Effectiveness of Seat Belts in Reducing Injuries

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June 2007

Submitted to: Mack-Blackwell Transportation Center
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ACKNOWLEDGEMENT

This project was funded jointly by Mack Blackwell Transportation Center (MBTC) with matching funds from the Kansas Department of Transportation (KDOT) through the Kansas Transportation Research and New Developments (K-TRAN) research program. MBTC is a national center at the University of Arkansas that addresses rural oriented national problems. The Kansas KTRAN program is an on going cooperative and comprehensive research program addressing the needs of the State of Kansas utilizing academic and research resources from KDOT, Kansas State University (KSU) and the University of Kansas (KU).

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ABSTRACT

This study estimated the effectiveness of seat belts in reducing injuries and estimated the associated economic benefits using state of Kansas data. The estimation process included three stages. In the first stage, seat belt effectiveness in reducing injuries to motor vehicle occupants was estimated. Crash data from Kansas Accident Reporting System (KARS) database was used to accomplish this estimation process. Seat belt effectiveness was estimated using logistic regression method. The associated results were then compared with estimated values obtained from double pair comparison method. The two vehicle type groups considered in the study were limited to passenger cars group, and other passenger vehicle group that included pickup trucks and vans. In the second stage, the estimated seat belt effectiveness values resulted from the first stage were subsequently used to estimate potential injury reductions due to increased seat belt usage. In the third stage, obtained injury reduction values were converted into economic values by assigning economic costs for each injury type severity.

According to the obtained estimations, seat belts are 56% effective in preventing fatal injuries when used by passenger car front seat occupants. In the other passenger vehicle group that included vans and pickups, seat belts were found to be 61% effective in preventing fatalities. The seat belt effectiveness, in reducing incapacitating and non-incapacitating injuries, was respectively found to be 53% and 55% for passenger cars group, and 52% and 51% for other passenger vehicle group.

Based on the analysis conducted in this study, it was found that 1% incremental increase in current seat belt usage rate could annually save about $13 million to the state of Kansas. If seat belt usage in Kansas reaches the national average rate of 82% (2005 value), the resulted annual economic savings are estimated to be around $260 millions.

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CHAPTER 1 INTRODUCTION

1.1 Background

Deaths due to unintentional injuries are ranked 5th among different causes of deaths in the USA and motor vehicle crashes are the leading cause of unintentional injuries. Moreover, motor vehicle crashes are the leading cause of death among persons between 1 to 34 years of age (CDC, 2006). In the year 2005, it was estimated that 43,443 people died due to motor vehicle crashes and another 2.8 million were injured (NHTSA, 2006). In Kansas, 428 persons died and 22,723 were injured in the same year (KDOT, 2006). The economic impacts due to highway crashes are enormous. It has been estimated that the economic loss due to highway crashes in year 2000 was about $230 billion. This loss is equivalent to 2.3% of the US Gross Domestic Product for the year 2000 (Blincoe, et al., 2002). In the same year, the state of Kansas loss is estimated at about $1.9 billion due to highway crashes. This is equivalent to $700 yearly loss per every Kansan.

Numerous efforts have been made to mitigate the vast impact of highway crashes. One of the remarkable implementations, in this regard, is the introduction of seat belts into vehicles. It has been proven that seat belts have been very effective in improving passenger safety, saving many lives and preventing many injuries to vehicle occupants. Economically, billions of dollars have been saved by the use of seat belts. For example, according to National Highway Traffic Safety Administration's (NHTSA) estimations (Blincoe, et al., 2002), use of seat belts have saved about 135,000 lives and prevented 3.8 million injuries during the period from 1975 to 2000. Additionally, the study speculates that if all motor vehicle occupants were restrained, then 314,824 deaths and 5 million injuries could have been prevented during the same time period. In terms of economic savings, for the 1975 to 2000 time period, use of seat belts has saved $588 billion. Based on year 2000 seat belt usage rate (Blincoe, et al., 2002), seat belts are annually saving about $50 billion (in terms of 2000$). On the other hand, seat belt non-use has resulted in $930 billion loss to the economy, during the same period of time, and the annual loss is estimated at about $26 billion (Blincoe, et al., 2002).

Due to high benefits already realized and potential future benefits that could be achieved through higher seat belt usage rate, many states have enacted seat belt laws to mandate the use of seat belts. As of 2005, 25 states plus District of Columbia and Puerto Rico have primary adult seat belt laws, where police officers can stop and cite a motorist for the violation of the seat belt law (Glassbrenner, 2006). In the remaining states, except New Hampshire, the law is secondary where motorists can only be cited for violating the seat belt law after having been stopped for unrelated traffic violation. The state of New Hampshire is the only US state that does not mandate any seat belt law.

Despite the proven economical and health benefits derived from the seat belt usage, many US states still observe very low seat belt usage rates. According to the 2005 seat belt survey results, about 50% of the US states still have seat belt usage rates that are less than the national average rate of 82% (Glassbrenner, 2006). In Kansas, where the law is secondary, the observed usage rate in 2005 was at 69%, which is significantly lower than the national average. Additionally, Kansas is among the 10 states with the lowest seat belt usage rates. Overall, Kansas is ranked 45th in the nation, in seat belt usage rate, among 48 US states plus District of Columbia and Puerto Rico (Glassbrenner, 2006).

Considering the aforementioned seat belt usage benefits, it is unfortunate to note that many motorists are still not taking advantage of these benefits. Failure to use seat belts is not only costly to the non-user of the seat belt, but to the whole society. Therefore, it is very important for transportation authorities to find ways that can increase the seat belt usage rate among motorists. This is especially important for a state like Kansas, which has a comparatively low seat belt usage rate. Previous research efforts have indicated that that the most effective way to increase the seat belt usage rate is through strong enforcement. In other words, seat belt usage rate can be increased by mandating the enforcement of a primary seat belt use law. According to NHTSA seat belt survey results, the change in law from secondary to primary has dramatically increased the observed seat belt usage in many states (Glassbrenner, 2006). However, such a decision should be well supported by proven benefits at the local level. Although, national estimations are available to quantify the seat belt benefits, it would be useful for the local authorities to have the estimated benefits derived from their local conditions in order to better promote the seat belt usage among local motorists.

1.2 Objectives of the Study

The main objective of this study was to estimate the effectiveness of seat belts in reducing injuries and to estimate associated economic benefits using state of Kansas data. This objective was achieved through two major stages. In the first stage, the motor vehicle crash data for the state of Kansas was used to estimate the effectiveness of seat belts in reducing fatal and nonfatal injuries. In the second stage, the expected economic benefits were estimated using the effectiveness values estimated in the first stage.

1.3 Outline of the Report

The first chapter of this report discusses the background and the objectives of the study. The second chapter discusses details of seat belt effectiveness estimation techniques including details of previous studies, data and methods used, and the associated results. The third chapter of the report includes details of seat belt benefit estimation procedure. This chapter includes details of past studies, the methodology used, and the results obtained. Chapter five concludes the report with summary and conclusions.

CHAPTER 2 SEAT BELT EFFECTIVENESS

2.1 Introduction

The benefits of seat belts are estimated based on their ability to mitigate impacts to a motorist due to a crash, thereby reducing the severity of injuries. This is commonly referred to as the seat belt effectiveness. In other words, the seat belt effectiveness could be defined as the reduction in risk (or probability) of being injured due to the use of seat belt when involved in a crash. Thus, the estimated benefits due to seat belt usage are dependent on the used seat belt effectiveness values. According to National Highway Traffic Safety Administration (NHTSA) (NHTSA, 2001) estimations, seat belts are about 45% effective in preventing fatal injuries and 60% effective in reducing nonfatal injuries.

The NHTSA seat belt effectiveness values have been estimated based on national data and thus represent average conditions. Therefore, use of those effectiveness values in safety analyses for a particular state may lead to inaccurate estimations. For example, Kansas rural highways account for 91% of total highway mileage and for about 50% of the state vehicle miles of travel. On the other hand, at the national level, all U.S. rural highways account for only 16% of vehicle miles of travel. Therefore, seat belt usage patterns in Kansas may be different from that is observed nationally. In addition, since Kansas enforces secondary seat belt law, seat belt usage patterns among motorists in Kansas may be different from what is observed in states that enforce primary seat belt law. Thus, the use of seat belt effectiveness values based on Kansas crash data would provide more accurate benefit estimates.

The seat belt effectiveness values estimated by NHTSA are based on Abbreviated Injury Scale (AIS). AIS is a method used to rank the injury type severity based on a scale ranging from 1 to 6. KABCO is another scale used to measure the injury type severity associated with motor vehicle crashes. KABCO scale uses 5 different levels to rank the injury type severity. Table 2.1 illustrates the different levels used to express injury type severity according to both AIS and KABCO scales. It can be seen that the two scales use completely different injury severity levels to express the severity of nonfatal injuries.

TABLE 2. 1   Levels of Injury Type Severity Used in AIS and KABCO Scales

AIS Scale		KABCO Scale	
Level	Severity	Level	Severity
6	Fatal	K	Fatal
5	Critical	A	Incapacitating
4	Severe	B	Non-incapacitating
3	Serious	C	Possible
2	Moderate	O	No-injury (Property Damage Only)
1	Minor	*	*

** - Not applicable*

Almost all US states including the state of Kansas use KABCO injury severity scale in their highway crash databases to report injury severity. Because of this incompatibility in severity scales, it is difficult to combine information from these two data sources when conducting safety analyses. For example, to assess the effectiveness of safety belt promotion programs in Kansas in terms of number of injuries prevented due to increased seat belt use, the KABCO levels need to be converted into a compatible AIS injury levels because Kansas highway crash data base uses the KABCO scale. For this purpose, conversion factors are required. Unfortunately, in most cases such conversion factors are not available at the state level. Although few studies have developed conversion factors using national data (Miller et al., 1991), those factors have not been updated to account for recent conditions/data. Thus, the use of those conversion factors may negatively impact the accuracy of results obtained. For this reason, seat belt effectiveness values based on KABCO scale would be more useful in the state level safety analyses.

In this study, seat belt effectiveness for different injury types was estimated based on available Kansas highway crash data. Consequently, seat belt effectiveness values obtained were used to assess the economic savings resulting from any projected increase in seat belt usage rates.

2.2 Literature Review

The Final Regulatory Impact Analysis conducted by NHTSA in 1984 estimated the effectiveness of restraint systems in reducing fatalities and injuries (NHTSA, 1984). This study considered both manual (both lap and lap/shoulder) and automatic (two-point and three-point) seat belts. Data from National Crash Severity Study (NCSS) and National Accident Sampling System (NASS) for the period of 1979 to 1982 were used in this study. The estimation method was based on rate of restrained and unrestrained occupants who were injured due to highway crashes. The results showed that lap/shoulder seat belts are 40%-50% and 45%-55% effective in reducing fatalities and nonfatal injuries, respectively. When lap/shoulder seat belts were combined with air bags, the estimated effectiveness slightly increased to the 45%-55% range for fatalities and the 50%-60% range for nonfatal injuries. However, the seat belt effectiveness study did not account for the possible impact of other uncontrolled associated factors due to the insufficient availability of crash data during the study time period.

NHTSA later conducted series of research studies to evaluate the estimated seat belt effectiveness values using more recent crash data in order to fulfill the requirements of the Intermodal Surface Transportation Efficiency Act (ISTEA) enacted by Congress in 1991 (NHTSA, 1996, 1999, 2001). These studies were conducted using the data from Fatality

Analysis Reporting System (FARS) and NASS Crash Worthiness System (CDS). According to the latest study in this series, considering manual-shoulder seat belts alone, the effectiveness of seat belts in preventing fatalities is estimated at 45% and at 60% in preventing nonfatal injuries (i.e., moderate to greater injuries). These new estimates are similar to the original estimates (NHTSA, 2001).

