems were fully implemented in rural areas. Miller [9] conducted a comprehensive study of the costs associated with roadway accidents and fatalities. Monetary costs where defined 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 quality of life losses 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 rural mayday system (i.e., 100% market penetration) for different values of service availability is shown in Table 4-3. For a 60% service availability, the monetary benefits are about $1.03 billion per year while the comprehensive benefits are about $3.58 billion per year. An 80% service availability yields monetary benefits of about $1.43 billion per year while the comprehensive benefits come in at about $4.97 billion per year. For a 100% service availability, we get monetary benefits of $1.83 billion per year and comprehensive benefits of $6.37 billion.

Table 4-3. Net Benefits from a Rural Mayday System (in $'s)

Service Availabilitv	Monetary	Comprehensive
60%	1,029,922,000	**3,582,718,000**
80%	1,427,698,000	4,966,432,000
100%	1,830,244,000	6,366,741,000

Section 5

Conclusions

A multivariate model was presented to identify the effect of accident notification time on fatalities. Other explanatory variables were introduced into the analysis as well, allowing us to identify the independent effect of the accident notification time. The explanatory variables were shown to account for a substantial portion of the variation in the numbers of fatalities on rural roadways.

The analysis demonstrated that accident notification time is an important determinant of the number of fatalities for accidents on rural roadways. Identifying the occurrence of accidents as quickly as possible so that EMS services may be sent can result in substantial reductions of fatalities.

Although the analysis was conducted across states for the 1990 time period, we demonstrated that the results were applicable to other years. The important relationship derived from this analysis is the elasticity of rural roadway 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.

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