DEVELOPMENT AND TESTING OF METHODOLOGIES TO ESTIMATE BENEFITS ASSOCIATED WITH SEAT BELT USAGE IN KANSAS

by

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B.Sc., University of Moratuwa, 2001
M.S., Kansas State University, 2005

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

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Abstract

Seat belt usage is considered to be one of the most effective ways of improving safety of motor vehicle occupants. Thus, increasing seat belt usage among motorists has become one of the top prioritized goals of many highway safety improvement programs. The main objective of this study was to develop a methodology to estimate potential economic benefits associated with increased seat belt usage by Kansas motorists based on conditions prevailing in the State of Kansas. Seat belt effectiveness in reducing injuries was estimated and those values were then used to estimate economic benefits due to injury reductions. Five methodologies were used to estimate seat belt effectiveness which included multiple logistic regression, double pair comparison method, Cox proportional hazards regression, conditional logistic regression, and risk ratio model using estimating equation approach. Crash data from Kansas Accident Reporting System (KARS) database was used. A procedure was developed to estimate economic benefits due to increased seat belt usage based on State conditions.

The highest variation in estimated seat belt effectiveness values using different methods were observed for incapacitating injuries while the lowest variation was observed for possible injuries. For fatal injuries, the estimated seat belt effectiveness values ranged from 50-69% for passenger cars and 57-70% for other passenger vehicles. The range of seat belt effectiveness values for incapacitating injuries was 47-65% for passenger cars and 44-69% for other passenger vehicles. It was also found that the multiple logistic regression method provide relatively narrower confidence intervals for almost all the nonfatal injury categories in both vehicle groups. Based on estimations using logistic regression method, seat belts are 56% effective in preventing fatal injuries in passenger cars and 61% effective in other passenger vehicles. The seat belt effectiveness in reducing incapacitating injuries was found to be 53% in passenger cars and 52% in other passenger vehicles.

It was found that if seat belt usage rate in Kansas reaches the national average rate of 81% (2006), the resulted annual economic benefits to the State is estimated to be about $ 191 millions in 2006 dollars or in other words, due to lower seat belt usage currently observed in

Kansas compared to national usage level, the annual estimated economic loss is about $ 191 millions.

Seat belt effectiveness values are currently not available based on KABCO (K-Fatal, A-Incapacitating, B-Non-incapacitating, C-Possible, and O-No injuries) injury scale. Therefore, this study could serve as an initiative towards establishing a procedure to estimate benefits of seat belt usage based on State highway crash data.

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CHAPTER 1 - INTRODUCTION

1.1 Background

Highway safety is a prime concern universally due to the magnitude of social and economic impacts imposed by highway crashes. In the United States, deaths due to unintentional injuries are ranked 5th among different causes of death and motor vehicle crashes are the leading cause of unintentional injuries. In addition, motor vehicle crashes are the leading cause of death among persons between 1 to 34 years of age (CDC, 2006). According to year 2005 statistics, estimated 43,443 people died and another 2.7 million were injured on US roadways due to motor vehicle crashes (NHTSA, 2006). The economic impacts due to highway crashes are also estimated to be significant. It has been estimated that the economic loss due to highway crashes in year 2000 was about $ 230 billion, and this was equivalent to 2.3% of the U.S. Gross Domestic Product for that year or, $ 820 per every person based on 281.4 million of the U.S. population (Blincoe et al., 2002).

Thus, improving highway safety is a critical need that has been nationally recognized. There have been numerous efforts made by highway agencies during the past decades to improve highway safety. Those efforts could be categorized into areas such as roadway improvements, improvements to vehicle designs, application of advanced technologies (Intelligent Transportation Systems), introduction of occupant protection systems (seat belts and air bags), enactment of laws and increased law enforcement, and education. Out of all these strategies, the occupant restraint systems in vehicles are considered to be one of the most effective ways of improving safety of motor vehicle occupants.

According to estimations based on national data, seat belts have saved many lives and prevented many injuries to occupants saving billions of dollars in injury related costs. For example, National Highway Traffic Safety Administration (NHTSA) estimated in year 2002 (Blincoe et al., 2002) that the use of seat belts by motor vehicle occupants have saved about 135,000 lives and prevented 3.8 million injuries during the period from 1975 to 2000. In addition, if all motor vehicle occupants were retrained, 314,824 deaths and 5 million injuries could have been prevented during that period of time. In terms of economic savings, use of seat belts has saved $ 588 billion during 1975 to 2000. Based on year 2000 seat belt usage rate, seat belts are saving $ 50 billion yearly (based on 2000$) (Blincoe et al., 2002). On the other hand, seat belt nonuse has resulted in $ 930 billion loss to the economy during the same period of time and annual loss is estimated to be about $ 26 billion (Blincoe et al., 2002).

Because of significant benefits associated with the use of seat belts, many States in the USA have enacted laws to mandate the use of seat belts by motorists. There are two types of seat belt laws in the USA: primary and secondary seat belt law. When the law is primary, police officers can stop and cite a motorist solely for violating the seat belt law. In case of secondary seat belt law, motorists cannot be stopped for a safety belt violation unless there is another primary violation of traffic law. As of year 2006, primary seat belt law was in effect in 25 States plus District of Columbia and Puerto Rico while in rest of the States, except in New Hampshire, where there was no seat belt law, the law was secondary (Glassbrenner, 2007).

However, many States in the U.S. still observe comparatively low seat belt usage rates despite the efforts made by highway agencies to increase the seat belt usage. According to 2006 National Occupant Protection Usage Survey (NOPUS) results, about 45% of States still have seat belt usage rates less than the national average rate of 81%, and about 75% of those States with low seat belt usage rates have secondary seat belt law in effect (Glassbrenner, 2007). One of the major reasons for low seat belt usage rates in those States could be the lack of awareness among motorists about the safety benefits associated with seat belt usage. For example, many States have observed significant increase in seat belt usage after changing their secondary seat belt law to a primary law. In year 2006, the average seat belt usage rate in States with a primary law was 85% compared to 74% usage rate in States with a secondary seat belt law (Glassbrenner, 2007). However, many States in the US, including the State of Kansas, have been unsuccessful in changing the seat belt law to a primary law mainly due to the lack of public support.

According to NOPUS data, the observed seat belt usage rate in Kansas in year 2006 was 73%, which is significantly lower than the national average rate of 81%. As a State with secondary seat belt law in effect, seat belt usage rate in Kansas was the 6th lowest in the nation (Glassbrenner, 2007). The comparatively lower seat belt usage among Kansas motorists is a major concern in the State of Kansas. In year 2006, there were 468 highway related fatalities in Kansas and seat belt usage rate among fatally injured occupants was only 40% (KDOT, 2007 a).

