RISK: Health, Safety & Environment (1990-2002)

Volume 9 | Number 1 Article 7

January 1998

A Method of Identifying Hazardous Highway Locations Using the Principle of Individual Lifetime Risk

Paul J. Ossenbruggen

A Method of Identifying Hazardous Highway Locations Using the Principle of Individual Lifetime Risk

Abstract
Dr. Ossenbruggen presents a scientific framework for identifying hazardous highway locations that may be more easily understood by non-scientists and has potential for comparing highway with other risks to health.

Keywords
motor vehicle, car, auto, accidents, fatality, crash, highway, freeway, expressway, 101

Cover Page Footnote
The work was supported by a grant from the U.S. Department of Transportation, University Transportation Centers Program.

A Method of Identifying Hazardous Highway Locations Using the Principle of Individual Lifetime Risk*

Paul J. Ossenbruggen**

Introduction

A scientific method for identifying hazardous highway locations is presented. The method employs the basic principles of probability and expected value theory, in which motor vehicle accidents are treated as random events. The risk R is defined as the expected loss or damage associated with the occurrence of a harmful event and is calculated as the product of $R = h\theta$ where h is the number of individuals exposed to a given harmful event, and θ is the probability of the event taking place. For the purpose of identifying a hazardous highway location, θ is the probability that an individual will be killed in a motor vehicle accident within a given year and h is the number of vehicle trips made at a given location. The highway risk R is therefore the expected number of fatal accidents per year for a given highway location.

A primary source of accident information is a report form that contains over thirty items.[1] These items collectively characterize a crash, its outcome, and the possible cause. State regulations vary, but typically a crash involving property damage over $1,000, injury or death must be reported. The form includes several items describing the motor vehicle(s), driver(s), occupants, and crash location, with space provided for a description of the accident and a collision diagram. Photographs of the event and surroundings are often attached. To illustrate the use of the hazardous highway location identification method, counts of fatality and injury producing collisions were

* The work was supported by a grant from the U.S. Department of Transportation, University Transportation Centers Program.

** Dr. Ossenbruggen is Professor of Civil Engineering, University of New Hampshire. He holds B.S., M.S., and Ph.D. (Cvil Engineering) from Syracuse University. Email: *pjo@ciunix.unh.edu.*

1 Uniform Police Accident Reporting Form.

obtained from the Town of Durham, New Hampshire (NH), Police Accident records from 1990 to 1997. Values for the highway exposure h were obtained from traffic count records,[2] and individual demand for highway services was obtained from the National Personal Transportation Survey.[3]

Table 1 contains a list of factors describing motor vehicle accidents in Durham and throughout the nation.[4] Investigation of the accident records generally shows traffic accidents are rare. For example, an estimated 30 million trips were made in Durham each year, yet, during the same time period, only about 250 injury and property damage accidents and one fatal accident are reported. Expressed as a probability, the chance of an accident resulting in either injury or property damage is about 8 in 1,000,000. The probability of a fatal collision, estimated to be 3 in 100 million, is much smaller. For this reason, probability theory is used to derive a lifetime highway risk model and to develop a method for hazardous highway location identification.

The use of the term "hazardous highway location" might suggest that the purpose of developing the method is solely to identify poorly designed highways. Clearly, given the factors listed in Table 1, fatal accidents may occur on even the best designed highways. The objective of the model and identification method is to identify those locations that have an incidence of fatal crashes which is higher than what is considered acceptable. Once a hazardous highway is identified, factors including poor design, driver error, traffic congestion, poor weather conditions, and lax law enforcement, can be investigated to determine the cause or causes of the accident.

The Lifetime Highway Risk Model

A model for calculating θ, the probability that an individual will be killed in a fatal crash over his or her lifetime, is derived from geometric and Poisson probability distributions.

---

2 N.H. Dept. Transp., Bur. Transp. Planning, Automatic Traffic Recorder Data for 1990-1994.

3 Stat. Abstract U.S., *National Personal Transportation Survey — Summary of Travel Trends 1969 to 1990,* 86 (115th ed. 1995).

4 Nat'l Highway Traffic Safety Admin. (NHTSA), Traffic Safety Facts 14, 43, 144–45 (1994).

The trip number in which an individual is killed is assumed to have a geometric distribution. The probability that an individual will be killed on trip number T, where t = 1,2, ... ∞, is expressed as

$$P(T = t) = \omega(1 - \omega)^{t-1} ,$$

where ω is the probability that an individual will be killed in a single motor vehicle trip. In other words, P(T = t) is the probability that an individual will make t - 1 trips without being killed and then will be killed on trip t.