The logistic regression method has been applied by many researchers to estimate the seat belt effectiveness. In this method, the odds ratios between restrained and unrestrained occupants are estimated. The advantage of this method is that the seat belt effectiveness can be controlled for possible effects of various other factors such as occupant and vehicle characteristics, roadway and environmental conditions, etc. Walker (1996) discussed the use of logistic regression method to estimate the seat belt effectiveness using data from Crash Outcome Data Evaluation System (CODES). In this study, Walker (1996) addressed the application of the logistic regression method from various aspects related to methodology, assumptions, limitations, and possible biases and errors. Johnson and Walker (1996) applied the logistic regression method to estimate the seat belt effectiveness using CODES data for seven states. This study was conducted to provide a report to the congress on benefits of safety belts and motorcycle helmets (NHTSA 1996). The seat belt effectiveness was controlled for many factors such as occupant characteristics (age, gender), type of occupant (driver, passenger), location of crash (rural, urban), crash type, speed limit, etc. The injury type severity was categorized at 4 different levels: died (level 1), died or inpatient (level 2), died, inpatient, or transported (level 3), and any injury (level 4). Johnson and Walker (1996) found that seat belts are 89% and 52% effective in preventing Level 1 (fatalities) and Level 4 (any injury) type injuries, respectively. They also discussed the impact of over-reporting of seat belt usage rate on the estimated seat belt effectiveness values.

To estimate the effectiveness of automatic shoulder belt system, Rivara et al. (2000) used multiple logistic regression method. The odds ratios were estimated for restrained vs. unrestrained occupants while controlling for effects of factors such as occupant age and gender, principle direction of force, automobile model year, change in the speed during the crash, and air bag deployment. The effectiveness was estimated using data from Crashworthiness Data System (CDS) for the period of 1993 to1996 and limited to fatalities and injuries that have an AIS score of 2 or higher. The results by Rivara et al. (2000) indicated that automatic shoulder belts alone (without lap belt) are effective in reducing fatality risk by 29% in frontal crashes and 34% in all other types of crashes. In addition, it showed significant increase in risk of chest and abdominal injuries to occupants using automatic shoulder belts compared to unrestrained occupants

The method introduced by Evans (1986a), which is called double pair comparison method, has been widely used by many researchers to estimate the effectiveness of seat belts. The rationale behind this method is that it compares injury risk to a subject occupant and another occupant under two different conditions (i.e., restrained and unrestrained in this case).

The double pair comparison method has been used in many studies to estimate the seat belt effectiveness. Evans (1986b) used this method to estimate the seat belt effectiveness in preventing fatal injuries based on crash data from Fatality Accident Reporting System (FARS) for the period of 1975 to 1983. The results showed that the overall seat belt effectiveness, in preventing fatal injuries to front seat passengers in passenger cars, to be around 41% with an error margin of 3%. In Evans (1986b) study, the other occupant was disaggregated by age and seating positions in order to consider the confounding effects of occupant age and seating positions.

In another study, Evans (1988) analyzed FARS data from 1975 to 1985 and estimated the effectiveness of rear seat restraint systems in preventing fatalities using the double pair comparison method. The subject occupant was considered as the right or left rear seat occupant. The results obtained indicated that the average restraint effectiveness against fatalities for rear seat passengers (left and right passengers only) is in the 9% - 27 % range.

Kahane (2000) applied the double pair comparison method to examine the appropriateness of NHTSA's long-standing estimates of seat belt effectiveness values. An empirical tool was developed to adjust for double pair analyses of using FARS data from 1986 to 1999. Results obtained reconfirmed the NHTSA's earlier effectiveness estimates of 45% for passenger cars and 60% for light trucks in reducing fatalities. Double pair comparison method has been applied to estimate seat belt effectiveness by many other researchers such as Kahane (1987), and Morgan (1999).

Cummings et al. (2003a) studied the use of matched-pair cohort methods in traffic crash analysis. In this study, different methods were examined in estimating the relative risks in matched-pair cohort data. Mantel-Haenszel stratified method, double pair comparison method, regression method including conditional Poisson regression, and Cox proportional hazards regression methods were used to estimate the relative risk of front seat passengers. Based on results obtained from several simulations using each method, Cummings et al. (2003a) have concluded that conditional Poisson regression and Cox proportional hazards regression can produce unbiased estimates. However, it may be required to consider interaction terms between seat position and vehicle or crash characteristics.

Cummings et al. (2003b) used Conditional Poisson regression method to study the seat belt effectiveness in motor vehicle crashes. Using FARS data from 1975 to 1998, they estimated that the risk of death for a front passenger is reduced by 61% when using seat belts. In another study, Cummings (2002) applied the Conditional Poisson regression method to compare the estimated seat belt effectiveness against fatalities based on police reported data and data obtained through trained crash investigators. The risk ratios for front seat passengers were estimated using data from CDS database for time period 1988 to 2000. The CDS database includes information on seat belts usage, which has been reported by both police officers and trained crash investigators. The results showed that the estimated seat belt effectiveness based on police reported data were not substantially different from estimated values based on data from crash investigators. Estimated values for both cases were equal (relative risk of 0.36).

It can be observed that many studies have used matched-pair analysis techniques in estimating the seat belt effectiveness, thereby limiting the analysis only to vehicles occupied by two occupants (driver and front seat passenger). However, factors associated with vehicles containing only the driver may differ from cases where vehicles occupied are by more than one occupant. For example, many studies have found that the presence of an unrestrained occupant increases the injury risk of a restrained occupant in the same vehicle (MacLennan et al., 2004; Mayrose et al., 2005).

Vehicles with two front seat occupants may not represent a considerable proportion of all vehicles involved in crashes. Thus, sample size may be reduced further as matched-pair methods only consider pairs with at least one occupant having an outcome (the injury type severity). This will definitely increase the sampling errors. For example, in Kansas, during the 10 year period (from 1993 to 2002) vehicles with two front seat occupants represented only 23% of all vehicles involved in crashes. This percentage is reduced to 16% when vehicles with no reported occupant injuries were excluded. As a result, assuming seat belt effectiveness values estimated via matched-pair methods to represent the overall seat belt effectiveness for all crashes may not be a reasonable assumption/approach.

Another issue related to double-pair and other matched-pair analysis methods is the difficulty of controlling the seat belt effectiveness for effects of other variables such as occupant age, gender, etc. Evans and Frick (1986) examined the effect of accident, vehicular, and environmental factors on seat belt effectiveness against fatalities using the double pair method. They found that most of the considered factors did not have any effect on the effectiveness. However, due to data limitations, interaction effects of those factors were not considered, although such interaction effects are very important in estimating the seat belt effectiveness.

The logistic regression method could be expected to eliminate possible biases involved in matched-pair analysis methods. The logistic regression method considers all vehicles involved in a crash irrespective of the number of occupants involved. Another advantage of the logistic regression method is it ability to control, during the estimation process, potential biases caused by many other factors on the estimated seat belt effectiveness values. Therefore, Walker (1996) study utilized the logistic regression method to estimate the effectiveness of seat belts in reducing injuries. The seat belt effectiveness values were also estimated using double-pair comparison method. The outcomes from the double-pair comparison method were then used to evaluate their consistency with the logistic regression estimated values.

2.3 Database

Highway crash data from Kansas Accident Reporting System (KARS) database was used to estimate the seat belt effectiveness. Data related to vehicles, which were involved in crashes between 1993 and 2002, were extracted from the database. Only front seat occupants of passenger cars, vans and pickup trucks were considered in the analysis. Since the data availability for vans was limited, especially for fatalities, pickup trucks and vans were combined and considered as a single vehicle group. Thus, the estimations were based on two vehicle groups: passenger cars and other passenger vehicles. Occupants younger than 15 years were discarded from the database since Kansas has a primary seat belt law for that age group compared to a secondary seat belt law for other occupants (15 years or older). In addition, data related to crashes involving pedestrians, bicyclists, motorcycles, and trains were also discarded. The final dataset included data related to single-vehicle and multi-vehicle crashes.

Seat belt restraint usage is reported in 4 categories: i) both shoulder and lap belts, ii) shoulder belt only, iii) lap belt only, and iv) none used. Records with unknown restraint uses were discarded from the dataset. It is to be noted that KARS database did not have any information regarding the air bag deployment due to a crash. As a result, the effect of air bags on seat belt effectiveness was not considered in the analysis. Details of reported seat belt usage by front seat occupants, based on the final dataset, are shown in Table 2.2.

It can be seen that seat belt usage among occupants involved in fatal crashes is significantly lower when compared with seat belt usage among occupants in nonfatal crashes. In nonfatal crash cases, overall seat belt usage among drivers is higher when compared with seat belt usage for front seat passengers. In all crash type categories, it is noted from Table 2.2 that the majority of occupants were restrained with both lap and shoulder belts.

TABLE 2. 2 Seat Belt Usage by Front Seat Passengers (KARS data from 1993 to 2002)

Crash Type (Severity)	Occupant	Type of Seat Belt Used					Total Involved	% Seat Belt Use
		Lap belt Only	Shoulder belt only	Lap & Shoulder belts	Total Used	None Used		
Fatal	Driver	30	15	1637	1682	2417	4099	41.03
	FRP*	12	4	574	590	825	1415	41.70
	Total	42	19	2211	2272	3242	5514	41.20
Incapacitating	Driver	309	46	13440	13795	7685	21480	64.22
	FRP	82	15	3826	3923	2833	6756	58.07
	Total	391	61	17266	17718	10518	28236	62.75
Non-incapacitating	Driver	2279	171	84232	86682	26838	113520	76.36
	FRP	538	57	21698	22293	9998	32291	69.04
	Total	2817	228	105930	108975	36836	145811	74.74
Possible	Driver	2646	191	122802	125639	18140	143779	87.38
	FRP	558	34	29912	30504	6429	36933	82.59
	Total	3204	225	152714	156143	24569	180712	86.40
No Injury (PDO)	Driver	11,200	537	554,561	566,298	55,683	621,981	91.05
	FRP	2,720	115	139,596	142,431	18,946	161,377	88.26
	Total	13,920	652	694,157	708,729	74,629	783,358	90.47

** FRP –Front Right Passenger*

As previously mentioned, the injury severity of crash victims is reported based on KABCO scale in the KARS database, which include: fatal, incapacitating, non-incapacitating, possible injury, and no-injury (property damage only or PDO). The severity of a crash was defined based on the highest reported injury severity sustained by an involved occupant. Based on this criterion, the total crash database could be divided into five categories based on the crash severity. It could be reasonable to assume that occupants involved in each of these crash types are under different levels of risks to sustain a particular injury type severity. For example, two occupants who are recorded to have the same personal injury type severity, but involved in two different crash types with different severities, may not be under the same level of risk. Thus, placing these two occupants in two different crash categories would minimize any biases in estimated seat belt effectiveness.

Therefore, the total database was split into 5 different datasets based crash severity. The dataset related to PDO crashes was discarded. In the selected 4 datasets, the fatal crash category included occupants with all 5 types of injury severities. The non-incapacitating crashes contained 4 injury type severities except fatalities. The incapacitating category had 3 injury types, while the possible injury crashes category contained occupants with minor injuries and unharmed (none injured) occupants. These 4 datasets were then used to estimate the effectiveness of seat belts in reducing each injury severity level.

2.4 Methodology

The seat belt effectiveness was estimated using both logistic regression and double pair comparison methods. Details of each method are discussed in the following sections.