Figure 1.1 shows the reported seat belt usage rates among occupants who were involved in crashes on Kansas roadways and the observed seat belt usage rates among general motorist population in Kansas (KSBEO, 2007). As indicated in Figure 1.1, seat belt usage among fatally injured occupants is significantly lower compared to occupants with nonfatal injuries.

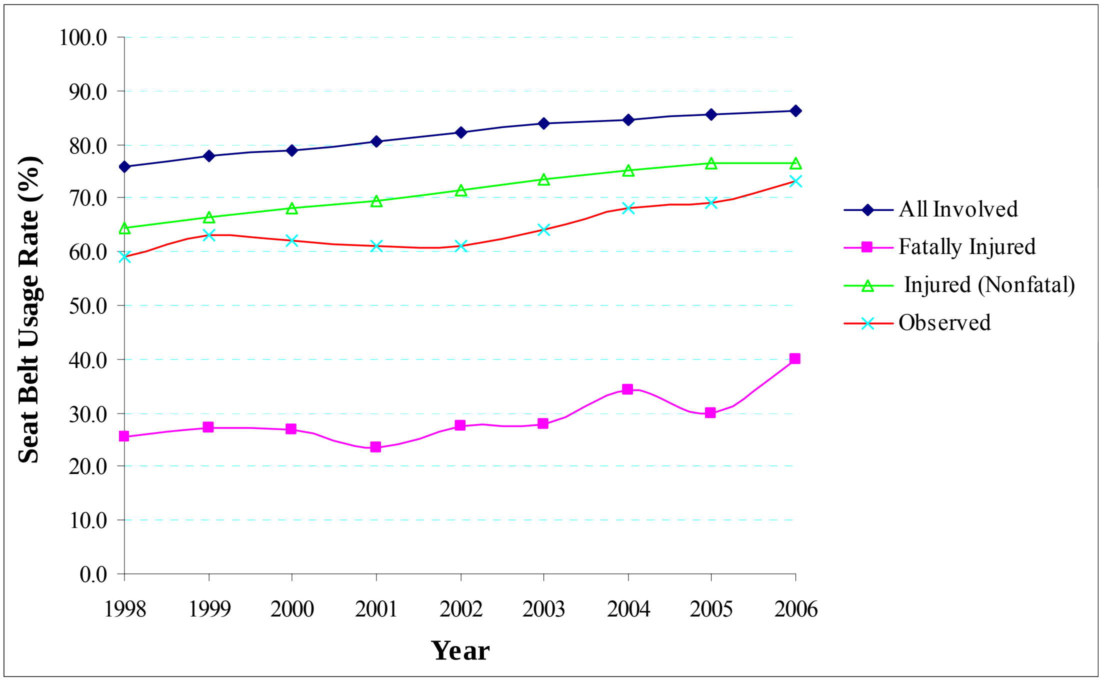
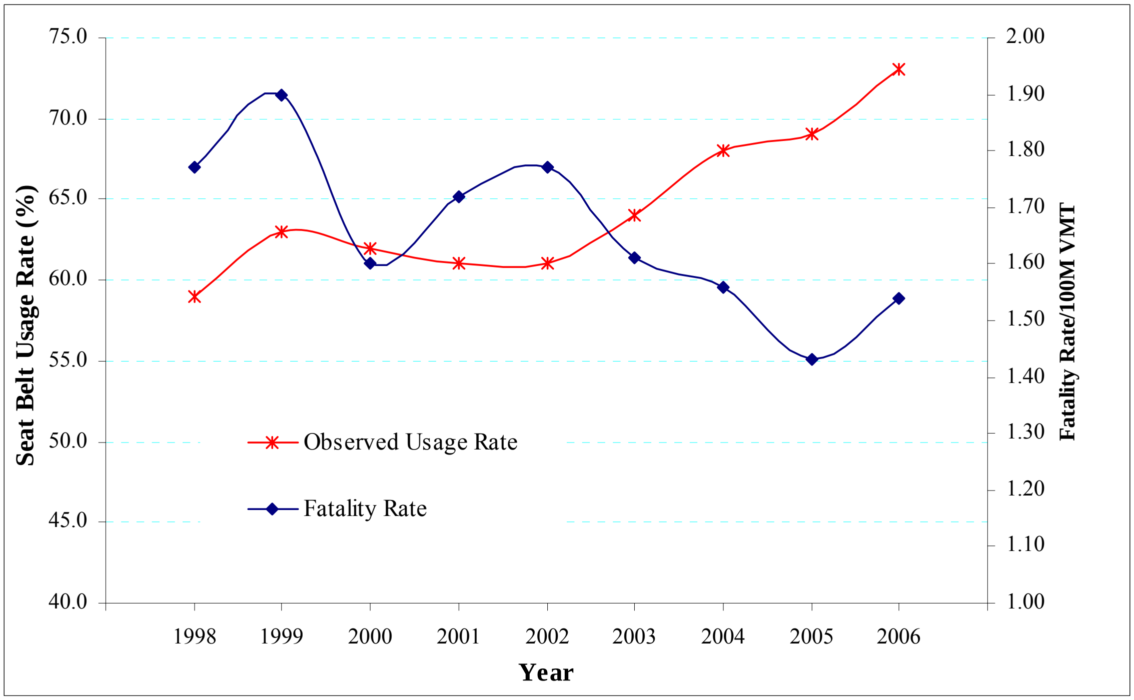


Figure 1.1 Comparison of Seat Belt Usage Rates among Different Occupant Types in Kansas

Figure 1.2 shows the observed seat belt usage rates among Kansas motor vehicle occupants during 1998 to 2006 and the fatal injury rates per 100 million vehicle miles travelled (VMT) due to highway crashes on Kansas highways during the same period of time. A significant drop in fatality rates can be observed after year 2002 and has been decreasing until 2005 after which there is a slight increase. On the other hand, the observed seat belt usage rate has been increasing since the year 2002 until 2006. Therefore, the increased sear belt usage among motor vehicle occupants may have influenced on the reduction in fatality rates during that period of time.



Note: Fatality Rate per 100 Million Vehicle Miles Traveled (100M VMT)

Figure 1.2 Comparison of Observed Seat Belt Usage Rates and Fatal Injury Rates in Kansas

Considering the above facts, it can be seen that low seat belt usage among motorists is a major concern for highway agencies in many States. Accordingly, improving seat belt usage has been identified as one of the prime objectives of many of the federal and State highway safety plans. The Strategic Highway Safety Plan (SHSP), which was initiated by American Association of State Highway and Transportation Officials (AASHTO) with a goal of reducing nation's highway fatality rate by 2008 to not more than one per 100 million vehicle miles travelled, has identified 22 different areas that need to be addressed in improving highway safety (AASHTO, 2005). Increasing seat belt usage is one of the top prioritized areas among them. Some of the major strategies suggested by SHSP to increase seat belt usage include publicized enforcement campaigns, enhanced education, and enactment of primary seat belt law (Lucke et al., 2004).