Table 1
Motor Vehicle Crash Factors and Driver Characteristics

- *Crashes are Rare*. The Durham Police report about 250 motor vehicle crashes per year. It is estimated that over 30 million trips are made annually in Durham, NH.
- *Crashes Vary with Traffic Conditions*. Crashes are often assumed to be related to traffic congestion and episodic events. An episodic event, such as those triggered by special functions, e.g., sporting events and concerts, is suspected of causing traffic shock waves that frequently surprise drivers and cause a chain reaction of crashes.
- *Crashes Vary by Collision Type*. Accidents involve either single motor vehicles, two or more vehicles and pedestrians. NHTSA for 1994 reported that, nationwide, 20,505 fatality crashes involved a single vehicle; 15,718 fatality crashes involved multiple vehicles; and 5,472 fatality crashes involved pedestrians.
- *Crashes Vary Spatially*. In 1994, approximately 60% of crashes in Durham occurred on in-town, high-volume roads and parking lots. The remainder occurred on out-of-town, high-speed roads.
- *Crashes Vary Temporally*. Accidents are reported at different times of the day and in different seasons. In 1994, the number of weekday fatalities reached a nationwide peak of 6 fatalities per hour between 3:00 PM and 3:59 PM. The number of weekend fatalities reached a peak of 6.5 fatalities per hour between 1:00 AM and 2:59 AM.
- *Crashes Vary with Driving Conditions*. Accidents are reported for wet, dry and icy pavements.
- *Crashes Vary with Drivers' Physical Condition*. Drivers are involved in accidents when sober or under the influence of alcohol or drugs. NHTSA reports that 41% of all fatal crashes in 1994 involved alcohol. A driver's age can also affect his or her reaction time.
- *Crashes Vary with Driver Attitude*. NHTSA reports that young drivers tend to speed, and twice as many males as females are involved in accidents.
- *Crashes Vary with Driver Experience*. In 1994, NHTSA reported that 16–20 year-olds had the highest fatality rate (30.7 per 100,000) and 55– 64 year-olds the smallest fatality rate (10.7 per 100,000).

An individual is assumed to make a total of n trips in a lifetime. Mathematically, an individual is a survivor if the total number of trips T exceeds the total number of trips n an individual can make in a lifetime. The probability that an individual is a survivor is denoted by P(T > n) and is determined by summing $P(T = t)$ over all trip numbers t greater than or equal to n + 1. After simplifying, the survival probability, which is expressed as a conditional probability since n is given, is

$$P(T > t|N = n) = \omega^n \quad .$$

The number of trips that an individual makes in a lifetime is assumed to be a random variable N with Poisson distribution,

$$P(N = n) = (e^{-\eta}\eta^n)/n! \quad ,$$

where η is the mean number of trips made by an individual in a lifetime. The probability that an individual is a survivor, expressed in terms of N and $P(T > N)$, is calculated by summing the product $P(T > t|N = n) \times P(N = n)$ for n equal to and greater than zero. After simplifying this expression, the product reduces to $P(T > N) = \exp(-\eta\,\omega)$. Since $P(T > N) + P(T \leq N) = 1$, the probability that an individual will be killed in a motor vehicle crash is given by the compound distribution[5]

$$\theta = P(T \leq N) = 1 - \exp(-\eta\,\omega) \quad . \qquad (1)$$

This lifetime highway risk model forms the basis of the hazardous highway location identification method.

A Safety Compliance Standard Using Individual Lifetime Risk

The lifetime highway risk model is a function of an individual's demand for highway services η, and the probability of a fatal crash in a single trip ω. To develop a method of hazardous highway location identification, a "statistical traveler" will be defined and the traveling behavior of the "statistical traveler" will be used to assign the model parameter η. Concepts of public health risk assessment of chronic low-level exposure to chemical contaminants and the public's perception of highway risk will be used to assign θ and, in turn, to determine ω.

The "Statistical Traveler:" According to the National Personal Transportation Surveys,[6] the average number of daily trips per household for 1990 was reported to be 4.66. Given that there were 2.56 persons per household, the average person traveled about nine miles per day while making 1.82 trips. In 1990, the average person made about about 664.4 trips and traveled slightly less than 6,000 miles per year.

5 Marcel F. Neuts, Probability 224 (1973).

6 *See supra* note 3 at 636.

For the purposes of hazardous highway location classification, 1990 is assumed to be the base year and the "statistical traveler" makes η = 664.4 trips per year.