2.4.1 <u>Logistic Regression Method</u>

The response variable for the logistic regression model is the injury type severity for an occupant, which is considered as a binary variable. Denoting the conditional probability that a particular injury severity level is present by $\mathrm{P}(Y=1 \mid X)=\pi(X)$ for a given set of p covariates (i.e. X= x_1, x_2, x_3... x_p), then the multiple logistic regression model could be written in the following form (Hosmer et al., 2000, Agresti, 2002);

$$\log it\,[\pi(X)] = \log\left(\frac{\pi(X)}{1-\pi(X)}\right) = \alpha + \sum_{i=1}^{p} \beta_i X_i \tag{2.1}$$

and,

$$\pi(X) = \frac{e^{[\alpha+\sum_{i=1}^{p}\beta_i X_i]}}{1+e^{[\alpha+\sum_{i=1}^{p}\beta_i X_i]}} \tag{2.2}$$

where,

α, β = regression parameters that needed to be estimated

Consider a binary explanatory variable x, which takes values of 1 or 0 to represent two conditions. The odds ratio for this particular variable can be defined as the ratio between odds for an outcome (injury severity) being present when x =1 and x = 0. This can be expressed in the following formula.

$$OR = \frac{\pi(1)/[1-\pi(1)]}{\pi(0)/[1-\pi(0)]} \tag{2.3}$$

where,

OR= Odds Ratio

$\pi(1)/[1-\pi(1)]$ = odds of the outcome (injury severity) being present when x =1

$\pi(0)/[1-\pi(0)]$ = odds of the outcome (injury severity) being present when x =0

In this case, the explanatory variable x represents the occupant's restraint condition (x = 1 if restrained and x = 0 if unrestrained). The odds ratio compares the occupant's chance of sustaining a particular injury severity under restrained and unrestrained conditions. If the restraint system is not effective at all, this ratio should be close to one. In the case of a highly effective restraint system, the odds ratio should be smaller. Thus, the effectiveness of the restraint system can be defined as

$$E = (1 - OR) * 100 \tag{2.4}$$

where,

E = effectiveness of the restraint system (%)

OR = odds ratio between restrained and unrestrained occupants for a given injury

Type severity

The response variable (injury severity) of a logistic regression model for a particular crash category is typically coded as follows: i) the response variable takes value of 1 for all occupants who sustained highest injury severity in the considered crash category, and ii) the response variable is assigned a 0 (zero) value for all occupants sustaining other injury type severities. For example, in the case of a fatal crash, the response variable takes a value of 1 for all occupants with fatal injuries, and it takes value of 0 for all occupants with nonfatal injuries. In our case, a total of four different models can developed for each injury severity level using the 4 datasets explained earlier.

The potential explanatory variables for the models can be selected based on findings of previous studies and professional engineering judgment. The selected candidate variables and their representation in the models are shown in Table 2.3. It should be noted that some of the variables, which might have an effect on seat belt effectiveness, could not be considered in the models due to the lack of information in the database. One such variable is the direction of initial force during a crash. However, the database contained data related to the manner of collision of vehicles such as head-on, angle, sideswipe or rear-end, in cases where two or more vehicles were involved in a crash. Therefore, manner of collision was considered as a surrogate measure of the direction of impact.

Actual travel speed at the time of the crash and mass of the vehicle could also be important variables in assessing the seat belt effectiveness, even though KARS database does not include an accurate data related to those variables. Due to the importance of controlling for those two variables in the developed models, posted speed limit was used as a surrogate measure for the actual vehicle speed. Even though it was not possible to directly consider the effect of vehicle mass in the models, it was assumed that this effect would be minimized by considering different vehicle types.

TABLE 2. 3 Selected Candidate Variables for Logistic Regression Models

Variable	Description
ALCOHOL	=1 if the driver was under influence of alcohol or drugs, =0 otherwise
ANGLE_CRASH	=1 if an angle crash, =0 otherwise
ARTERIAL	=1 if the crash occurred on an arterial roadway, =0 otherwise
COLLECTOR	=1 if the crash occurred on a collector, =0 otherwise
DR_AT_FLT	=1 if the driver was at fault for the crash, =0 otherwise
DRIVER	=1 if the passenger was the driver, =0 otherwise
HDON_CRASH	=1 if a head-on crash, =0 otherwise
INTERSTATE	=1 if the crash occurred on an interstate, =0 otherwise
INTR_SECN	=1 if the crash occurred at an intersection, =0 otherwise
LIGHT_CON	=1 if crash happened in dark or unlit conditions, =0 otherwise
OCC_AGE	Age of the occupant in years
OCC_EJECT	=1 if occupant was ejected due to the crash, =0 otherwise
OCC_TRAPPED	=1 if occupant was trapped inside the vehicle, =0 otherwise
OCC_MALE	=1 if the occupant was male, =0 otherwise
RD_CUR_GRAD	=1 if roadway was not straight and level, =0 otherwise
REAREND_CRASH	=1 if a rear-ended crash, =0 otherwise
RFP	=1 if the passenger was in the right front seat, =0 otherwise
RURAL	=1 if the crash occurred in a rural area, =0 otherwise
SB_USED	=1 if the passenger was restrained, =0 otherwise
SIDESWIPE_CRASH	=1 if a sideswipe crash, =0 otherwise
SNG_VEH_CRASH	=1 if the crash was a single vehicle crash, =0 otherwise
SPEED	Posted speed limit in mph
URBSP	=1 if there was at least one unrestrained passenger on the rear seat, =0 otherwise
VEH_AGE	Age of the vehicle in years
VEH_AT_FLT	=1 if the vehicle was at fault for the crash, =0 otherwise
VEH_DESTROY	=1 if the vehicle was destroyed due to the crash, =0 otherwise
VEH_DISABLED	=1 if the vehicle was disabled due to the crash, =0 otherwise
VEH_STRAIGHT	=1 if the vehicle was traveling straight before crash, =0 otherwise
VEH_TURN	=1 if vehicle was making a turn before crash, =0 otherwise
WET_RD_SURF	=1 if the crash occurred on a wet road surface, =0 otherwise

Logistic regression models were developed using the LOGISTIC procedure available in the SAS software (SAS Institute Inc., 2004). For each injury severity level, two models were developed: a crude model with only one explanatory variable in the model (i.e. seat belt usage), and an adjusted model including all explanatory variables were considered. The idea behind this logic, was to examine the effect of other variables on the seat belt effectiveness. Before starting the model building procedure, the explanatory variables were tested for their independence. This was done by assessing the correlation between each variable. Correlation coefficients were estimated for each variable and highly correlated variables were removed from the variable list (SAS Institute Inc., 2004). This was done in order to minimize any bias of having highly correlated explanatory variables in the model, thereby violating basic model assumptions.

The adjusted models were developed using stepwise selection technique, which is an inbuilt feature provided in SAS's LOGISTIC procedure (SAS Institute Inc., 2004). In this method, the model building starts with no variables in the model and variables are then added one at a time based on the given level of significance. Once a variable is added, its significance into the model is checked against the variables that are already in the model. If the variable does not meet the given significance level, then it is dropped from the model. The advantage of this procedure is its ability to select the best model with the most significant variables toward the outcome. The quality of each model can be assessed by utilizing the R^2 (Coefficient of Determination) values as well as other model fitting statistics.

2.4.2 ***The Double Pair Comparison Method***

The double pair comparison method is applicable to cases where the vehicle was occupied by at least two occupants (i.e., driver and front right passenger) and at least one occupant was injured due to the crash. Therefore, in this type of analysis, crash data related to vehicles with two front seat occupants need to be extracted from the datasets within each crash category (i.e., fatal, incapacitating, non-incapacitating, and possible). Note that datasets that have cases with no occupant injuries need to be discarded. For example, consider a case where two vehicles with two front seat occupants in each vehicle were involved in a fatal crash, but occupants in one vehicle sustained only minor injuries, while the driver of the other vehicle died. In this case, the occupants who sustained minor injuries should not be considered in the analysis since the considered injury severity level is fatal.

A brief description about the rationale behind the double pair comparison method is presented herein. More detailed description about this method can be found in publications by Evans (1986*a, 1986b*). To illustrate this method, the hypothetical dataset related to driver and front right passenger fatalities, given in Table 2.4, is used. In this illustration, the passengers are disaggregated by their restraint condition. For other injury type severities, similar procedure can be utilized.

TABLE 2. 4 Hypothetical Dataset for Double Pair Estimation of Seat Belt Effectiveness

Hypothetical Data Used to Illustrate the Double Pair Method		
Category	No. of Driver Fatalities	No. of Front Right Passenger Fatalities
Driver Restrained, Front Right Passenger Unrestrained	d	e
Both Unrestrained	m	n

The procedure starts with the estimation of fatality risk ratios between restrained and unrestrained drivers to unrestrained passengers. If the ratio between restrained driver and unrestrained passenger is r_1, then r_1 can be estimated as

$$r_1 = d / e \tag{2.5}$$

Similarly, the ratio of unrestrained driver to unrestrained passenger, r_2 is given by

$$r_2 = m / n \tag{2.6}$$

By using r_1 and r_2, the restrained driver to unrestrained driver fatality ratio (R_1) is estimated as

$$R_1 = r_1 / r_2 \tag{2.7}$$

The standard error in the estimate of R_1, denoted by ΔR_1 is given by

$$\Delta R_1 = R_1 \sqrt{\sigma^2 + 1/n + 1/d + 1/m + 1/e} \quad (2.8)$$

where σ^2 is an estimate of the intrinsic uncertainty and assumed to be equal to 0.1 (Evans, 1986a).

Similarly, by comparing restrained and unrestrained drivers with restrained passengers, the fatality ratio between restrained and unrestrained drivers (R_2) can be estimated. The weighted average of the ratio between restrained and unrestrained drivers denoted by $\overline{R}$ can be estimated using the following equation:

$$\overline{R} = exp\left[\frac{\sum_{i=1}^{2}\{(R_i/\Delta R_i)^2 \text{ x } log(R_i)\}}{\sum_{i=1}^{2}\{(R_i/\Delta R_i)^2\}}\right] \quad (2.9)$$

The standard error of the estimate ($\Delta\overline{R}$) is given by

$$\Delta\overline{R} = \frac{\overline{R}}{\sum_{i=1}^{2}\{(R_i/\Delta R_i)^2\}} \quad (2.10)$$

Finally, the seat belt effectiveness for drivers (E_D) can be estimated by

$$E_D\,(\%) = 100(1 - \overline{R}) \quad (2.11)$$

To estimate the overall seat belt effectiveness, the individual effectiveness values estimated in the previous steps should be weighted by utilizing some weight factors. The proportion of actual fatalities occurred at the two seating positions (driver and front right passenger) can be used as the weight factors. The estimation procedure is shown in Table 2.5.

TABLE 2. 5 Estimation of Overall Seat Belt Effectiveness

Subject Occupant	Fraction of Actual Fatalities	Estimated Effectiveness (%)	% of Fatalities Prevented
Driver	a	E_D	C=a* E_1
Front Right Passenger	b = (1-a)	E_P	D=b*E_2
Total	1		E = C+D

Assume that the proportions of actual driver and front right passenger fatalities are a and b, respectively (where b = 1- a). Also, assume that the percentages of driver and passenger fatalities prevented by the seat belts are C and D, respectively. Then quantities C and D can be estimated from Equations 2.12 and 2.13.

$$C = a * E_D\% \tag{2.12}$$

$$D = b * E_P\% \tag{2.13}$$

Finally, the overall effectiveness, *E* or the overall fatality reduction if all front seat occupants used their seat belts can be estimated as

$$E = (C + D)\% \tag{2.13}$$

According to (Evans, 1986b), the standard error of the overall seat belt effectiveness could be assumed to be equal to the standard error of the effectiveness estimate for drivers.

2.5 Results

Estimated logistic regression parameters and odds ratios from the models based on passenger car occupants are shown in Table 2.6. The model for fatal crashes seems to fit better since it has a comparatively higher R^2 value. Although, the R^2 values for low injury severity level models are relatively low, still more variables are significant in these models. The model results for the other passenger vehicle group also showed similar trends.