According to one of the requirements of the federal surface transportation act known as "Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users" (SAFETEA-LU), which was implemented in year 2005, the State highway agencies (i.e. State Department of Transportation) should develop their own SHSP. These are called State DOT Strategic Highway Safety Plans and they provide the information about the strategies followed by individual States to achieve the goals identified by SHSP. About 98% of State DOT Strategic Highway Safety Plans (i.e. 49 out of 50 States) have identified that increasing seat belt usage is one of the primary goals in increasing highway safety (Stokes et al., 2007). According to Kansas SHSP for the fiscal year 2008, the State is aiming to increase the seat belt usage by 3% each year to 78% on 2008 and 84% in year 2010 (Sebelius et al., 2007). Millions of dollars have been allocated to implement different strategies to achieve the above objective.

In an effort to educate the Kansas motorists about number of fatalities and injuries on Kansas roadways, Kansas Department of Transportation (KDOT) along with Kansas Highway Patrol and Kansas Department of Health and Environment initiated a program called Kansas Safe Driving Campaign (KDOT, 2007 b). The program formed a task force called the Driving Force, which was assigned with a unique goal of identifying strategies to bring down number of fatalities and injuries on Kansas highways. The Driving Force has identified 11 different areas that need to be addressed and increasing seat belt usage is one of the prioritized recommendations. Some of the key strategies suggested by the Driving Force include enacting a primary seat belt law with an increase fine, developing strong media campaigns.

Therefore, increasing seat belt usage among motorists has become one of the prime objectives of many highway safety improvement programs both statewide and nationwide. The main strategies that have been identified by these programs include enacting primary seat belt laws, stronger law enforcements, and campaigning programs. For these strategies to be implemented and be effective there are two major requirements that need to be satisfied. One, all these strategies require great deal of capital investment and such investments should be justifiable. In other words, the suggested strategies need to be assessed based on anticipated benefits (e.g. cost-benefit analysis) after implementation. For this purpose, the estimated economic benefits that could be anticipated due to increased seat belt usage (as a result of implementation of the strategy) would be very useful.

The second and one of the most important requirements is the public support towards the implementation of suggested strategies. In Kansas, several attempts that have been made to change its secondary seat belt law to a primary law have been failed mainly due to lack of public support. According to findings of a recent study based on survey data obtained in the State of Kansas, only about 43% of the respondents were aware about the type of seat belt law in effect in Kansas (Dissanayake and Parikh, 2007). In addition, only 14% of the survey participants supported the idea that having a stricter seat belt law would motivate them to use their seat belts more often. The same study found that the highest increment in seat belt usage (about 11%) could be achieved by changing Kansas's secondary seat belt law to a primary law. Therefore, it is essential that highway agencies come up with ways to increase the awareness among general motorists about greater safety benefits associated with seat belt usage. The estimated potential economic benefits would be a very useful piece of information that could be used in seat belt promotion programs to increase the awareness of benefits associated with seat belt usage. This is because, in general, economic figures are easily understandable to the general public and by expressing the benefits associated with seat belt usage in terms of economic savings (or losses) could significantly influence their decision to wear seat belts.

Thus, the availability of information related to potential economic benefits due to increased seat belt usage is very useful for highway agencies.

1.2 Problem Statement

Safety benefits associated with seat belt usage are estimated based on their ability to reduce risks for motorists to sustain severe injuries when they are involved in crashes. This is commonly referred to as seat belt effectiveness. In other words, seat belt effectiveness could be defined as the percentage reduction in injuries for restrained occupants (occupants who wear seat belts or belted occupants) compared to unrestrained occupants (unbelted occupants) when they are involved in crashes. If the effectiveness of seat belts in reducing injuries is known, the expected injury reductions due to increased seat belt usage can be estimated. By assigning economic values to the resulted injury reductions, economic benefits associated with seat belt usage can be estimated. Thus, the initial and most important step in the benefit estimation process is the estimation of seat belt effectiveness in reducing injuries. Therefore, it is essential to obtain as accurate as possible estimations of seat belt effectiveness values as the accuracy of estimated economic benefits are very sensitive to the seat belt effectiveness values used.

Even though, effectiveness of seat belts in reducing injuries has been estimated by several studies in the past including studies conducted by NHTSA, the application of those effectiveness values to estimate economic benefits of seat belt usage in a particular State may have concerns due to many reasons.

First, the seat belt effectiveness values estimated by many studies including NHTSA studies are based on Abbreviated Injury Scale (AIS). The AIS is a method used to rank severity of an injury based on a scale ranging from 1 to 6. KABCO is another injury scale mostly used by State highway agencies to measure the injury severity motor vehicle crash victims, which has 5 different levels to rank injury severity. Table 1.1 illustrates the different levels used to express injury severities in the two injury severity scales. It can be seen that the two scales use completely different injury severity levels to express the severity of nonfatal injuries.

Table 1.1 Different Levels of Injury Severities Used in AIS and KABCO Severity Scales

AIS		KABCO	
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 the States in the USA including the State of Kansas use KABCO injury severity scale in their highway crash databases to report injury severities. However, many of the important data sources related to highway crashes such as seat belt effectiveness, cost of injuries, etc. are based on AIS injury severity scale. Because of this incompatibility in injury severity scales, it is somewhat 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 injuries have to be converted into AIS injuries if nationally estimated seat belt effectiveness values are to be used, since Kansas highway crash data base uses KABCO injury scale. For this purpose, conversion factors are required, but in most of the cases such conversion factors are not available at State level. Although some studies have developed conversion factors using national data (Miller et al., 1991), those factors have not been updated with more recent data. Thus, the use of those conversion factors may affect the accuracy of estimations. Therefore, seat belt effectiveness values based on KABCO injury scale would be very useful in State level safety studies to estimate benefits associated with seat belt usage.

Second, most of the available seat belt effectiveness values have not been updated with more recent crash data, especially for nonfatal injuries. For example, the latest updates to the NHTSA's seat belt effectiveness values for nonfatal injuries were made based on crash data from 1988 to 1997. However, vehicle designs and features have significantly changed during recent years and therefore the injury risks face by occupants who were involved in crashes while travelling in such vehicles may be different from injury risks faced by occupants travelling in older vehicles. Therefore, assessment of the available seat belt effectiveness values using more recent crash data is an important requirement.