Public Health Considerations: Since a lifetime highway risk probability is the same measure of effectiveness as that used in the public health risk assessment of chronic low-level exposure to chemical contaminants,[7 8] public health and highway risks are therefore comparable. As a result, the assignment of an acceptable lifetime risk probability θ^* for a toxic chemical will be used as a guide for assigning an acceptable lifetime risk probability θ^* for highways.

A national public health goal is to minimize the probability that an individual will die prematurely from chronic low-level exposure to a toxic chemical. For the purposes of risk assessment, a premature death occurs when an individual dies from such low level exposure before reaching 70 years of age. The probability that an individual dies prematurely from chemical exposure is generally accepted to be on the order of $\theta^* = 1$ in 1,000,000. The aim of a public health regulator is to determine an acceptable daily intake (ADI) for humans such that a premature death occurring has a probability of θ^*.

Animals are typically exposed to heavy dosages of chemicals relative to the animal's weight. The data are used to develop a dose response function, which is used to determine a virtual safe dose (VSD). Once known, an acceptable daily intake is determined from ADI = VSD/sf where sf is a safety factor dealing with uncertainties associated with the use of simple mathematical model structures; extrapolation of animal response data from high to low chemical doses; biological, intake and weight differences between animals and humans; and unknown chemical effects on humans. Depending on the level of uncertainty, safety factor assignments range in magnitude from 10 to 1,000.

The procedure adopted for highway risk will adopt the assumption that a premature death is one that occurs before 70 years of age; i.e., the "statistical traveler" is assumed to have the same life span of 70 years. Given a fixed lifespan and θ^*, the annual and single trip risk probabilities of θ and ω can be determined.

7 Leonardo Ortolano, Environmental Regulation and Impact Assessment 385-392 (1997).

8 Paul Ossenbruggen, Fundamental Principles of Systems Analysis and Decision-Making 193-200 (1994).

A Highway Safety Compliance Standard: The lifetime highway risk probability will not be assigned a value as small as given for chemical exposure: $\theta^* = 1$ in 1,000,000. Society will generally accept a higher level of highway risk than chemical risk. Society's perception and acceptance of these risks are summarized in Table 2. For these reasons, chemical risks, particularly those associated with carcinogenic chemicals, are considered dread risks. Despite public awareness of their dire consequences, motor vehicle accidents are considered less threatening than dread risk. Consequently, a highway safety compliance standard of $\theta^* = 1$ in 1,000 is considered to be a reasonable assignment of risk. Statistical evidence will illustrate that this assignment is sufficiently rigorous because, if met, there would be a six-fold decrease in the number of fatal collisions reported nationally.

Given $\theta^* = 1$ in 1,000 and η = (664.4 trips per person per year) x (70 years per lifetime), or 46,508 trips in a lifetime, a value of 2.2 in 100 million is obtained for ω using the lifetime highway risk model. Substituting $\eta = 664.4$ and $\omega = 2.2$ in 100 million into the lifetime highway risk model once again, an annual value of $\theta = 1.4$ in 100,000 is obtained for the highway compliance standard.

The same highway safety compliance standard of $\theta = 1.4$ in 100,000 is assumed to apply to all categories of highway systems. That is, freeways, two lane undivided highways, local roads, etc. are expected to provide the same level of safety. The assumption of a universal standard differs from current practice of hazardous highway identification, which categorizes highways by highway system type, location (urban or rural), and other features. This point will be explored in greater detail in the Discussion section.

The Method of Hazardous Highway Location Identification

Given the definition of risk $R = h\theta$ and the highway safety compliance standard θ, the numerical value of R can be calculated. The value of R is assumed to be an acceptable (or critical) number of fatal crashes per year for a given location. Similarly, a highway safety standard for injury accidents, R_I, will also be established. Given R and R_I and the fatality and injury counts, C and C_I, it is a simple matter to identify a highway location as being either safe or hazardous. In this section, the focus is on developing a fundamental understanding of the definition of risk and how it applies to the method of hazardous highway location identification.

Fatal Accidents: Each vehicle that passes a specific spot on a highway is considered to be a candidate for a fatal motor vehicle accident. Consequently, the average daily traffic (ADT) level is considered the best and most practical measure of exposure; therefore, the exposure h is assumed to be equal to ADT.