Table 2.7 shows the estimated seat belt effectiveness values with their error margins and R^2 values for both vehicle groups. All models seem to fit satisfactorily with the data as indicated by the reasonably high R^2 values obtained. However, the errors of estimations are higher for the other passenger vehicle group. A significant change in estimated seat belt effectiveness values can be observed when the seat belt use is adjusted for different explanatory variables. This change is comparatively higher for lower severity models. Therefore, some of the variables considered seem to have significant effects on the estimated seat belt effectiveness.

TABLE 2. 6 Results of Logistic Regression Models Based on Passenger Car Occupants

Variable	Fatal		Incapacitating		Non-incapacitating		Possible	
	Parameter	Odds Ratio	Parameter	Odds Ratio	Parameter	Odds Ratio	Parameter	Odds Ratio
ALCOHOL	-	-	-	-	0.28	1.32	-	-
ANGLE_CRASH	-	-	-0.10	0.91	-0.22	0.81	-	-
ARTERIAL	-	-	-	-	-	-	-0.07	0.94
BLACK_RD_TOP	-	-	0.12	1.13	-	-	-	-
COLLECTOR	-	-	-	-	0.07	1.07	-	-
DR_AT_FLT	0.50	1.65	-	-	-0.18	0.84	-0.87	0.42
DRIVER	0.64	1.90	0.32	1.37	0.30	1.36	0.25	1.28
HDON_CRASH	-	-	0.20	1.22	-	-	-	-
INTERSTATE	-	-	-	-	-	-	-0.07	0.94
INTR_SECN	-0.30	0.74	-	-	-	-	-	-
OCC_AGE	0.03	1.04	0.01	1.01	0.01	1.01	0.01	1.01
OCC_EJECT	1.68	5.35	1.57	4.82	1.63	5.10	1.51	4.51
OCC_MALE	-	-	-0.74	0.48	-0.67	0.51	-0.85	0.43
OCC_TRAPPED	1.96	7.07	2.46	11.76	2.54	12.62	2.30	9.98
RD_CUR_GRAD	-	-	-	-	0.06	1.07	0.04	1.04
REAREND_CRASH	-	-	-	-	-0.19	0.83	-	-
RURAL	-	-	-0.11	0.90	-	-	-	-
SE_USED	**-0.83**	**0.44**	**-0.76**	**0.47**	**-0.80**	**0.45**	**-0.50**	**0.61**
SNG_VEH_CRASH	0.34	1.40	0.84	2.32	1.12	3.05	1.66	5.24
POSTED_SPEED	-	-	-	-	-	-	-	-
URBSP	-	-	-	-	-	-	-	-
VEH_AGE	-	-	-	-	-	-	-	-
VEH_AT_FLT	-	-	-	-	-	-	-0.63	0.53
VEH_DESTROY	1.53	4.62	1.46	4.32	1.74	5.68	1.72	5.61
VEH_DISABLED	0.93	2.53	1.16	3.20	1.22	3.40	1.23	3.44
VEH_STRAIGHT	-	-	-	-	-	-	-0.24	0.79
VEH_TURN	-	-	-0.14	0.87	-	-	-0.09	0.92
WEEK_DAY	-	-	0.18	1.19	-	-	-	-
R^2	0.42		0.30		0.24		0.20	

- *Variables are not Significant in the Model under 95% confidence level*

According to logistic regression estimations, for passenger cars group, seat belts are 56% effective in preventing fatalities to front seat occupants in passenger cars. In other words, 56% of fatally injured front seat occupants, who were unrestrained at the time of the crash, could have survived if all of them were restrained. As far as nonfatal injuries are concerned, seat belts are more effective in reducing non-incapacitating injuries (55%) compared to incapacitating injuries

(53%). The estimated seat belt effectiveness values for fatal injuries and severe nonfatal injuries (incapacitating and non-incapacitating injuries) are fairly similar. Additionally, seat belts are 33% effective in reducing possible injuries to passenger car front seat occupants.

TABLE 2. 7 Estimated Seat Belt Effectiveness Values for Each Vehicle Group

Vehicle Group	Model	Fatal		Incapacitating		Non-incapacitating		Possible	
		E^* (Error)	R^2	E (Error)	R^2	E (Error)	R^2	E (Error)	R^2
Passenger Cars	Adjusted	0.56 (0.17)	0.42	0.53 (0.07)	0.30	0.55 (0.03)	0.24	0.33 (0.05)	0.20
	Crude	0.63 (0.10)	0.08	0.63 (0.05)	0.07	0.63 (0.02)	0.05	0.44 (0.04)	0.01
Other Passenger Vehicles	Adjusted	0.61 (0.26)	0.55	0.52 (0.11)	0.39	0.51 (0.06)	0.32	0.34 (0.08)	0.25
	Crude	0.80 (0.09)	0.16	0.69 (0.06)	0.10	0.67 (0.03)	0.08	0.46 (0.05)	0.02

** E= seat belt effectiveness*

For other passenger vehicles group, seat belts are 61% effective in preventing fatal injuries to front seat occupants. Seat belts are 52% effective in reducing incapacitating injuries and 51% effective in reducing non-incapacitating injuries in this vehicle group. The seat belt effectiveness for possible injuries in this vehicle group is 34%, which is slightly higher than the value obtained for the passenger cars group.

The double pair estimation procedure of seat belt effectiveness for fatal injuries for passenger car occupants is shown in Tables 2.8 and 2.9. It can be seen from Table 2.8 that seat belts are almost equally effective in reducing fatal injuries to drivers and front passengers as the estimated effectiveness values for drivers and front seat passengers are 53% and 54%, respectively.

TABLE 2. 8 Seat Belt Effectiveness Against Fatalities for Drivers and Front Passengers in Passenger Cars

<table>
<tr><th>Category</th><th>Driver Fatalities</th><th>FRP Fatalities</th><th>r</th><th>R</th><th>ΔR</th><th>$\bar{R}$</th><th>$\Delta\bar{R}$</th><th>E_D or E_P</th><th>Remarks</th></tr>
<tr><td>Driver Restrained, FRP* Unrestrained</td><td>23</td><td>49</td><td>0.47 (r_1)</td><td rowspan="2">0.53 (R_1)</td><td rowspan="2">0.22</td><td rowspan="4">0.47</td><td rowspan="4">0.14</td><td rowspan="4">0.53 (E_D)</td><td rowspan="4">Subject Occupant is the Driver</td></tr>
<tr><td>Driver Unrestrained, FRP Unrestrained</td><td>192</td><td>218</td><td>0.88 (r_2)</td></tr>
<tr><td>Driver Restrained, FRP Restrained</td><td>127</td><td>141</td><td>0.90 (r_1)</td><td rowspan="2">0.41 (R_2)</td><td rowspan="2">0.18</td></tr>
<tr><td>Driver Unrestrained, FRP Restrained</td><td>42</td><td>19</td><td>2.21 (r_2)</td></tr>
<tr><td>FRP Restrained, Driver Unrestrained</td><td>19</td><td>42</td><td>0.45 (r_1)</td><td rowspan="2">0.40 (R_1)</td><td rowspan="2">0.17</td><td rowspan="4">0.46</td><td rowspan="4">0.14</td><td rowspan="4">0.54 (E_P)</td><td rowspan="4">Subject Occupant is the Front Right Passenger</td></tr>
<tr><td>FRP Unrestrained, Driver Unrestrained</td><td>218</td><td>192</td><td>1.14 (r_2)</td></tr>
<tr><td>FRP Restrained, Driver Restrained</td><td>141</td><td>127</td><td>1.11 (r_1)</td><td rowspan="2">0.52 (R_2)</td><td rowspan="2">0.22</td></tr>
<tr><td>FRP Unrestrained, Driver Restrained</td><td>49</td><td>23</td><td>2.13 (r_2)</td></tr>
</table>

** FRP- Front Right Passenge*

Note: All the symbols used in this table has the same meanings as those are defined in the section 6.2.4.1

TABLE 2. 9 Overall Seat Belt Effectiveness Against Fatalities in Passenger Cars

<table>
<tr><th>Subject Occupant</th><th>Actual Fatalities</th><th>Fraction of Actual Fatalities</th><th>Estimated Effectiveness (%)</th><th>% of Fatalities Prevented</th><th>Overall Effectiveness (%)</th></tr>
<tr><td>Driver</td><td>3,003</td><td>0.80</td><td>53</td><td>C = 42 (0.8*53%)</td><td rowspan="3">53</td></tr>
<tr><td>Front Right Passenger</td><td>770</td><td>0.20</td><td>54</td><td>D=11 (0.2*54%)</td></tr>
<tr><td>Total</td><td>3,773</td><td>1</td><td></td><td>E = 53</td></tr>
</table>

Table 2.10 shows the summary of estimated seat belt effectiveness values from double pair comparison method for different injury type severities. According to double pair estimations, seat belts are 53% and 57% effective in preventing fatal injuries in passenger cars and other passenger vehicles group, respectively. These values are lower than the values

obtained from logistic regression. Seat belt effectiveness in preventing incapacitating injuries is 52% in passenger cars group and 47% in other passenger vehicles group. For non-incapacitating injuries, seat belts are equally effective in both groups as their estimated seat belt effectiveness is 42%.

TABLE 2. 10 Estimated Seat Belt Effectiveness From Double Pair Comparison Method

Vehicle Type	Effectiveness (%) (Error) (%)			
	Fatal	Incapacitating	Non-incapacitating	Possible
Passenger Cars	53 (10)	52 (11)	42 (13)	34 (15)
Other Passenger Vehicles	57 (18)	47 (14)	42 (14)	28 (18)

Table 2.11 shows the comparison of estimated seat belt effectiveness values using both methods.

TABLE 2. 11 Comparison of Estimated Seat Belt Effectiveness Using Both Methods

Vehicle Type	Effectiveness (%) (Error) (%)							
	Fatal		Incapacitating		Non-incapacitating		Possible	
	Logistic Regression	Double Pair	Logistic Regression	Double Pair	Logistic Regression	Double Pair	Logistic Regression	Double Pair
Passenger Cars	56 (17)	53 (10)	53 (7)	52 (11)	55 (3)	42 (13)	33 (5)	34 (15)
Other Passenger Vehicles	61 (26)	57 (18)	52 (11)	47 (14)	51 (6)	42 (14)	34 (8)	28 (18)

The estimated seat belt effectiveness values from logistic regression method, for both vehicle groups, are higher than those obtained from double pair comparison method for all injury type severities, except for the possible injury case in the passenger cars group. This difference is less than or equal to 6% for all cases, except for non-incapacitating injury case. Generally, results from both methods show similar trends as the seat belt effectiveness values decrease when the injury type severity level decreases from the fatal to the possible category. The higher estimated seat belt effectiveness values from logistic regression method may be due to the fact that logistic regression method considers, unlike the double pair comparison method, all vehicles involved in crashes irrespective of the number of occupants involved. The errors associated with estimated seat belt effectiveness values obtained from logistic regression method are significantly lower than the errors associated with estimations based on the double pair method, except for the fatal injury category. The higher estimated errors associated with fatal injury category compared to other injury categories may be attributed to the smaller sample sizes used in the estimation process for fatal injuries.

Based on the results obtained, the seat belt effectiveness values estimated via logistic regression method could be considered more accurate than the values estimated using the double pair comparison method.

It should be noted that the use of state crash data to estimate seat belt effectiveness may be impacted by the accuracy of the data used. This is especially important when considering variables such as injury severity and seat belt usage. The accuracy of the police reported KABCO injury severities are often criticized for their accuracy in comparison with the one reported according to the AIS injury severity scale. Note that, injury severity in AIS scale is typically reported by experienced medical officials at the hospital. For example, in case of nonfatal injuries, the police officer at the crash site has to decide and report the level of injury severity, which may be different from hospital reported injury severity that is based on thorough medical examinations by experienced medical officers. Additionally, the reported severities are mostly subjective to the differences in individuals' personnel judgments. To this end, Shinar et al. (1983) have found that injury severity is one of the least reliable variables in police reported data.