Additionally, the available seat belt effectiveness values have been estimated based on national data and thus represent average conditions. However, the prevailing conditions in a particular State may differ from national conditions. For example, rural highways account for 91% of total highway mileage in the State of Kansas and about 50% of vehicle miles travelled on those highways compared to only 16% of vehicle miles travelled on all U.S. rural highways (FHWA, 2007). Crashes on rural highways could be more severe compared to crashes on urban highways which have comparatively lower speed limits compared to rural highways. This may be reflected by the fact that rural highways accounted for about 68% of fatal crashes in year 2006 (KDOT, 2007). In addition, the distribution of crash types on rural and urban highways could also be different from State to State. In Kansas, single vehicle crashes account for about 33% of total rural highway crashes while about 85% of urban crashes are related to crashes involving two or more vehicles. Majority of the single vehicle crashes on rural highways are related to collisions with fixed objects after running off the road. In addition, rural highways account for significant amount of rollover crashes compared to urban highways. Therefore, the impact forces on vehicles due to crashes could be different in crashes on rural and urban highways.

Distribution of different vehicle types on roadways and the different use patterns of those vehicles is also an important factor in assessing the injury risk for occupants involved in crashes. Latest vehicle models are equipped with more advanced safety features such as side and passenger air bags compared to older vehicles. On the other hand, some of the latest economical vehicle models such as compact cars or family size-sedans may not be as protective as those heavy vehicle types such as SUVs, minivans and pickup trucks. The use pattern of these different vehicle types may also be different from place to place and will result in different crash patterns. For example, some vehicle models such as SUVs and pickup trucks may be driven more frequently on rural highways and involve in single vehicle crashes compared to other passenger vehicle types.

Different methodologies are available to estimate seat belt effectiveness in reducing injuries to motor vehicle occupants. However, the applicability of those methods under different conditions has hardly been studied. Double-pair comparison method and logistic regression method are the most commonly applied methods to estimate seat belt effectiveness. In double pair comparison method, injury risks for a subject occupant is compared with the corresponding risks for other occupant in the same vehicle, who is considered as the control occupant, under two different conditions: restrained and unrestrained. Therefore, this method is only applicable to cases where there are at least two occupants in the same vehicle and at least one of them was injured due to the crash. Thus, the application of this method in situations where majority of the involved vehicles are occupied by only one occupant may lead to biased estimations of seat belt effectiveness. For example, in Kansas, during the 10 year period from 1993 to 2002, out of all vehicles involved in crashes, only 23% were occupied by more than one occupant and this proportion further reduced to 16% when vehicles with no reported occupant injuries were excluded.

The distribution of vehicle occupancy is also an important factor in assessing injury risks to a particular occupant, especially when there are unrestrained occupants in the vehicle. Many studies have found that the presence of an unrestrained occupant in the vehicle increases the injury risks for a restraint occupant in the same vehicle (Cummings et al. 2004, Evans, 1998, Mayrose et al., 2005, MacLennan et al., 2004). In case of a head-on crash, a rear-seat unbelted occupant who is sitting right behind the driver could significantly increase the injury risks for the driver (Mayrose et al., 2005).

In logistic regression method, the injury risk for a restrained occupant is compared with the corresponding injury risk for an unrestrained occupant while considering the effects of other explanatory variables. Therefore, the accuracy of estimated seat belt effectiveness values is dependent on the quality of the fitted model and thus on the significance of selected explanatory variables. Therefore, when the availability of data related to significant explanatory variables is limited, the application of this method to estimate seat belt effectiveness might result in inaccurate estimations. Similarly, other methods that are used to estimate seat belt effectiveness may also have different issues when applying under different conditions.

Thus, selection of a suitable method to estimate seat belt effectiveness that best suits the conditions prevailing in a particular State should be based on proper evaluation of each methodology. Cummings et al. (2003) examined some of the methods used to estimate seat belt effectiveness using fatal crash data. However, none of the previous studies have carried out a comprehensive analysis based on every methodology using crash data for all the injury severity levels.

Considering the above facts, it can be seen that the use of available nationally estimated seat belt effectiveness values to estimate economic benefits based on Kansas data would result in biased and inaccurate estimations. Thus, it would be more appropriate to use seat belt effectiveness values estimated based on Kansas crash data in such economic analyses. In addition, seat belt effectiveness values estimated based on KABCO injury severity scale would be a useful source of information for other States as well where the State highway crash databases are based on the same injury severity scale.

1.3 Objectives

The prime objective of this study was to develop a methodology to estimate potential benefits associated with increased seat belt usage by Kansas motorists based on conditions prevailing in the State of Kansas. A two-phased estimation procedure was used to achieve the objective. In the first phase, seat belt effectiveness was estimated based on KABCO injury severity scale using different available methodologies and the results were compared. In the second phase, the economic benefits that could be expected due to reduction in injuries as a result of increased seat belt usage were estimated. The following main activities were employed in achieving the objectives of the study.

- Identify different methodologies available to estimate seat belt effectiveness.
- Use the identified methodologies to estimate seat belt effectiveness using crash data for the State of Kansas.
- Compare the results from each method and identify limitations and weaknesses of each method.

- Estimate potential injury reductions due to increased seat belt usage using the seat belt effectiveness values estimated in the previous steps.
- Obtain costs associated with different injury severities.
- Estimate economic benefits due to increased seat belt usage by converting injury reductions estimated in previous steps into economic values.

CHAPTER 2 - LITERATURE REVIEW

2.1 Seat Belt Effectiveness

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, the effectiveness of lap/shoulder belts in preventing fatalities was about 40-50 % and seat belts were 45-55 % effective in reducing nonfatal injuries. When lap/shoulder belts were combined with air bags, the estimated effectiveness was 45-55 % for fatalities and 50-60% for nonfatal injuries. However, the seat belt effectiveness was not controlled for possible effects of other factors in this study due to the insufficient availability of crash data during the study time period.

NHTSA later conducted series of studies to evaluate the above estimated seat belt effectiveness values using more recent crash data 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 of this series, considering the seat belts alone, the effectiveness of seat belts in preventing fatalities is 45% (manual-shoulder belts) and 60% in preventing non-fatal injuries(moderate to greater injuries), which are similar to the original estimations (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. 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 report, Walker addressed the application of logistic regression method in different aspects such as 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 the effects of many variables such as occupant characteristics (age, gender), occupants' seating position (driver, passenger), location of crash (rural, urban), crash type, speed limit, etc. The injury severity was considered in 4 different levels: died (level 1), died or inpatient (level 2), died, inpatient, or transported (level 3), and any injury (level 4). They found that seat belts are 89% effective in preventing fatalities (level 1) and 52% effective for any injury (level 4). Authors also discussed the effect of over-reporting of seat belt usage 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 variables 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 from 1993 to 1996 against fatalities and injuries, which had an AIS score of 2 or higher. The results indicated that effectiveness of automatic shoulder belts alone (without lap belt) reduces the fatality risk by 29% in frontal crashes and 34% reduction in all 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 (1986 a), 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 for a subject occupant to the corresponding risk for other occupant, which is the control group, under two conditions: restrained and unrestrained.