The number of fatal accidents occurring at a given spot within a given year is represented by a random variable X. The probability of an individual being killed in a fatal collision is assigned to be θ. The probability of x events in h trials, $P(X = x)$, is typically assigned a binomial distribution. However, since is $h = ADT >> 100$, $\theta << 0.01$, and $h\theta \leq 20$, the distribution of X can be approximated by a Poisson distribution[9] with mean, $\lambda = h\theta = ADT\ \theta$. The acceptable number of fatal crashes at a given location for a given time span is estimated to be

$$R = ADT\ \theta = ADT\ [1 - \exp(-\eta\ \omega)] \qquad (2)$$

If the fatal crash count for a given location C exceeds the expected number of fatal crashes R, then the location is classified as hazardous; otherwise, the location is considered safe.

Injury Accidents: The hazardous highway location method can also be extended to injury crashes. If $C_I > R_I$, then the location is identified as hazardous. The principle of conditional probability and national highway injury and fatal crash counts are used to establish a safety compliance standard θ_I for injury crashes and, in turn, R_I.

According to NHTSA, motor vehicle accidents, 1988–94 ranged from 6 million to almost 7 million annually. During this period, the percentages of fatality and injury causing crashes remained almost constant at 0.6% and 32%, respectively. These data will be used to estimate the probability of a injury crash in a single trip ωI.

The conditional probability δ that, given an injury producing crash, it will be fatal is estimated to be the ratio of the number of fatal accidents to the number of injury producing accidents, or $\delta = 18/1{,}000$. The probability of a fatal crash is the product of its conditional probability given an injury-producing crash times the probability of an injury-producing crash or $\omega = \delta\omega_I$. Given $\omega = 2.2$/million and $\delta =$

[9] Jay L. Devore, Probability and Statistics 114 (1987).

18/1,000, the value of ω_I is calculated to be ω_I = 1.2/million. Substituting h = 664.4 and ω_I into the lifetime highway risk model, $\theta_I = 1 - \exp(-\eta\ \omega_I)$, a value of the highway safety compliance standard for injury crashes is calculated to be θ_I = 7.8/10,000. An acceptable number of injury crashes at a given location is then:

$$R_I = ADT\ \theta_I = ADT\ [1 - \exp(-\eta\ \omega_I)] \quad . \qquad (3)$$

Classification: If either C > R or $C_I > R_I$, then the highway location is classified as hazardous; otherwise, it is classified as safe.

Table 2

Public Perception of Highway and Public Health Risks[10]

Category	*Highway*	*Chemical*	*Generalizations*
Degree of Fear	Little	Great	In the U.S., fear of lingering death from chemical exposure death is greater than the fear of sudden death from a vehicle crash.
Controllability	Great	Little	In comparison to a driver, individuals exposed to toxic chemical have little or no control.
Blame and Injustice	Individual	Someone else	A negligent driver can be blamed for damages to involuntary victims and himself. An injustice may have occurred when involuntary victims are involved and the driver is unharmed. When the negligent driver only harms himself, it can be argued that justice has been served. In both cases, it is reasonable to assume that no financial gain is received by the driver. A negligent chemical manufacturer can be blamed for exposing involuntary victims to toxic chemicals while receiving financial benefits from the sale of products. In comparison to a negligent driver, an injustice is perceived to have occurred in this incident.
Exposure Benefits	Great	Little	The personal automobile is considered essential to the economy of the U.S. In comparison, the benefits derived from a chemical tend to affect fewer individuals or companies.

10 Adapted from Adam M. Finkel, *Comparing Risks Thoughtfully*, 7 Risk 325 (1996).

Case Study

Injury and fatal accident counts for Routes 4 and 108, both two-lane, undivided highways in Durham, are used to illustrate the identification method. Route 4 is a primary east-west corridor connecting the capital, Concord, in the middle of the state to Portsmouth on the Atlantic. Route 108 runs north-south.

The fatality and injury counts listed in Table 3 are divided into four groups. The highways are similar, yet each stretch possesses some distinctive characteristics. Route 4 West is a 2.25 mile stretch of roadway with limited access and freeway-type features, including two road-separated interchanges. A signalized intersection is located midway between interchanges. The intersection has a generous right-of-way, having paved breakdown lanes 9.5 feet in width and guardrails located 10 feet from the edge of the driving lane. In contrast, Route 4 East is a three mile section of highway with a narrow right-of-way. Its paved breakdown lanes range in width from 2–9.5 feet, with guardrails located in some places as close as two feet from the edge of the driving lane. Routes 108 North and South have highway characteristics most similar to those of Route 4 East. However, Route 108 does not have paved breakdown lanes.