The accuracy of data related to seat belt usage, especially in nonfatal crashes, may also affect the accuracy of the estimated seat belt effectiveness. According to Table 2.2, reported seat belt usage in incapacitating crashes is about 64% and in possible injury crashes it is about 87%, which are higher than the Kansas observed seat belt usage rates during that time period. Reason for this over-reporting of seat belt usage may be due to the occupants' unwillingness to disclose the truth in order to prevent any adverse consequences such as increased insurance premiums, fines, etc. The over-reported seat belt usage may result in higher estimated seat belt effectiveness when compared with actual effectiveness. For example, an unharmed occupant, who is incorrectly reported as restrained but was unrestrained at the time of the crash, tend to falsely increase the estimated seat belt effectiveness. Therefore, the over-reported seat belt usage in low severity crashes may result in biased estimations of seat belt effectiveness. However, data related to seat belt use in fatal crashes, in which at least one dead occupant is involved, could be expected to be more accurate (Cummings et al., 2003b).

CHAPTER 3 ECONOMIC BENEFITS OF SEAT BELTS

3.1 Introduction

The benefits associated with seat belts were discussed in the previous chapter in terms of seat belt effectiveness in reducing injuries. However, it would be more useful and understandable to the general public if benefits of seat belt usage are expressed in terms of economic savings. To achieve this objective, the potential reduction in injuries due to any incremental increase in seat belt usage, from current level, will need to be estimated. The resulting injury reduction values can then be converted into economic benefit values by assigning an appropriate economic saving value for each injury type category. This chapter provides a detailed discussion on this procedure used to achieve the aforementioned objective.

3.2 Literature Review

The safety benefits of seat belt usage and impacts of nonuse have been studied by many researchers. Blincoe (1994) developed a methodology to quantify the safety benefits from seat belt use in terms of economic savings. In this study, several algorithms and methodologies were developed using different data sources to determine i) current fatality and injury incidence, ii) seat belt usage rates in current and future time periods, iii) lives and injuries that can be prevented due to increase in use of seat belt usage, and iv) economic savings resulting from these improvements (i.e., increase in seat belt usage rates). The procedure developed by Blincoe (1994), followed in this study, has been widely used by many highway agencies in analyzing seat belt benefits. For ease of use, this procedure (Blincoe, 1994) has been implemented, by the National Highway Traffic Safety Administration (NHTSA), into a software program called

MVS. This procedure is used herein to estimate the benefits of seat belts. More details of the utilized methodology/procedure are given in the following section of this chapter.

Blincoe et al. (2002) used the procedure developed by Blincoe (1994) to estimate the economic savings due to seat belt use as well as the economic loss due to nonuse in order to quantify the economic impact of motor vehicle crashes. In this study, they estimated the cost of different injury type severities, resulted from a motor vehicle crash, utilizing the Abbreviated Injury Scale (AIS). In estimating the comprehensive costs resulted from motor vehicle crashes, Blincoe et al. (2002) estimated two types of costs: i) direct economic costs, and ii) intangible costs due to consequences resulting from the crashes. The direct economic costs were mainly categorized into injury components and non-injury components. Injury components included costs related to medical and emergency services, market and household productivity, insurance administration, workplace and legal activities. Non-injury component included the costs related to travel delay and damage to the property. The value of intangible costs was then added to the direct economic costs in order to obtain the comprehensive costs. According to the comprehensive cost estimations, the cost of a fatality is about \$3.4 million and it decreases with the decrease in injury severity.

Miller et al. (1998) estimated the highway crash costs based on driver age, blood alcohol level, victim age, and restraint use. They used data from NHTSA's Fatal Accident Reporting System (FARS), General Estimates System (GES), and National Accident Sampling System (NASS). Costs of injuries were estimated based on KABCO injury scale and different cost categories were considered such as medical, work loss, public service, employer costs, travel delay, property damage, and costs related to quality of life loss. Miller et al. (1998) found that the annual safety costs for an unrestrained occupant are five times the safety costs for a restrained occupant. Moreover, they found that the 13% of unrestrained occupants have accounted for 42% of the total crash costs. In the even that these 13% unrestrained occupants buckle up, then the medical costs would decline by 18% ($ 4 billion annually) and the comprehensive costs will decrease by 24%.

Singleton et al. (2005) studied the cost of low safety belt usage in motor vehicle crashes in Kentucky. The main intention was to study the long-term direct medical costs resulting from severe injuries such as traumatic brain injuries and spinal cord injuries. The data, for the 2002 to 2004 time period, was obtained from the Kentucky Hospital Discharge Database (HIDD) and Kentucky's Crash Outcome Evaluation System (CODES). The total medical costs were considered in two categories: i) medical costs during the first year after injuries, and ii) medical costs associated with the subsequent years. The analysis was conducted to answer the following question: If Kentucky increases its seat belt usage rate to the national average level, due to the legislation of a primary seat belt law in year 2006, then how much savings from medical costs could be achieved during the time period from 2006 to 2015? Using CODES data, a 55% weighted seat belt effectiveness value in preventing moderate to critical injuries, based on different vehicle types, was estimated for Kentucky conditions. Singleton et al. (2005) indicated in their study that the change in legislation, to a primary seat belt law starting year 2006, would result in at least $118 million savings in direct medical costs during the indicated 2006 to 2015 time period.

Perkins (2003) analyzed the data from Alaska Trauma Registry (ATR) for the period from 1996 to 1999 to study the health care costs for restrained and unrestrained motor vehicle occupants who were admitted to hospitals after being involved in motor vehicle crashes. The study found that the average hospital cost for unrestrained and restrained occupants, during the 3 year period following the crass, is $24,419 and $19,952, respectively. The total medical costs, during the same 3 year period, were estimated at $21.8 and $15.8 millions for unrestrained and restrained occupants, respectively.

Ebel et al. (2004) studied the lost working days and productivity among motor vehicle crash victims based on restraint use. Data from Crashworthiness Data System (CDS) from 1993 to 2001 was analyzed using multiple logistic regression method. Occupants aged 18 to 65 years were considered in two categories: occupants who survived and were working before involved in the crash, and occupants who were killed by the crash and were estimated to have been working before the crash. According to the findings, about 30% of occupants who were involved in a crash lost at least one day of work while mean number of days lost at work was 28 days including losses due to fatal injuries. An unrestrained occupant lost 96 days at work on average compared to 10 working days on average by a restrained occupant. In terms of lost productivity, unrestrained occupants accounted for $5.6 (74% of total) billion lost while restrained occupants only accounted for about $2 billion.

Gill et al. (2002) studied the difference in hospital charges for restrained and unrestrained motorists in South Carolina. Their study was based on two data sources: i) data taken from Crash Outcome Data Evaluation System (CODES) for the period of 1998 to 1999, and ii) trauma data for 1999 year taken from South Carolina's Level I trauma centers. Besides comparing hospital charges, the study also investigated the relationship between restraint usage and insurance status. According to the analysis results based on CODES data the average inpatient hospital charges were 25% higher, per admission, for an unrestrained occupant when compared with hospital charges for a restrained occupant. The trauma data showed similar trends but more significant difference. In this case, the average hospital charges for unrestrained occupants were

87% higher than those for restrained occupants. In addition, the length of stay for unrestrained occupants was also longer than that for restrained occupants. The least users of restraint devices were found to be the self-payers and Medicaid recipients. On the other hand, restrained occupants were commonly found to be covered by private insurance or Medicare.

To study the effect of restraint systems on injury severity and to compare the hospital charges for restrained and unrestrained occupants Reath et al. (1989) analyzed hospital data related to motor vehicle crash victims who were treated in the emergency unit at University of Tennessee Medical Center at Knoxville. The study period was 6 months during the 1987 year. The total database included 613 motor vehicle crash victims. According to the obtained results, the followings were concluded: i) hospitalization was more frequently required for unrestrained crash victims and their length of stay was longer than that for restrained crash victims, ii) unrestrained victims were more often males and younger in age than restrained victims, iii) the mean Injury Severity Score (ISS) for unrestrained victims were significantly higher than that for restrained victims, iv) unrestrained victims had significantly higher mean hospital charges compared to restrained victims, and v) the unrestrained group was dominated by self-payers and Medicaid recipients while the restrained victims were more commonly covered by private insurance or Medicare.

Kaplan & Cowley (1991) analyzed the data from Trauma Center of the Maryland Institute for Emergency Medical Service Systems to study the seat belt effectiveness and cost of noncompliance among drivers who were admitted to the trauma center after being involved in a crash. The analysis was based on randomly selected sample of 55 drivers from a total population of 689 patients. They found that seat belts usage has reduced the total number of injuries by 34%, major injuries by 57% and minor injuries by 20%. The average hospital cost for an unrestrained driver ($38,845) was almost double the cost reported for a restrained driver ($19,414). Additionally, mean Injury Severity Score (ISS) and length of hospitalization stay was significantly higher for unrestrained drivers.

Rutledge et al. (1993) studied the effect of seat belt usage on the outcomes of motor vehicle accidents. Data from North Carolina Trauma Registry from 1987 to 1989 was used in the analysis. They found that the mean hospital charge for unrestrained passengers were significantly higher than that for restrained passengers. Similar trends were observed for mean ISS, length of stay in intensive care unit and total length of stay in the hospital. Moreover, seat belt usage was associated with a significant decrease in mortality rate. Overall, seat belts usage, during the study period, could have saved at least 74 lives and 7.2 million dollars.

Nelson et al. (1993) used data from Iowa Restraint Assessment to estimate the economic savings associated with increased safety belt use in Iowa. The total database consisted of 997 records of injured motor vehicle occupants who were treated at 11 Iowa hospitals. The study time period was from 1987 to 1988. According to results obtained, injuries were more serious for unrestrained occupants. Also, fatalities and permanent disabilities cases occurred more among unrestrained occupants in comparison with restrained occupants. The nonuse of seat belts was associated with higher hospital charges in nearly all age, sex, and vehicle speed categories. Nelson et al. (1993) also estimated that the lifetime direct and indirect savings, from Iowa's safety belt law, for motorists injured in one year was about $69.5 million.

Coley et al. (2002) studied the relationship between seat belt use and injury patterns, hospital charges, morbidity, and mortality in elder motor vehicle crash victims. The study was based on data sample of 339 elder occupants (i.e., at least 65 years of age) extracted from Rhode Island Hospital (an urban, academic, Level I trauma center) database. The study period was two years spanning from 1997 to 1999. Coley et al. (2002) found that unrestrained occupants were more likely to require hospitalization. Moreover, hospital charges for unrestrained group were found to be significantly higher than that for restrained occupants.

Allen et al. (2006) conducted a comprehensive statewide analysis in Wisconsin to investigate the association of seat belt nonuse with injury patterns, injury severity, and in-patient hospital admission among adults (aged 16 years or older) to emergency departments (ED). Data from CODES database for 2002 was used for the analysis. Results showed that unbelted occupants were more likely to be males and to be under the influence of alcohol. Unrestrained occupants had higher ED charges and generally were younger than restrained occupants. Furthermore, unrestrained occupants accounted for: i) 68% of all patients who died in ED, and ii) 20% of all patients treated in ED and then discharged.

3.3 Methodology

The procedure described by Blincoe (1994) was used to estimate the benefits associated with seat belt usage. Some adjustments were made in the original procedure in order to accommodate for Kansas local conditions. This section describes the step-by-step procedure used in this study. More detailed discussion regarding the original procedure can be found in the document by Blincoe (1994).