The double pair comparison method has been applied by many researchers to estimate seat belt effectiveness. Evans (1986 b) used this method to estimate 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 this study, the other occupant was disaggregated by age and seating positions 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 estimations showed that the average restraint effectiveness against fatalities for rear seat passengers (left and right passengers only) is between 9 to 27 %. Evans and Frick (1986c) 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.

Kahane (2000) applied the double pair comparison method to examine the appropriateness of NHTSA's long-standing estimates of seat belt effectiveness values, which were based on FARS data before 1986, for more recent FARS data. An empirical tool was developed to adjust for double pair analyses of later FARS data from 1986 to 1999. Results reconfirmed the NHTSA's earlier effectiveness estimates of 45% for passenger cars and 60% for light trucks against fatalities.

Kahane (1987) estimated the fatality and injury reducing effectiveness of lap belts for back seat occupants using double pair method. In this study the subject occupant was considered as the backseat passenger and the other occupant was the driver. The effectiveness was estimated against fatalities alone and other injury severity levels. These injury severity levels were classified as, serious injuries (category "A" in KABCO scale and fatal), moderate to serious (categories "A", "B" and fatalities), and overall injury severity (including all injury severities). Based on FARS data from 1975 to 1976, the estimated lap belt effectiveness against fatalities for back seat occupants was 17 to 26 %. For other injury severities, the effectiveness values were estimated using crash data from Pennsylvania for 1982 to 1985. The estimated effectiveness against serious injuries was 37% while lap belts are 33% effective against moderate to serious injuries. The lap belt effectiveness against any severity was found to be 11%.

To estimate the effectiveness of seat belts in preventing fatal injuries to rear-seat passengers, Morgan (1999) uses the double pair comparison method. One of the main objectives of the study was to compare the effectiveness of lap belts with the combination of lap and shoulder belts when worn by rear-seat passengers. The subject group was the rear-seat passengers (both restrained and unrestrained) while the control group was the front seat passengers. The subject group was considered in three categories: lap belted, lap/shoulder belted, and unbelted, while the control group had only two groups: lap/shoulder belted and unbelted. Data from FARS database for the period from 1988 to 1997 was used in the analysis. The results showed that lap belts alone are 32% effective in reducing fatal injuries to rear-seat passengers while combination of lap and shoulder belts are 44% effective against fatalities in passenger cars. In passenger vans and sports utility vehicles (SUV) the corresponding effectiveness values were found to be 63% and 73%. The study also found that the combination of lap and shoulder belts are 15% more effective than lap belts alone in all crashes.

Cummings et al. (2003) 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, the double pair comparison method and some regression analysis techniques such as conditional Poisson regression, conditional logistic regression, and Cox proportional hazards regression were used to estimate the relative risk of front seat passengers. Based on results from several simulations using each method, authors have concluded that conditional Poisson regression and Cox proportional hazards regression can produce unbiased estimates, but consideration of interaction terms between seat position and vehicle or crash characteristics may require.

Cummings et al. (2003) used Conditional Poisson regression method to study 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 1988 to 2000, which 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, since both estimated values were equal (relative risk of 0.36).

Conditional logistic regression method is commonly used in case-control studies to estimate the effect of selected covariates on the presence of an outcome. In traffic crashes, this method can be applied to estimate the effect of using a seat belt on the injury severity to a motorist after involving in a crash. The method estimates the odds ratio between restrained and unrestrained occupants by considering two occupants in the same vehicle or in two different vehicles. Crandall et al. (2001) used conditional logistic regression method to estimate effectiveness of air bags and seat belts in reducing fatal injuries to occupants involved in head-on crashes. This study considered only those cases which involved two vehicles and estimated the odds ratios by comparing injury risks for the two drivers of the vehicles. The effects of variables such as driver characteristics (age, gender), ejection due to the crash, and vehicle age were considered in the analysis. They found that, the combination of air bag deployment and wearing a seat belt could reduce the driver's risk of fatally injuring by 80%.

Greenland (1994) used an estimating equation approach to estimate effectiveness of motorcycle helmets in preventing fatal injuries to motorcycle riders using FARS data. Injury risk ratios for two riders on the same motorcycle were estimated while controlling for the effects of rider characteristics such as age, gender, and riding position. Thus, the method is based on matched-pair analysis techniques and it is very similar to conditional logistic regression method (detailed discussions on these methods are provided in chapter 3 of this dissertation). However, the advantage of this method is information from double death pairs (cases where both driver and passenger died) can be utilized in the estimation process unlike in conditional logistic regression method where double-death pairs are omitted.

By replacing the two motorcycle riders with two front seat occupants of a motor vehicle, this method can be applied to estimate seat belt effectiveness for motor vehicle occupants. Although, Rice and Anderson (unpublished manuscript, 2007) used this method to estimate seat belt effectiveness in preventing fatal injuries using FARS data, there is no published literature available on this study. Apart from that study, this method has not been applied by any studies to estimate seat belt effectiveness in preventing injuries to motor vehicle occupants.

Based on the literature review it can be seen that mainly two types of methods have been applied to estimate seat belt effectiveness. Those methods can be categorized as matched-pair comparison techniques and regression methods. In matched-pair analysis methods, relative risk between two occupants who are under two different conditions (restrained and unrestrained) but in the same vehicle, is estimated. Thus, these methods use pairs of observations in the estimation process. Methods fallen into this category include double pair comparison method, Cox proportional hazards regression, conditional Poisson regression, conditional logistic regression, and estimating equation approach. The other category includes regression methods, which consider each occupant individually irrespective of the vehicle they travel and estimates the relative risk under restrained and unrestrained conditions. This category includes logistic regression method. Out of all these methods, double pair comparison and logistic regression methods are the most commonly used methods to estimate the effectiveness of seat belts.

Although many studies have estimated seat belt effectiveness in preventing fatal injuries, there have been very few studies that have estimated seat belt effectiveness in reducing nonfatal injuries. This may be mainly due to the significantly higher impacts involved with a fatality compared to a nonfatal injury. However, the impacts of nonfatal injuries may also become very significance in some cases. For example, impacts due to disable injury (incapacitating injury) could also be considered as significant as the impacts of a fatality. Therefore, preventing nonfatal injuries is also as important as preventing fatal injuries.