Table 3

Motor Vehicle Fatal and Injury Accident Counts for Durham, NH[11]

	Route 4 E		*Route 4 W*		*Route 108 N*		*Route 108 S*	
Year	C	C_I	C	C_I	C	C_I	C	C_I
1990	1	8	0	3	0	7	0	3
1991	0	4	0	3	0	3	0	9
1992	2	12	1	2	0	4	0	3
1993	2	8	1	8	0	1	0	3
1994	0	3	0	3	0	3	0	5
1995	0	4	0	3	0	3	0	1
1996	1	6	0	2	0	3	0	6
Ave.	0.86	6.4	0.29	3.4	0	3.4	0	4.3

The average speeds on all these highways are estimated to be least 40 mph. The only exception is the one-half mile portion of Route 4 North, which is a business district with an average speed of about 35 mph. The ADT for Routes 4 East and West is 15,470 vehicles per day.

[11] Durham, NH Police Dept., *TIPS Accident Statistics Report* (computer output sheets, 1990–96).

The ADT values for Route 108 North and South are 10,000 and 9,250 vehicles per day, respectively.

The values of C and C_I for Routes 4 and 108 are shown in Table 3. The seven-year averages of C and C_I given at the bottom of the table are used for classifying a highway location as either safe or hazardous.

Table 4 contains the results of analyses obtained using the hazardous highway location identification method for stretches of highways of length L, expressed in miles. All classifications were made using the procedures described in the previous section.

After further evaluation of the spatial distribution of collisions, Route 4 West shown in Table 4 was reclassified. The method of hazardous highway location identification is derived for a spot location, but can also be applied to stretches of highway, as illustrated in Table 4. Classifying stretches of highways has important practical significance, but it should be realized that classifying crashes for long stretches can inflate the counts of C and C_I, thereby increasing the likelihood that a given stretch of highway will be classified as hazardous. For example, the average C and C_I values for Route 4, a 5.25 mile stretch of highway, are 1.14 and 9.8, respectively. In this case, the inequalities of $C > R$ and $C_I < R_I$ remain the same, but these inequalities may artificially give the impression that the 5.25 mile stretch of Route 4 is hazardous. Spatial distribution of crashes should be therefore considered in such cases.

Table 4

Hazardous Highway Location Classifications for Fatal Crashes in Durham

Location	*ADT*	*L*	*R*	*C*	R_I	C_I	Classified
4 E	15,470	2.25	0.22	0.86	12.1	6.4	Hazardous
4 W	15,470	3	0.22	0.29	12.1	3.4	Safe*
108 N	10,000	1	0.14	0.0	7.8	3.4	Safe
108 S	9,290	3	0.13	0.0	7.2	4.3	Safe

* Note that $C > R$; therefore, according to the hazardous highway location method, the stretch of Route 4 W is classified as hazardous. However, after considering spatial distribution of crashes, Route 4 W was reclassified. See text for explanation.

Investigation of the two fatal accident reports for Route 4 West shows that one crash occurred at a signalized intersection and the other at an interchange. Given this, the C averages for Route 4 West in Table 4 have been modified. The average values at the signalized intersection and interchange are reduced to C = 0.15. No injury crashes were reported at the interchange. All injury crash counts (C_I = 3.4 per year including a total of eight injury crashes in 1993) are located at the signalized intersection. Since $C < R$ and $C_I < R_I$, the two locations on Route 4 West satisfy the condition for a safe highway location, and the entire 2.25 mile stretch of Route 4 West is therefore classified as safe.

In comparison, all six fatal crashes on Route 4 East listed in Table 3 occurred on Route 4 at four different local street intersections. Two intersections on Route 4 were each the location of two fatal crashes. Given this information and the fact that all four intersections within the three-mile stretch of highway have similar design characteristics, the entire stretch of Route 4 East is classified as hazardous. The average number of injury crashes meets the highway safety standard, but the number of fatal accidents exceeds the safety compliance standard by a factor of four. While the average number of motor vehicle crashes on Route 4 East may be considered small, the crashes that have occurred on this stretch of highway have been extraordinarily violent.

Discussion

A Rigorous Safety Criterion: Since the same safety compliance standard of θ = 1.4 in 100,000 is assumed to be applicable to all highway classifications, the total number of fatal accidents satisfying the highway safety compliance standard can be estimated and compared to the reported number of fatal collisions that occurred nationwide. NHTSA reported for 1990 that there were 39,836 fatal crashes with 47,151 deaths, and 2,122,000 injury producing crashes.