Step 1: Obtain injury frequencies

The procedure starts by determining frequencies of different injury type severities resulted from motor vehicle crashes during the base year considered. The base year is the year in which the most recent crash data is available. In some cases, it might be possible that the crash data is not available, for the current year considered, but data related to seat belt usage rates may be available. In such a case, the year for which the most recent crash data is available can be used as the base year. During our study period, the most recent year for which both crash data and seat belt usage rates were available for Kansas is year 2005. Therefore, years 2005 and 2006 are selected as the base and current years, respectively. The injury frequencies for each severity level (fatal, incapacitating, non-incapacitating and possible) for the base year (2005) were obtained from KARS database. The corresponding frequency values are listed in Table 3.1. It should be noted that the listed frequencies are those applicable to front seat passenger injuries in passenger cars, vans, and pickup trucks resulted from two-vehicle and single-vehicle crashes.

TABLE 3.1 Injury Frequencies for the Base Year (2005)

Injury Severity	Frequency
Fatal	288
Incapacitating	1,374
Non-incapacitating	7,238
Possible	8,407
Total	17,310

Step 2: Estimate average seat belt effectiveness

The seat belt usage rates for Kansas are not available for different vehicle types and different seating positions, but are available in the overall usage rates. Therefore, average seat belt effectiveness values need to be estimated for each injury severity level. This can be estimated by applying weight factors to the estimated individual seat belt effectiveness values for the two vehicle type groups. The weight factors were considered as the proportions of total injuries occurred in each vehicle type. The estimation procedure is illustrated in Table 3.2.

For example, to estimate the average effectiveness for fatal injuries, the percentages of fatalities in each vehicle type, which are used as the weight factors, are estimated as shown in the 4th column of Table 3.2 (64% and 36% respectively). The estimated seat belt effectiveness values shown in the 5th column are then multiplied by the weight factors from 4th column to estimate the adjusted seat belt effectiveness values for each vehicle type. The average effectiveness is estimated by taking the sum of adjusted effectiveness values for the two vehicle groups. These values are listed in the last column of the Table 3.2.

TABLE 3.2 Estimation of Average Seat Belt Effectiveness

Injury Severity	Vehicle Type (Front Seat)	Frequency	%	Estimated Effectiveness	Adjusted Effectiveness	Average Effectiveness
Fatal	Passenger Cars	184	64	0.56	0.36	0.58
	Other	104	36	0.61	0.22	
	Total	288	100.00		0.58	
Incapacitating	Passenger Cars	982	71	0.53	0.38	0.53
	Other	392	29	0.52	0.15	
	Total	1374	100.00		0.53	
Non-incapacitating	Passenger Cars	5462	75	0.55	0.42	0.54
	Other	1776	25	0.51	0.13	
	Total	7238	100.00		0.54	
Possible	Passenger Cars	6422	76	0.33	0.25	0.33
	Other	1985	24	0.34	0.08	
	Total	8407	100.00		0.33	

<u>Step 3: Obtain seat belt usage rates</u>

The seat belt usage rates in fatal and nonfatal crashes in the base and current years as well as expected future rates are obtained in this step. The seat belt usage rates in nonfatal crashes were assumed to be equal to the observed seat belt usage rates. The observed seat belt usage rate in Kansas in year 2005 was about 69%. Therefore, base year seat belt usage rate in nonfatal crashes was assumed to at 69%.

The base year usage rate in potentially fatal crashes was estimated using the following equation:

$$U_t = \frac{[U_f/(1-e)]}{[U_f/(1-e)] + 1 - U_f} \tag{3.1}$$

where,

U_t = overall seat belt usage rate of both survivors and fatalities in potentially fatal crashes

U_f = the seat belt usage rate of fatally injured occupants

e = the estimated seat belt effectiveness for fatalities

In this case, the seat belt usage rate (by occupants who were fatally injured) was estimated from the crash data. Due to the concerns regarding the accuracy of such data, although seat belt usage by survivors was available in the database, it was decided to use Equation (3.1) to obtain the overall seat belt usage in potentially fatal crashes.

According to the procedure outlined by Blincoe (1994), the seat belt usage in the current year can be assumed to be equal to base year usage rate unless there is enough evidence to believe there are significant improvements in the seat belt usage. Such evidence may include an introduction of a primary seat belt law. In such a case, the seat belt usage rate in potentially fatal crashes should be estimated form current year fatal crash data. However, in our study, crash data was not available for the year 2006. Additionally, it was not possible to find any strong evidence to conclude that noted improvements, from base year, in seat belt usage have occurred. Therefore, the current year seat belt usage rates were assumed to be applicable to base year usage rates for both fatal and nonfatal crashes.

To estimate the future seat belt usage rate in potentially fatal crashes, Blincoe (1994) used the second order regression model, developed by Partyka and Womble (1989), to predict the number of lives saved based on the observed seat belt usage rates. Taking advantages of relatively more recent data, the second order model, in 2003, was updated by Wang and Blincoe (2003). The model format was changed to predict the seat belt usage in potentially fatal crashes instead of predicting the number of lives saved. In this update, Wang and Blincoe (2003) considered 6 different model types. They found that the best model can be expressed in the following form:

$$U_t = 0.43751 * U_0 + 0.47249 * U_0^{\,2} \tag{3.2}$$

where,

U_t = overall seat belt usage rate in potentially fatal crashes

U_0 = observed seat belt usage rate

This model has an R^2 value of 0.9941 and a predicted seat belt usage rate of 91%, in potentially fatal crashes, when the observed rate is 100%. Due to the fact that model given in Equation (3.2) has been developed based on national average data, it was decided to update it based on Kansas data. A model based on Kansas data is expected to provide more realistic predictions for conditions prevalent in Kansas.

To update the model, overall seat belt usage rates (U_0) and seat belt usage in fatal crashes (U_t) for the time period from 1998 to 2005 were used. It should be noted that the selection of time duration was based on the assumption that there were no drastic changes in the conditions during that period of time. The U_0 values were directly obtained from the Kansas Safety Belt Education Office (KSBEO, 2006), which are based on state seat belt survey data. To obtain U_t values, the seat belt usage rates among fatally injured occupants (U_f) were obtained from KARS database for the same time period. Obtained U_f values were then substituted in equation (3.1) to estimate the corresponding U_t values. Consequently, the estimated U_t values and the observed U_0 values were used to update the regression model for Kansas conditions. SAS software was used to perform this task (SAS Institute Inc., 2004).

Step 4: Estimate expected safety improvements

The potential safety improvements that could be expected from increased seat belt usage are estimated in this step. Equation (3.3) can be used to achieve this objective (Blincoe, 1994).

$$IR = \frac{U_{n+1} - U_n}{(1/e) - U_b} \tag{3.3}$$

where,

IR = injury reduction rate due to increased seat belt use

U_{n+1} = predicted future seat belt usage rate

U_n = current seat belt usage rate

U_b = base year seat belt usage rate

e = average seat belt effectiveness

By using Equation (3.3), reduction rates in each injury severity category can be estimated. In our study, the effectiveness values used are the average effectiveness values estimated in the step 2.

Step 5: Obtain potential reduction in injuries

The estimated injury reduction rates, obtained in step 4, can be used to estimate the number of injuries that could be reduced due to the increase in seat belt usage rates. For example, the potential reduction in fatal injuries, FR can be estimated via Equation (3.4) (Blincoe, 1994).

$$FR = (IR)_{fatal} * F \tag{3.4}$$

where,

$(IR)_{fatal}$ = fatal injury reduction rate due to increase in seat belt usage rates (obtained from step 4)

F = number of fatalities in the base year

Similarly, the potential reduction in other injury types can also be estimated.

Step 6: Estimate economic savings

Once the potential reductions in each injury category are quantified, the expected economic benefits can be estimated. For this purpose, an economic value needs to be assigned for each level of injury severity. Many studies have been conducted to estimate cost of injuries due to highway crashes (Blincoe et al., 2002; Miller et al., 1991). According to these studies, the crash costs can mainly be measured in two different ways. One way is to measure it as a comprehensive cost, which is also referred to as willingness-to-pay cost. The other way is to measure it as a human capitol cost. The human capitol cost include costs related to property damage, lost market productivity (or lost earnings), lost household production, increase in medical services, increase in travel delay, workplace cost, increase in administrative and legal fees. In fact, the aforementioned costs are the cost elements involved with a typical highway crash that can be practically defined in monetary terms. The comprehensive costs include both tangible human capitol costs and non-tangible costs related to pain and lose in quality of life due to injuries suffered. In general, non-tangible costs are very subjective and various studies have suggested different values.

To estimate comprehensive benefits from a state level safety program, the aforementioned cost elements should be derived from state specific data. However, in Kansas, data related to many of the above mentioned cost elements are not readily available or at least they are not accessible to the public. Albeit, some data such as hospital costs related to motor vehicle crash victims are available through Kansas Trauma Registry (KTR), it is not possible to link those records with any other databases due to the lack of unique identifier for individual records. In view of the fact that Kansas is not involved in the CODES program, in which many of the crash related information from different sources are linked together, use of CODES database was not possible. For this reason, this study used injury costs estimated from the national database coupled with some adjustments in order to make these costs applicable to state economic conditions. Details of these adjustments are described in step 7.

Even though such adjustments were made, the actual state injury costs may differ from national average costs. Therefore, the benefits estimated using national average data would not be able to provide accurate dollar amounts of economic savings due to increase in seat belt usage in the state. However, they could be used to only provide approximate dollar amounts. This approach, even though not fully accurate, would be very useful, for state highway safety agencies, in approximately evaluating the expected benefits of the state safety belt promotion programs.

The comprehensive injury costs recommended by Federal Highway Administration (FHWA) that are to be used in economic analyses, by State and local highway and safety agencies, were published in the 1994 FHWA technical advisory report (FHWA, 1994). These values have been extracted from Miller et al. (1991) and updated to 1994 economic conditions using price implicit deflators for Gross Domestic Product (or GDP deflators). Those injury cost figures were updated to 2006 dollars using Consumer Price Index (CPI). The 2006 values are shown in Table 3.3. Although, FHWA recommends the use of GDP deflator to update the injury costs, the CPI was used in this study since it is the method recommended by KDOT (KDOT, 2006). A detailed discussion of this procedure is given in step 7.

In year 2002, Blincoe et al. (2002) developed injury costs by making significant changes to previous cost estimations. These cost figures could be considered as the most recent and updated injury cost figures available. Therefore, in this study, a separate benefit analysis based on these updated injury cost figures was carried out. It is expected that the results of this additional analysis would provide more options to state highway safety agencies in evaluating the state safety belt promotion programs. The injury costs developed by Blincoe et al. (2002) are listed in Table 3.4, which have been updated to 2006 dollars using CPI index.

TABLE 3.3 Cost of Injuries Recommended by FHWA (2006 dollars)

Injury Severity		Cost / Injury (2006 Dollars)
Fatal	K	3,526,539
Incapacitating	A	244,145
Non-incapacitating	B	48,829
Possible	C	25,771
Property Damage Only	O	2,713

(Source: FHWA, 1994)

In year 2002, Blincoe et al. (2002) developed injury costs by making significant changes to previous cost estimations. These cost figures could be considered as the most recent and updated injury cost figures available. Therefore, a separate benefit analysis based on these updated injury cost figures was also carried out. It is expected that the results of this additional benefit analysis would provide more options to state highway safety agencies in evaluating safety belt promotion programs. The injury costs developed by Blincoe et al. (2002) are shown in Table 3.4. Note that these costs have been updated to 2006 dollars using the CPI index.

It should be noted that when AIS severity scale is used in transportation safety studies, the injury severity is commonly expressed as the maximum injury severity (typically abbreviated as MAIS). In many cases, occupants may sustain multiple injuries and each injury is given an injury severity score associated with the injured body region. Out of these different scores, the maximum severity score is considered as the individual’s overall injury severity, and is expressed in terms of MAIS.