2.2 Benefits of Seat Belt Usage

Safety benefits associated with 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 current fatality and injury incidence, seat belt usage rates in current and future time periods, lives and injuries prevented by increased use of seat belts, and finally the economic savings resulted from improvements (increased belt usage). This procedure has been widely used by many highway agencies in analyzing seat belt benefits and National Highway Traffic Safety Administration (NHTSA) has developed a software program called MVS based on the above algorithms for easy calculations. The above procedure was used to estimate the benefits of seat belts in this study and more detailed discussion of the method can be found in the following sections of this chapter.

Blincoe et al. (2002) used the above procedure to estimate the economic savings due to seat belt use and the economic loss due to not wearing them in their study to estimate the economic impact of motor vehicle crashes. In this study, they estimated the cost of different injury severities resulted from a motor vehicle crash based on Abbreviated Injury Scale (AIS). In estimating comprehensive costs resulted from motor vehicle crashes, the authors estimated two types of costs, economic costs and costs due to the intangible consequences of the crash incidences. The 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 while non-injury component included the costs related to travel delay and damage to the property. The value of intangible consequences was then added to the economic costs to obtain comprehensive costs. According to the comprehensive cost estimations, the cost of a fatality is about \$3.4 million and it decreases with the decrease of injury severity. These values were used in this study to estimate seat belt benefits and more details of those cost values can be found in the chapter three of this report.

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. They found that, the annual safety costs for an unrestrained occupant are five times the safety costs for a restrained occupant. In addition, the 13% of unrestrained occupants accounted for 42% of the crash costs, and if these unrestrained occupants buckle up, the medical costs would decline by 18% (\$ 4 billion annually) and the comprehensive costs 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 longer-term direct medical costs resulted from severe injuries such as traumatic brain injuries and spinal cord injuries. The data was obtained from the Kentucky Hospital Discharge Database (HIDD) for 2002 to 2004 and Kentucky's Crash Outcome Evaluation System (CODES). The medical costs were considered in two categories, medical costs for the first year after injuries and costs for the subsequent years. The analysis was based on the assumption that if Kentucky reaches its seat belt usage rate to the national average level of 80% due to legislation of a primary law in year 2006, then how much savings from medical costs could be achieved during the period of 2006 to 2015. Using CODES data, a weighted seat belt effectiveness value in preventing moderate to critical injuries based on different vehicle types was estimated for Kentucky conditions and that value was 55%. Authors found that, it would result in at least $118 million savings in direct medical costs during the considered period of time due to a legislation of a primary seat belt law in Kentucky.

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 involved in motor vehicle crashes. The study found that the average hospital cost for an unrestrained occupant during the 3 year period considered was $ 24,419 while that cost for a restraint occupant was$19,952 only. The total medical costs during the same period of time were $21.8 million and $15.8 million 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. The study was based on two data sources, data from Crash Outcome Data Evaluation System (CODES) for the period of 1998 to 1999 and trauma data for 1999 from South Carolina’s Level I trauma centers. In addition to comparing hospital charges, the study also investigated the relationship between restraint usage and insurance status. According to analysis results based on CODES data, the average inpatient hospital charges were 25% greater per admission for an unrestrained compared to restrained occupant. The trauma data showed similar trends but more significant difference as 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 the self-payers and Medicaid recipients while restrained occupants were more commonly 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 in 1987 and total dataset included 613 motor vehicle crash victims. According to the analysis results, hospitalization was more frequently required for unrestrained crash victims and the length of stay was longer for such occupants. Unrestrained victims were more often males and younger than restrained victims. The mean Injury Severity Score (ISS) for unrestrained victims were significantly higher than that for restrained victims. Unrestrained victims had significantly higher mean hospital charges compared to restrained victims. The unrestrained group was predominated 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 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 reduce total number of injuries by 34%, major injuries by 57% and minor injuries by 20%. The average hospital cost for an unrestrained driver was almost double as that for a restrained driver ($19,414 vs. $ 38,845). In addition, mean ISS and length of stay was also significantly higher for unrestrained drivers.

Rutledge et al. (1993) studied the effect of seat belt usage on outcome in 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. In addition, seat belt usage was associated with a significant decrease in mortality rate and overall, seat belts could have saved at least 74 lives and 7.2 million dollars during the study period.

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 data sample consisted of 997 records for injured motor vehicle occupants treated at 11 Iowa hospitals and the study period was from 1987 to 1988. According to results, injuries were more serious for unrestrained occupants and more fatalities and cases of permanent disabilities occurred among unrestrained occupants. The nonuse of seat belts was associated with higher hospital charges in nearly all age, sex, and vehicle speed categories. They also estimated that the lifetime direct and indirect savings from Iowa's safety belt law for motorists injured in one year was $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 (at least 65 years of age) extracted from Rhode Island Hospital database, which is an urban, academic, Level I trauma center. The study period was two years from 1997 to 1999. They found that unrestrained occupants were more likely to require hospitalization and hospital charges for unrestrained group is significantly higher than that for restrained occupants.

Allen et al. (2006) conducted a comprehensive statewide analysis in Wisconsin to investigate the association of failure to use seat belts with injury patterns, injury severity, and in-patient hospital admission among adults (aged 16 years or older) presenting 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 they were younger than restrained occupants. In addition, unrestrained occupants accounted for 68% of the patients dying in the ED and they only accounted for 20% of patients treated in the ED and discharged.

CHAPTER 3 - ESTIMATION OF SEAT BELT EFFECTIVENESS

3.1 Introduction

Based on the information from the literature review, this study used five different methods to estimate seat belt effectiveness in reducing injuries. These methods include multiple logistic regression, double pair comparison method, conditional logistic regression, Cox proportional hazards regression, and estimating equation approach. The selection of these methods was based on two major reasons. First, the selected set of methods includes at least one method from the two categories of estimation techniques mentioned earlier (i.e. regression and matched-pair analysis methods). Second, the rational behind the estimation techniques and the assumptions are different for each method. The following sections provide detailed discussion of the crash data used to estimate seat belt effectiveness and the estimation procedures of each selected method.

3.2 Data

This study utilized highway crash data from Kansas Accident Reporting System (KARS) database for all the estimations. Data related to vehicles which were involved in crashes between 1993 and 2002 were extracted from the database. Three passenger vehicle types were initially selected for the analysis: passenger cars, vans, and pickup trucks. Since the data availability for occupants in vans was limited, especially for cases with fatal injuries, pickup trucks and vans were combined and considered as a single vehicle group. Thus, the final estimations were based on two vehicle groups: passenger cars and other passenger vehicles.

In general, in case of a crash, occupants in front seats are at higher risks for sustaining severe injuries compared to back seat passengers, especially by being ejected out of the vehicle when unrestrained. In addition, the proportion of back seat passengers was significantly low compared to front seat occupants and in many cases, only front seat occupants are targeted by seat belt laws. Therefore, seat belt effectiveness was estimated only for front seat occupants in the selected vehicle groups. Occupants younger than 15 years of age were discarded from the selected dataset since Kansas has a primary seat belt law for that age group compared to a secondary seat belt law for adult occupants (15 years or older). In addition, data related to crashes involving pedestrians, bicyclists, motorcycles, and trains were also discarded.