Given 93 million households and 4.66 daily trips per household in 1990, the total number of trips per day is estimated to be TPD = (93 million) (4.66) = 433.4 million. The acceptable number of fatal crashes for θ = 1.4 in 100,000 is TPD θ = (433.4 million) (1.4/100,000) = 6,214. Likewise, the acceptable number of injury crashes for θ_I = 7.8 in 10,000 is TPD θ_I = (433.4 million) (7.8/10,000) = 340,355. The reported numbers of fatal and injury producing collisions exceed the number of fatal and injury producing accidents deemed acceptable by the safety compliance standards by factors of 6.4 and 6.2, respectively. These data give assurance that the highway compliance standards of θ = 1.4 in 100,000 and θ_I = 7.8 in 10,000 are rigorous and, at the same time, suggest that more work is needed to reduce the number of motor vehicle crashes on the nation's highways.

Highway Safety Trends: In accordance with the lifetime highway risk model, the trip exposure η affects θ and R and, in turn, affects the safety classification of a highway location. The impact of exposure can be most vividly illustrated by example.

In 1969, the U.S. population was 226 million, compared to 249 million in 1990. During this 31 year period, however, the number of motor vehicle trips made per person increased by 50%. According the National Personal Transportation Survey, the average person in 1990 made daily 1.21 trips. The "statistical traveler" of 1969 made $\eta = 442$ trips per year, compared to the "statistical traveler" of 1990, who made $\eta = 664.4$ trips per year. The average trip length of about nine miles per trip has remained constant over this period.

Since an individual's trip exposure was less in 1969, the highway risk R is obviously less than the 1990 value. Given the same value of $\omega = 2.2$ in 100 million as in 1990 and $\eta = 442$ trips per year, the highway safety compliance standard for 1969 is calculated to be $\theta = 9.5$ in 1,000,000, a value less than $\theta = 1.4$ in 100,000 for 1990. Given 62.5 million households and 3.83 daily trips per household, TPD = (62.5 million) (3.83) = 239.4 million trips per day. The acceptable number of fatal crashes for 1969 is TPD θ = (239.4 million) (9.5/1,000,000) = 2,280. The reported number of fatalities for 1969 is 53,543 and the number of fatal accidents for 1969 was estimated to be about 50,000. Both greatly exceeded the acceptable number of 2,280 fatal crashes per year.

The decline in the reported number of fatal crashes from 50,000 in 1969 to 39,836 in 1990 is an indication that the steps taken to improve safety have been effective. Some of the most notable steps have been providing motor vehicles with standard safety equipment such as safety belts and collapsible steering wheel columns; making driving while intoxicated a criminal offense; passing mandatory seat belt laws; and educating the public to drive more responsibly.

Average Accident Rates: Various measures of the average accident rate are used to describe highway safety and identify hazardous locations.[12] The accident rate per 100 million vehicles miles traveled

(RMVM) is widely used in the analysis of accident data and for highway safety comparison. For fatal accidents, the RMVM used for stretches of highway is given by

$$\text{RMVM} = (100 \cdot C) / (365 \cdot L \cdot ADT)$$

and for injury crashes, RMVM_I is given by

$$\text{RMVM}_I = (100 \cdot C_I) / (365 \cdot L \cdot ADT)$$

Comparing RMVM and RMVM_I values for the Durham highways with various highway system categories for NH and the U.S. shows that the RMVM values for stretches of Route 4 East and West are larger than the values for all of the highway categories listed in Table 5. With the exception of Route 4 West, which was classified as safe after the spatial distribution of crashes was considered, the Durham highway classifications are consistent with the RMVM statistics for the system categories given in Table 5.

Table 5

RMVM Measures for Durham and U.S. Highways[13]

Location	*C*	*RMVM*	C_I	RMVM_I
4 W	0.29	2.25	3.43	27.0
4 E	0.86	5.06	6.43	38.0
108 N	0.0	0.0	3.43	93.93
108 S	0.0	0.0	4.29	42.31
System Category: Urban Principal Arterial for 1992				
NH	16	1.59	1,195	118.91
U.S.	5,246	1.52	488,228	141.85
System Category: Urban Total Systems for 1992				
NH	29	0.78	1,722	171.34
U.S.	15,202	1.12	781,631	227.09
System Category: Total Systems for 1992				
NH	110	1.09	6,850	68.04
U.S.	34,928	1.56	2,216,245	98.95

The Critical Accident Rate Factor Method: This method is used to identify possible hazardous highway locations. If the critical accident rate at a location is significantly higher than the average for that highway system type, then the location is considered hazardous. To

12 Nicholas J. Garber & Lester A. Hoel, Traffic Highway Engineering 138-42 (1997); Conn. Dept. Transp., *Accidents Records and Statistics Manual* (1993).