TABLE 3.4 Cost of Injuries Developed by Blincoe et al. (2002) in AIS Scale (2006$)

Injury Severity		Cost / Injury (2006 Dollars)
Unsurvivable (Fatal)	MAIS6	3,931,892
Critical	MAIS5	2,801,109
Severe	MAIS4	846,707
Serious	MAIS3	360,024
Moderate	MAIS2	179,923
Minor	MAIS1	12,213
Property Damage Only	MAIS0	200

(Source: Blincoe et al., 2002)

The injury costs given in Table 3.4 should be converted into KABCO injury severity scale since the injury reductions estimated in step 5 are based on KABCO scale. The conversion factors developed by Miller et al. (1991), using National Accident Sampling System data from 1982 to 1986, were used to perform this conversion. The conversion factors are listed in Table 3.5, while the updated injury cost figures, based on KABCO injury scale, are shown in Table 3.6.

To estimate the total economic savings, the estimated injury reductions obtained in step 5 will need to be multiplied by the corresponding injury cost values from Table 3.3 or Table 3.6.

TABLE 3.5 Conversion Factors used to Convert KABCO Injuries into AIS Injures

MAIS	Fatal K (%)	Incapacitating A (%)	Non-Incapacitating B (%)	Possible C (%)	No-injury O (%)
0	0.00	1.50	5.20	20.50	92.70
1	0.00	48.60	78.80	70.90	7.00
2	0.00	28.00	12.60	7.00	0.20
3	0.00	16.90	3.10	1.50	0.03
4	0.00	2.80	0.30	0.06	0.00
5	0.00	1.70	0.10	0.01	0.00
6	100.00	0.50	0.03	0.01	0.00
All	100	100	100	100	100

(Source: Miller et al.., 1991)

TABLE 3.6 Cost of Injuries Developed by Blincoe et al. (2002) in KABCO Scale (2006$)

Injury Severity		Cost / Injury (2006 Dollars)
Fatal	K	3,931,892
Incapacitating	A	210,650
Non-incapacitating	B	50,136
Possible	C	27,926
Property Damage Only	O	1,508

(Source: Blincoe et al 2002)

<u>Step 7: Perform adjustments</u>

As previously mentioned, CPI was used to update the injury costs into current economic conditions. According to the Kansas Accident Facts report published by KDOT (KDOT, 2006), injury costs should be updated by using CPI. Based on KDOT recommended procedure, the updated costs are estimated as follows.

$$C_{TY} = C_{BY}\left[\frac{CPI_{TY}}{CPI_{BY}}\right] \tag{3.5}$$

where,

C_{TY} = updated cost in targeted year economic conditions

C_{BY} = cost in base year economic conditions

CPI_{TY} = CPI for the month of January of the year that follows the accident

CPI_{BY} = CPI for the month of January of the base year

The CPIs are published monthly by the Bureau of Labor Statistics of the US Department of Labor (BLS, 2006). For example, to update the cost of a fatality from 1994 dollars to 2006 dollars, the CPIs for January 1994 and 2006 are required. From BLS publications (BLS, 2006), these two values are 146.2 and 198.3, respectively. Utilizing Equation (3.5), the corresponding costs in 2006 dollars, C_{2006} will be

$$C_{TY} = 2{,}600{,}000[\frac{198.3}{146.2}] = \$3{,}526{,}539$$

The costs estimated in step 6 are based on national average economic conditions. To convert these costs into state economic conditions, a state cost factor can be used. The state cost factor was estimated by utilizing the ratio between the national and the Kansas per capita incomes (Blincoe, 1994). For year 2006, the Kansas and the US per capita incomes were \$34,743 and \$36,276, respectively (USBEA, 2006). Thus, the estimated cost factor for Kansas is 0.96.

3.4 Results and Discussion

This section presents: i) illustration of sample numerical results performed, pertinent to the data used in this study, in accordance with steps 3 to 7, and ii) brief discussion of the results obtained.

Step 3: Obtain seat belt usage rates

The seat belt usage among fatally injured occupants in the base year (2005) was 38%. The average seat belt effectiveness for fatalities is obtained from Table 3.2, which is 0.58. Using Equation (3.1), the overall seat belt usage in potentially fatal crashes can be estimated as follows:

$$U_t = \frac{[0.38/(1-0.58)]}{[0.38/(1-0.58)] + (1-0.38)} = 0.59$$

Thus, the overall seat belt usage among occupants who were involved in fatal crashes is 59%. This value is significantly lower than the observed usage rate of 69% reported for year 2005. Because there is no significant evidence to prove that there were any improvements in seat belt usage from the base year, the seat belt usage in potentially fatal crashes in the current year is assumed to be equal to 59%.

Table 3.7 shows the observed seat belt usage rates in Kansas from 1998 to 2005 along with seat belt usage among fatally injured occupants. The last column in Table 3.7 lists the estimated overall seat belt usage rates, in potentially fatal crashes (including survivors), calculated via Equation (3.1). Moreover, Figure 3.1 shows the graphical comparison between the three seat belt usage rates, namely; U_0, U_f, and U_t.

TABLE 3.7 Seat Belt Usage Rates among Overall Motor Vehicle Population and Fatally Injured Occupants in Kansas

Year	Observed Seat Belt Usage Rates (U_0)	Seat Belt Usage Rates among Fatally Injured Occupants (U_f)	Average Seat Belt Effectiveness	Seat Belt Usage Rates in Potentially Fatal Crashes (U_t)
1998	0.59	0.29	0.58	0.49
1999	0.63	0.33	0.58	0.54
2000	0.62	0.29	0.58	0.49
2001	0.61	0.27	0.58	0.47
2002	0.61	0.32	0.58	0.53
2003	0.64	0.31	0.58	0.52
2004	0.68	0.40	0.58	0.61
2005	0.69	0.38	0.58	0.59

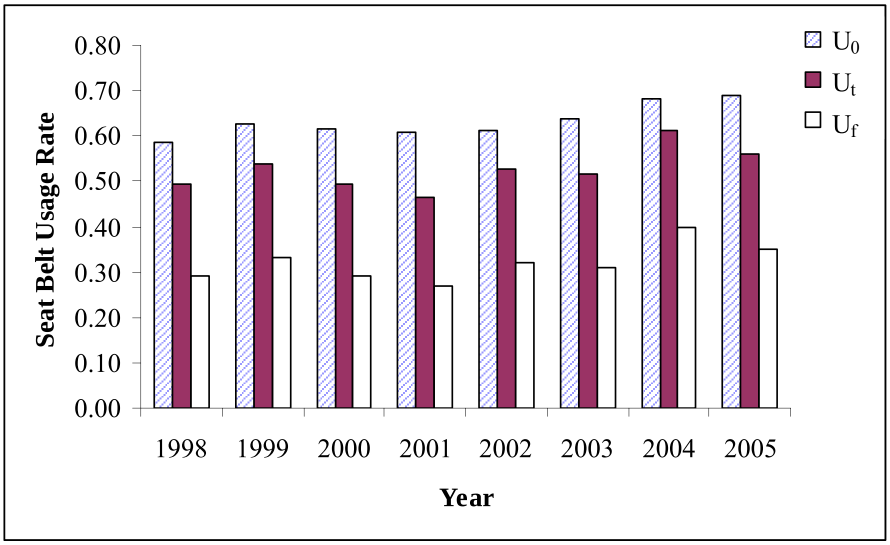

FIGURE 3.1 Comparison of Seat Belt Usage Rates

It can be seen that the seat belt usage among fatally injured occupants are significantly low. Although, the observed seat belt usage rate shows some improvements after year 2002, no consistent trends are observed in other two rates.

Based on U_0 and U_t values from Table 3.7, the estimated second order model can be expressed in the following form:

$$U_t = 0.58869 * U_0 + 0.38075 * U_0^{\ 2} \tag{3.6}$$

This model has an R^2 value of 0.998 and the estimated error of the model is 0.0046. One of the important factors that should be considered in assessing the quality of the model is its ability to accurately predict U_t at high U_0 values. For example, theoretically, the model should predict the U_t as 100% when U_0 is 100%. The above model predicts U_t as 97% at 100% observed seat belt usage level (i.e., U_0)

The trend of increasing U_t at higher U_0 values may be different from what is observed at lower U_0 values. This may be attributed to the fact that at higher observed seat belt usage levels, the remaining seat belt non-users could be considered as the highest risk takers and the least likely to be convinced, to use seat belts, by any promotion programs or law enforcement measures. Therefore, the use of the same model for predicting U_t at all levels of U_0 may not be accurate. Kansas has a current seat belt usage rate of 69% with a secondary seat belt law. The targeted seat belt usage rate, that safety belt promotion programs or any other means would expect to achieve, may likely increase to the 80%- 85% range. Therefore, this study assumes a targeted maximum future usage rate of 85%. Accordingly, the targeted range of seat belt usage rate, for this study, is between 69% and 85%. Within this range, the model developed in this study could be expected to provide reasonably accurate predictions of U_t. The predicted U_t values for the 70% to 85% range of U_0 are shown in Table 3.8.

TABLE 3.8 Predicted U_t Values for the Future Expected Observed Rates

Expected Future Observed Seat Belt Usage Rate U_0	Predicted Seat Belt Usage Rate in Potentially Fatal Crashes U_t
0.70	0.60
0.71	0.61
0.72	0.62
0.73	0.63
0.74	0.64
0.75	0.66
0.76	0.67
0.77	0.68
0.78	0.69
0.79	0.70
0.80	0.71
0.81	0.73
0.82	0.74
0.83	0.75
0.84	0.76
0.85	0.78

Table 3.9 summarizes the estimated inputs from steps 1 to 3.

TABLE 3.9 Summary of Results Obtained from Steps 1 to 3

Description	Value
Base year	2005
Current year	2006
Observed seat belt usage rate in the base year	0.69
Observed seat belt usage rate in the current year	0.69
Number of fatalities (base year)	288
Number of incapacitating injuries (base year)	1,374
Number of non-incapacitating injuries (base year)	7,238
Number of possible injuries (base year)	8,407
Average safety belt effectiveness for fatalities	0.58
Average safety belt effectiveness for incapacitating injuries	0.53
Average safety belt effectiveness for non-incapacitating injuries	0.53
Average safety belt effectiveness for possible injuries	0.34
Base year seat belt usage rate in nonfatal crashes	0.69
Current year seat belt usage rate in nonfatal crashes	0.69
Base year seat belt usage rate in fatal crashes	0.59
Current year seat belt usage rate in fatal crashes	0.59

Results from steps 1 to 3 could be considered as the inputs for estimating the anticipated economic benefits.

Steps 4 & 5

Assume that the observed seat belt usage rate will be increased by 1% from its present usage rate of 69%. From Table 3.8, the seat belt usage rate in potentially fatal crashes is estimated at 60% when the observed rate is 70%. Since the current seat belt usage rate in potentially fatal crashes is 58%, by using Equation (3.3) the expected fatality reduction rate, $(IR)_{Fatal}$ can be estimated as

$$(IR)_{Fatal} = \frac{U_{n+1} - U_n}{(1/e) - U_b} = \frac{0.60 - 0.59}{(1/0.58) - 0.56} = 0.008 = 0.8\%$$

In other words, there would be a 0.8 % reduction in fatalities if the seat belt usage rate increases by 1%. By using Equation (3.4), the total reduction in fatalities, FR can be estimated a:

$FR = (IR)_{fatal} * F = 0.008 * 288 = 2$

Accordingly, 1% increment in seat belt usage rate, from the current level, is estimated to save 2 additional lives. Similar procedure can be used in order to estimate reductions in other injury categories. Table 3.10 shows the summary of the estimated injury reductions due to the 1% incremental increase in the overall seat belt usage rate. It can be seen that 1% increase in seat belt usage rate would produce 0.8% reduction in both incapacitating and non-incapacitating injuries. In other words, there 11 incapacitating injuries and 60 non-incapacitating injuries could be prevented if 1% more motorists were restrained.