In KARS database, information related to seat belt usage by occupants is reported in 5 categories: both shoulder and lap belt, only shoulder belt, only lapbelt, none-used, and usage unknown. Records with unknown restraint uses were discarded from the selected dataset. Occupants who belonged to one of first three categories were considered as restrained occupants (seat belt used) while others were considered as unrestrained occupants. Information related to air bag deployment due to crash was not available in the KARS database and therefore the effect of air bags on seat belt effectiveness could not be considered in the analysis.

In KARS data, the injury severity of occupants involved in crashes is reported using KABCO injury scale. The severity of a crash was defined based on the highest reported injury severity sustained by an involved occupant. For example, if at least one of the involved occupants was fatally injured due to a crash then that crash was treated as a fatal crash. Based on this criterion, the total crash dataset included data related to five different crash categories: fatal, incapacitating, non-incapacitating, possible, and PDO crashes. It may be reasonable to assume that occupants involved in each of these crash types are under different levels of risks to sustain injuries with particular injury severity. For example, two occupants, who are recorded to have the same personal injury severity but involved in two different crash types with different severities, may not be under the same level of risk. Thus, by considering these two occupants in two different crash categories would minimize biases in estimated seat belt effectiveness values.

Therefore, the total dataset was split into 5 different datasets based on crash severity. Table 3.1 shows the details of front seat occupants involved in different crash types and their seat belt usage. It can be seen that seat belt usage among occupants involved in fatal crashes is significantly lower compared to seat belt usage among occupants in nonfatal crashes. In nonfatal crashes, seat belt usage among drivers is higher compared to that of front seat passengers. Majority of the occupants were restrained with both lap and shoulder belts in all types of crashes.

Since there were no injuries involved in PDO crashes, the dataset related to PDO crashes was discarded. Finally, 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 severities except fatalities, the incapacitating category had 3 injury types, and the possible injury crashes contained occupants with minor injuries and unharmed (no injuries) occupants. These datasets were then used to estimate seat belt effectiveness in reducing different injury severities by using the different methodologies mentioned earlier.

Table 3.1 Seat Belt Usage by Front Seat Occupants Involved in different Crash Types on Kansas Highways

Crash Type (Severity)	Occupant	Type of Seat Belt Used					Total	% Seat Belt Usage
		Lapbelt Only	Shoulder belt only	Lap & Shoulder belts	Total Used	None Used		
Fatal Crashes	Driver	30	15	1,637	1,682	2,417	4,099	41
	Front Right Passenger	12	4	574	590	825	1,415	42
	Total	42	19	2,211	2,272	3,242	5,514	41
Incapacitating Crashes	Driver	309	46	13,440	13,795	7,685	21,480	64
	Front Right Passenger	82	15	3,826	3,923	2,833	6,756	58
	Total	391	61	17,266	17,718	10,518	28,236	63
Non-incapacitating Crashes	Driver	2,279	171	84,232	86,682	26,838	113,520	76
	Front Right Passenger	538	57	21,698	22,293	9,998	32,291	69
	Total	2,817	228	105,930	108,975	36,836	145,811	75
Possible Crashes	Driver	2646	191	122,802	125,639	18,140	143,779	87
	Front Right Passenger	558	34	29,912	30,504	6,429	36,933	83
	Total	3,204	225	152,714	156,143	24,569	180,712	86
No Injury Crashes (PDO)	Driver	11,200	537	554,561	566,298	55,683	621,981	91
	Front Right Passenger	2,720	115	139,596	142,431	18,946	161,377	88
	Total	13,920	652	694,157	708,729	74,629	783,358	91

Note: Frequencies are based on the total dataset for the period from 1993 to 2002

3.3 Logistic Regression Method

3.3.1 Introduction

The logistic regression method estimates odds ratios between restrained and unrestrained occupants while controlling for the effects of other variables. Occupants are considered for the analysis irrespective of the vehicles in which they were sitting at the time of the crash. In other words, this method does not consider the effects of differences in factors associated with each vehicle (or between-vehicle effects) although occupants in different vehicles could be under the influence of effects of different factors.

3.3.2 The Method

The response variable of the logistic regression model is the injury severity of an occupant, which is considered as a binary variable. For example, in the model for fatal injuries, the response variable takes value 1 if the occupant was fatally injured and value 0 otherwise. If, the conditional probability that an occupant is injured with a particular level of severity is denoted by $\mathrm{P}(Y = 1 \mid X) = \pi(X)$ for a given set of *m* covariates (i.e. $X = x_1, x_2, x_3 \ldots x_m$), then the multiple logistic regression model can be written in the following form (Hosmer et al., 2000, Agresti, 2002);

$$logit\,[\pi(X)] = log\left(\frac{\pi(X)}{1-\pi(X)}\right) = \alpha + \sum_{i=1}^{m} \beta_i X_i \tag{3.1}$$

and,

$$\pi(X) = \frac{e^{[\alpha + \sum_{i=1}^{m} \beta_i X_i]}}{1 + e^{[\alpha + \sum_{i=1}^{m} \beta_i X_i]}} \tag{3.2}$$

where,

α, β = Regression parameters to be estimated

The regression parameters were estimated using maximum likelihood method. The likelihood function for the logistic regression model can be written in the following form;

$$L = \Pr(y_{1,} y_{2,} \ldots y_n) = \prod_{i=1}^{n} \left(\frac{\pi(X_i)}{1-\pi(X_i)}\right)^{y_i} [1 - \pi(X_i)] \tag{3.3}$$

where,

L = Likelihood of observing the outcome for all the observations

y_i = Outcome of the i^{th} observation

n = Total number of observations (sample size)

The logarithmic form of the likelihood equation can be written in the following form;

$$logL = \sum_{i=1}^{n} y_i \left(\frac{\pi(X_i)}{1-\pi(X_i)} \right) + \sum_{i=1}^{n} [1-\pi(X_i)] \tag{3.4}$$

The equation (3.4) is called the log-likelihood function and the regression parameters are estimated by maximizing the log-likelihood function.