13 Fed. Highway Admin., Highway Safety Performance — *1992* 5, 6, 16, 42 (1995).

illustrate, RMVM is used as a measure of effectiveness. The critical accident rate is calculated as an upper-level confidence level using statewide accident and traffic statistics, calculated from

$$RMVM_{cr} = \overline{RMVM} + Z \cdot S_{RMVM}$$

where $\overline{RMVM}$, S_{RMVM}, and Z are the average, standard deviation, and standard normal random variable for the sample, respectively. The values of Z, for example, are 1.645 for 95% and 2.576 for 99.5% upper confidence levels. A highway segment average is denoted as RMVM; therefore, if RMVM > $RMVM_{cr}$, then the segment is classified as hazardous; otherwise, it is classified as safe.

In practice, the critical accident rate factor method compares the accident history of a highway segment or intersection with the state accident history of the same type. The data are carefully sorted by highway system type, land use (rural and urban), geometric design, and traffic control characteristics. The goal of this method is to identify hazardous highway locations by category. In contrast, the goal of this paper is to identify hazardous highways independent of system type or any other type of categorization.

Sorting the data by highway category may lead to inconsistency and confusion in classification. For example, Routes 4 and 108 are designated to be urban principal arterial highways because the Durham population of over 10,000 people exceeds the required minimum population of 5,000. Given an urban designation, the RMVM values of Durham are compared to areas with much greater population densities. The NH statewide averages of $\overline{RMVM}$ and $\overline{RMVM}_I$ are 1.37 and 35.49 for rural principal arterial highways, and 1.59 and 118.91 for urban principal arterial highways, respectively.

For simplicity, Z = 0 and RMVMcr = $\overline{RMVM}$ and $RMVM_{Icr}$ = $\overline{RMVM}_I$. Given $RMVMI_{cr}$ = 35.49 and $RMVM_I$ = 38.0, Route 108 North is classified as hazardous when designated to be a rural principal arterial highway and, given $RMVM_{Icr}$ = 118.91, it is classified as safe when designated a urban principal arterial highway .

Consider another example dealing with sample variability. Because it reported a value for $\overline{RMVM}$ = 2.05, which exceeds the national average of $\overline{RMVM}$ = 1.56 for 1992, South Carolina may be considered one of the most dangerous states in the nation to drive. Ironically, for all urban principal arterial highways in South Carolina, no fatal accidents were reported in 1992; therefore, $\overline{RMVM} = 0$, $Z = 0$, and $RMVM_{cr} = 0$. Clearly, this statistic has little or no practical value in hazardous highway identification.

In contrast, the hazardous highway identification method does not lead to these types of anomalies because the method uses the same fatality and injury compliance standards for all highway system types.

Abnormal Accident Rate Experience: The concepts of individual lifetime risk are adapted to identify hazardous locations with abnormal accident rate experience. In lieu of using statistical summaries employed by the critical accident rate factor method, the upper confidence level is calculated using the Poisson distribution. The adaptation makes use of the following steps for a given highway location: (1) estimating $\hat{\theta}$ using a risk definition of $\hat{\theta} = C/TPD$, where C is the number of reported fatal accidents, and (2) calculating the critical X_{cr} for a given confidence level and the Poisson probability distribution with mean $\lambda = ADT \cdot \hat{\theta}$. The individual lifetime risk method departs from the critical accident rate method of sorting accident and traffic data by highway system type, land use, geometric design, and traffic control characteristics. The same steps are used for injury producing accidents.

Table 6
Abnormal Accident Rates for the Highways in Durham, NH

Year	*C*	*National Statistics* C_I	TPD	*Fatal* θ	*Injury* θ_I
1990	39,836	2,122,000	433.4M	9.2/100,000	4.9/1,000

Location	ADT	X_{cr}^* 95%	X_{cr}^* 99.5%	X_{Icr}^* 95%	X_{Icr}^* 99.5%
Route 4 W	15,470	4	5	90	99
Route 4 E	15,470	4	5	90	99
Route 108 N	10,000	3	4	61	68
Route 108 S	9,250	3	4	57	64

* At two confidence levels

Tables 6 and 7 contain the critical values of X_{cr} and X_{Icr}, for 95% and 99.5% confidence levels, obtained for Routes 4 and 108. Table 6 uses accident counts and TPD for the entire nation, whereas Table 7 uses accident counts and TPD only for NH. The Poisson distribution is a discrete probability distribution; therefore, X_{cr} and X_{Icr} are integers. Since $C < X_{cr}$ and $C_I < X_{Icr}$, Durham highways are not classified as locations with abnormal accident rates. Comparison of $\hat{\theta}$ and $\hat{\theta}_I$, as well as other statistics Tables 6 and 7, shows that, relative to national experience, NH is a safer place to drive.