Steps 6 & 7

As previously mentioned, the economic benefits were estimated based on two different injury cost categories. Therefore, to estimate total economic benefits from increased seat belt usage, the estimated injury reduction from Table 3.10 should be multiplied by corresponding injury cost values listed in Table 3.3 or Table 3.6. To obtain the adjusted economic benefits for local conditions, the estimated values are multiplied by the state cost factor of 0.96. Adjusted and unadjusted estimated economic benefits due to 1% increase in seat belt usage rate, based on the two injury cost categories, are listed in Tables 3.11 and 3.12, respectively. It can be seen that the difference between the total estimated economic benefits for the two injury cost categories is about $0.6 million.

TABLE 3.10 Estimated Injury Reductions due to a 1% Increase in Seat Belt Usage Rate

Injury Severity	Injury Frequencies (base year)	Injury Reduction Rate (%)	No. of Injuries Reduced
Fatal	288	0.8	2
Incapacitating	1374	0.8	11
Non-incapacitating	7238	0.8	60
Possible	8407	0.4	37

TABLE 3.11 Estimated Economic Savings due to 1% Increase in Seat Belt Usage Rate (Based on FHWA Injury Costs)

Injury Severity	No. of Injuries Prevented	Cost / Injury (2006 Dollars)	Unadjusted Economic Benefits (2006 Dollars)	Adjusted Benefits (2006 Dollars)
Fatal	2	3,526,539	7,053,078	6,700,424
Incapacitating	11	244,145	2,685,595	2,551,315
Non-incapacitating	60	48,829	2,929,740	2,783,253
Possible	37	25,771	953,527	905,851
Total			13,621,940	12,940,843

Refereeing to benefit estimates, based on FHWA injury costs, it can be observed that the total economic savings due to the 1% increase in seat belt usage rate is about $ 13 million in terms of 2006 dollars. About 52% of the total benefits (6.7 million) resulted from reduction in fatalities. Reductions in incapacitating and non-incapacitating injuries have almost equal contributions to the total benefits.

TABLE 3.12 Estimated Economic Savings due to 1% Increase in Seat Belt Usage Rate (Based on Injury Costs Developed by Blincoe et al., 2002)

Injury Severity	No. of Injuries Prevented	Cost / Injury (2006 Dollars)	Unadjusted Economic Benefits (2006 Dollars)	Adjusted Benefits (2006 Dollars)
Fatal	2	3,931,892	7,863,784	7,470,595
Incapacitating	11	210,650	2,317,150	2,201,293
Non-incapacitating	60	50,136	3,008,160	2,857,752
Possible	37	27,926	1,033,262	981,599
Total			14,222,356	13,511,238

Similarly, benefits were estimated for each 1% incremental increase in seat belt usage rate until the final anticipated seat belt usage rate of 85% is reached. The expected injury reductions due to different incremental increases in seat belt usage rate are listed in Table 3.13.

TABLE 3.13 Estimated Injury Reductions for Different Future Seat Belt Usage Rates

Expected Future Seat Belt Usage Rate (%)	Increment (%)	Injuries Prevented			
		Fatal	Incapacitating	Non-incapacitating	Possible
70	1	2	11	60	37
71	2	5	23	121	75
72	3	8	34	181	112
73	4	11	46	242	149
74	5	14	57	302	187
75	6	17	69	363	224
76	7	19	80	423	261
77	8	22	92	484	299
78	9	25	103	544	336
79	10	28	115	605	373
80	11	31	126	665	411
81	12	34	138	726	448
82	13	37	149	786	485
83	14	41	161	847	523
84	15	44	172	907	560
85	16	47	184	968	598

Assuming no economic benefits at current seat belt usage level, the estimated economic benefits at varying incremental increases of seat belt usage rate are listed in Table 3.14.

Additionally, Figure 3.2 shows a graphical trend of the anticipated economic savings for various incremental increases from the current 69% seat belt usage rate.

TABLE 3.14 Estimated Economic Savings for Different Future Seat Belt Usage Rates

Expected Future Seat Belt Usage Rate (%)	Increment (%)	Economic Benefits * (Million Dollars) (FHWA Injury Costs)	Economic Benefits * (Million Dollars) (Blincoe et al., 2002)
69	0	0	0
70	1	13	14
71	2	30	31
72	3	46	48
73	4	62	66
74	5	79	83
75	6	95	101
76	7	108	118
77	8	125	135
78	9	141	153
79	10	158	170
80	11	174	187
81	12	191	205
82	13	207	222
83	14	227	240
84	15	243	257
85	16	260	274

Benefits are in 2006 dollars

By examination of Table 3.13, it can be seen that, if the observed seat belt usage rate reaches the anticipated rate of 85%, 47 additional lives could be saved. Moreover, this would result reductions of about 184 incapacitating injuries and 968 non-incapacitating injuries. The corresponding reduction in possible injuries is expected to reach 598. According to the estimated economic benefits (listed in Table 3.14), when the overall seat belt usage rate reaches 85%, the expected economic savings would amount to about $260 million in terms of 2006 dollars. For further clarifications, assume that the national average seat belt usage rate for year 2006 is the same (i.e., 82%) as that reported for 2005 and the observed seat belt usage rate in Kansas, in year 2006, was equal to the national average (82%), then about $207 million could have been saved and 37 fatalities could have been prevented. In other words, the economic loss due to low seat belt usage in Kansas (compared to national average usage) in year 2006 was about $207 million. This could also be interpreted as the annual economic loss due to low seat belt usage in Kansas based on 2006 seat belt usage rate.

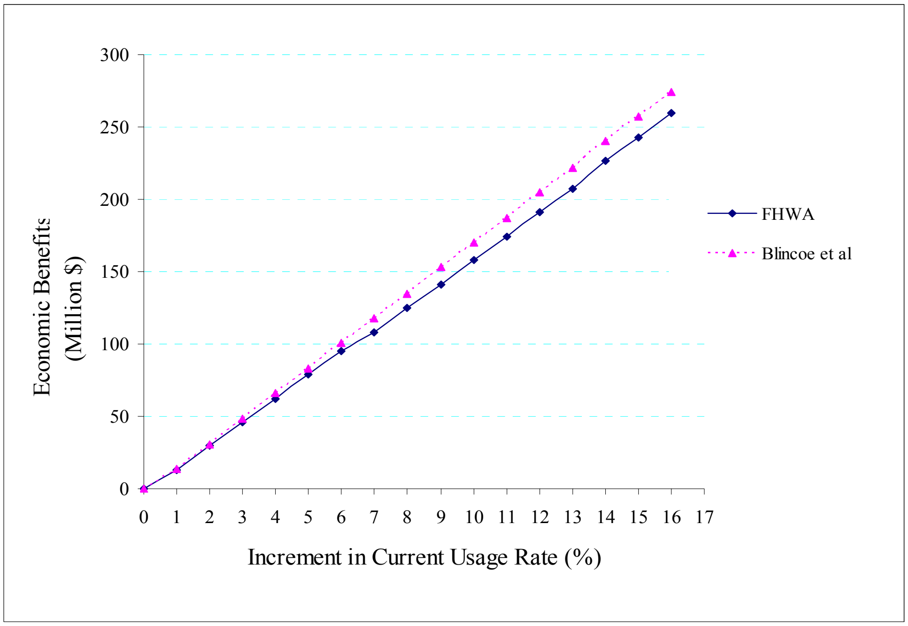

FIGURE 3.2 Estimated Economic Benefits due to Increased Seat Belt Usage Rates

The estimated benefits, obtained in this study, could be useful in many different venues. One such venue is to use them in benefit/cost analysis of seat belt usage promotion programs. For example, let us assume the following scenario: i) the state of Kansas is planning to launch a safety belt promotion program which includes a change of its secondary seat belt law to a primary law coupled with a vigorous enforcement program to crack down on the violators, and ii) it is expected that the promotion program would improve the current seat belt usage rate by 10%. Accordingly, the anticipated benefits (about $158 million in 2006 dollars) of the promotion program can directly be obtained from Table 3.14. If the total cost associated with the program is known, then the benefit/coast ratio can be easily obtained.

Furthermore, the benefit figures could be effectively used in seat belt education programs to improve the seat belt usage rate among motorists. In this case, it would be easier for the general motor vehicle occupants to understand the importance of seat belt usage if the resulted benefits are presented in economical terms. This would be more effective in convincing motorist to buckle up while driving.

The benefits estimated in this study are based on data (crash data and seat belt usage data) for the year 2005. However, if these values are to be used in any future analysis and the data is available for a year after 2005, then the later year should be considered as the base year and all associated values should be updated in accordance with the new data. Additionally, the injury costs should also be updated if any changes have been made to the original injury costs used in this study.

It should be noted that the economic benefits estimated in this study only provide approximate values and the real benefits may vary. For example, this study did not consider rear-seat passengers in the analysis. Considering this in the analysis might have underestimated the real benefits that could be expected due to increase in seat belt usage rate. Moreover, there may be some concerns about the accuracy of the data used in the analysis especially data related to seat belt usage and injury severities, which might have impacted the final estimated values. Hence, the use of these values in any analysis to estimate precise dollar amounts may not be recommended.

CHAPTER 4 SUMMARY AND CONCLUSIONS

This study estimated the effectiveness of seat belts in reducing injuries and estimated the associated economic benefits using state of Kansas data. The estimation process included three stages: i) estimating seat belt effectiveness, ii) estimating injury reductions, and iii) estimating economic benefits due to injury reductions. In the first stage, seat belt effectiveness in reducing injuries to motor vehicle occupants was estimated. Crash data from Kansas Accident Reporting System (KARS) database was used to accomplish this estimation process. All estimations were based on the KABCO injury scale. Seat belt effectiveness was estimated using logistic regression method. The associated results were then compared with estimated values obtained from double pair comparison method to check the accuracy of the estimations. Only front seat passengers were considered in the analysis. The two vehicle type groups considered in the study were limited to passenger cars group, and other passenger vehicle group that included pickup trucks and vans. In the second stage, the estimated seat belt effectiveness values resulted from the first stage were used to estimate potential injury reductions due to increased seat belt usage. In the third stage, obtained injury reduction values were converted into economic values by assigning economic costs for each injury severity level.

According to the obtained estimations, seat belts are 56% effective in preventing fatal injuries when used by passenger car front seat occupants. In the other passenger vehicle group that included vans and pickups, seat belts were found to be 61% effective in preventing fatalities. The seat belt effectiveness, in reducing incapacitating and non-incapacitating injuries, was respectively found to be 53% and 55% for passenger cars group, and 52% and 51% for other passenger vehicle group.

Based on the analysis conducted in this study, it was found that the first 1% incremental increase in current seat belt usage rate could annually save about $13 million to the state of Kansas. If seat belt usage in Kansas reaches the national average rate of 82% (2005 value), the resulted annual economic savings are estimated to be around $260 millions. In other words, due to the current low seat belt usage in Kansas as compared to the national average, the annual estimated economic loss is about $260 millions, based on the lower of the two estimations. Moreover, about 37 additional lives could be saved if the current state seat belt usage rate of 69% is increased to the national average of 82%.

It should be noted that the economic benefits estimated in this study only provide approximate values and the real benefits may vary. For example, this study did not consider rear-seat passengers in the analysis. Considering this in the analysis might have underestimated the real benefits that could be expected due to increase in seat belt usage rate. Moreover, there may be some concerns about the accuracy of the data used in the analysis especially data related to seat belt usage and injury severities, which might have impacted the final estimated values. Hence, the use of these values in any analysis to estimate precise dollar amounts may not be recommended.

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