Table 7
Abnormal Accident Rates for the Highways in Durham, NH

Year	*New Hampshire Statistics* C	C_I	TPD	*Fatal* θ	*Injury* θ_I
1992	110	1,978	417,000	5.7 /100,000	1/1,000

Location	ADT	X_{cr}* 95%	X_{cr}* 99.5%	X_{Icr}* 95%	X_{Icr}* 99.5%
Route 4 W	15,470	3	4	23	27
Route 4 E	15,470	3	4	23	27
Route 108 N	10,000	2	3	16	19
Route 108 S	9,250	2	3	15	18

* At two confidence levels

Risk Communication: A most difficult task facing transportation professionals is presenting scientific and technical facts to the public, particularly when it is often hostile and suspicious because a proposal may affect the status quo of a particular community. The results of traffic safety analyses, such as statistical results of the critical accident rate methods, cost-benefit analysis, and other planning tools are usually not appreciated. Expressing highway safety in terms of the number of accidents per RMVM or the loss of a life in monetary terms are often neither understood nor easily accepted. Values of RMVM, for example, are considered by transportation professionals to be valuable for comparing and ranking the safety of different highway systems and studying safety trends. At the other extreme, presenting a proposal without reference to accident counts or other highway-related statistics trivialize the importance of safety.

A benefit of using lifetime risk is that it can be expressed as a probability θ or an expected value measure R. Most people have been exposed to the fundamental ideas of chance. Lotteries are commonplace. A person can appreciate the notion that an outcome is a rare event if its chance of occurring over one's lifetime is expressed as 1 in 1,000 or, on an annual basis, 1.4 in 100,000. Using the definition of risk as an expected value, the highway safety compliance standard can be restated in terms that may be more easily understood by some lay people. For example, a compliance standard for Route 4 East was determined to have an expected value of R = 0.22 and was used to classify this highway stretch as hazardous. The same classification is obtained by using whole numbers for the expected value of R and rephrasing the definition of a safe highway. In other words, a highway location is defined to be safe if no more than one fatal accident occurs in a five year period. According to the data in Table 3, Route 4 East had two fatal crashes in two successive years and is therefore classified as a hazardous location because it does not meet the above definition.

Recently, the concern that some public health risks are trivial has led to a debate on regulatory risk reform.[14] Highway risk has mostly played a minor role in the debate. When it is discussed, the focus is generally directed at the highway safety cost-benefit analyses that tend to use figures which underestimate the value of life.[15] The concepts for describing highway safety using individual lifetime risk and a highway safety compliance standard of $\theta^* = 1/1{,}000$ brings a different perspective and hopefully better insight to the analysis and discussion of a common risk in life that affects virtually everyone daily. By introducing these highway risk concepts and a goal of achieving a highway safety compliance standard into the regulatory risk reform debate, some of the barriers preventing effective risk communication between highway safety experts and the public may be overcome.

---

14 Stephen Breyer, **Breaking the Vicious Cycle: Toward Effective Risk Regulation** 10-29 (1992). *See also,* John D. Graham, *Edging Toward Sanity on Regulatory Risk Reform* 11 Issues Science & Tech. 61–64 (1995).

15 **Risk, Costs and Lives Saved, Getting Better Results from Regulation** 137–49 (Robert W. Hahn, ed.1996).

Conclusions

A scientific framework for hazardous highway location identification is presented that considers both fatality and injury-producing accidents, the concept of individual lifetime risk and incorporates a safety compliance standard. A lifetime risk of 1 in 1,000 was chosen and defended by adopting principles from public health regulation and the public's perception of highway risk. The same safety standard is assumed to apply to all highway system categories. All highways are therefore expected to provide the same level of safety.

Using national accident counts, it was demonstrated that the selection of the value of lifetime risk is a rigorous standard. The application of the method was demonstrated by a case study of undivided two-lane highways in Durham, NH. It was shown that classifying highways with the hazardous highway location method is consistent with others used in practice. Since it employs the same measure of effectiveness used in public health, highway and public health risk can be compared and ranked. Further, since the method employs both probability and expected numbers of fatality and injury-producing crashes as measures of effectiveness, the results may be more easily understood by the lay public.