Consider a dichotomous explanatory variable, x which takes value 1 and 0 representing two different conditions of the occupant. The odds ratio for this particular variable can be defined as the ratio between odds for outcome (injury severity) being present when x=1 and x=0. This can be expressed in the following formula;

$$OR = \frac{\pi(1)/[1-\pi(1)]}{\pi(0)/[1-\pi(0)]} \tag{3.5}$$

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). Then, 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, and 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,

$$E = (1 - OR) * 100 \tag{3.6}$$

where,

E = Effectiveness of the restraint system (%)

OR = Odds Ratio between restrained and unrestrained occupants for a given injury severity level

To asses the quality of the fitted logistic regression models several statistics were estimated. The coefficient of determination or the R^2 of the logistic regression method can be estimated as follows (Cox and Snell, 1989);

$$R^2 = 1 - \left[\frac{L(0)}{L(\hat{\beta})} \right]^{\frac{2}{n}} \tag{3.7}$$

where,

$L(0)$ = Likelihood for the model with no explanatory variables

$L(\hat{\beta})$ = Likelihood for the fitted model with explanatory variables

However, above R^2 value achieves a maximum of less than one (0.75) for models with binary response variables. For those cases, Nagelkerke (1991) proposed the following adjusted R^2 value, which could achieve a maximum value of one.

$$\overline{R}^2 = \frac{R^2}{R^2_{\max}} \tag{3.8}$$

where,

$\overline{R}^2$ = Adjusted R^2

$R^2_{\max}$ = Maximum R^2 (0.75)

Another set of statistics are estimated based on the association between predicted probabilities using the fitted model and the observed responses. First, the observed responses are paired up and those pairs with both responses are either 1 or 0 are removed. Then, the remaining set pairs include one case with response 1 and other case with response 0. If, the case with a response of 1 has a higher predicted probability than the case with a response of 0 then such a pair is called a concordant pair. If the reverse is true for a pair, it is called a discordant pair while pairs for which both probabilities are equal are called ties. For a given data set, assume that the number of concordant pairs is C, number of discordant pairs is D, number of ties is T, and the total number of pairs is N. Using these numbers the following statistics are estimated.

$$Tau - a = \frac{C - D}{N} \tag{3.9}$$

$$Gamma = \frac{C - D}{C + D} \tag{3.10}$$

$$Somer's\ D = \frac{C - D}{C + D + T} \tag{3.11}$$

$$c = 0.5\ (1 + SSomer's\ D) \tag{3.12}$$

The values of these statistics vary between 0 and 1. If the estimated values for the above statistics are large that implies a strong association between the predicted and observed values. In general the statistic Tau-a is closed to the adjusted R^2.

To test the goodness of fit of the model several goodness-of-fit statistics were used. These statistics included a statistic estimated based on the log-likelihood of the model (-2 X log-likelihood or -2 Log L), Akaike's information criterion (AIC), and Schwartz Criterion (SC). Lower values of these statistics indicate a better fit of the model for the selected set of explanatory variables. A statistic called likelihood ratio chi-square was used to test the null hypothesis that all the estimated coefficients are zero (or the global null hypothesis). It is estimated by taking the difference of twice the log-likelihood for the fitted model and the log-likelihood for the model with no covariates. If this value is significant under selected level of significant that leads to reject the null hypothesis to conclude that the explanatory variables are not equal to zero.

The response variable (injury severity) of a logistic regression model for a particular crash category was coded as follows. The response variable takes value 1 for all the occupants who sustained highest injury severity in the considered crash category, while value 0 is assigned to the response variable for occupants with all other injury severities. For example, in the case of a fatal crash, the response variable takes value 1 for all occupants with fatal injuries, and it takes value 0 for occupants with nonfatal injuries. Total of four different models were developed for each injury severity level using the 4 datasets mentioned earlier.

The selected candidate variables and their representation in the models are shown in Table 3.2. 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 was 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 the KARS database does not have accurate data on those variables. Due to the importance of controlling for those two variables in the models, posted speed limit was used as a surrogate measure of the actual vehicle speed. Even though it was not possible to directly consider the effect of vehicle mass on seat belt effectiveness, it was assumed that this effect would be minimized up to some extent since the models were developed for different vehicle groups.

Table 3.2 Selected Candidate Variables for Logistic Regression Models

Variable	Mean	Standard Deviation	Description
ALCOHOL	0.04	0.19	=1 if the driver was under influence of alcohol or drugs, =0 otherwise
ANGLE_CRASH	0.40	0.49	=1 if the vehicles collided in an angular manner, =0 otherwise
ARTERIAL	0.62	0.49	=1 if the crash occurred on an arterial roadway, =0 otherwise
COLLECTOR	0.12	0.33	=1 if the crash occurred on a collector, =0 otherwise
DR_AT_FLT	0.46	0.50	=1 if the driver was at fault for the crash, =0 otherwise
DRIVER	0.78	0.41	=1 if the considered occupant was the driver, =0 otherwise
HDON_CRASH	0.03	0.16	=1 if the vehicles collided head-on, =0 otherwise
INTERSTATE	0.11	0.32	=1 if the crash occurred on an interstate, =0 otherwise
INTR_SECN	0.53	0.50	=1 if the crash occurred at an intersection, =0 otherwise
LIGHT_CON	0.25	0.43	=1 if crash happened in dark or unlit conditions, =0 otherwise
OCC_AGE	35.04	17.48	Age of the occupant in years
OCC_EJECT	0.01	0.08	=1 if occupant was ejected due to the crash, =0 otherwise
OCC_MALE	0.5	0.5	=1 if the occupant was male, =0 otherwise
OCC_TRAPPED	0.01	0.10	=1 if occupant was trapped inside the vehicle, =0 otherwise
POSTED_SPEED	40.7	12.18	Posted speed limit in mph
RD_CUR_GRAD	0.27	0.44	=1 if roadway was not straight and level, =0 otherwise
REAREND_CRASH	0.38	0.49	=1 if the vehicles collided rear-ended, =0 otherwise
RURAL	0.23	0.42	=1 if the crash occurred in a rural area, =0 otherwise
SB_USED	0.82	0.39	=1 if the passenger was restrained, =0 otherwise
SNG_VEH_CRASH	0.15	0.35	=1 if only one vehicle was involved, =0 otherwise
URBSP	0.13	0.18	=1 if there was at least one unrestrained passenger on the rear seat, =0 otherwise
VEH_AGE	8.18	10.27	Age of the vehicle in years
VEH_AT_FLT	0.01	0.11	=1 if the vehicle was at fault for the crash, =0 otherwise
VEH_DESTROY	0.09	0.28	=1 if the vehicle was destroyed due to the crash, =0 otherwise
VEH_DISABLED	0.41	0.49	=1 if the vehicle was disabled due to the crash, =0 otherwise
VEH_STRAIGHT	0.58	0.49	=1 if the vehicle was traveling straight before crash, =0 otherwise
VEH_TURN	0.13	0.34	=1 if vehicle was making a turn before crash, =0 otherwise
WET_RD_SURF	0.21	0.41	=1 if the crash occurred on a wet road surface, =0 otherwise

Note: The means and standard deviations are based on the total data set

Logistic regression models were developed using LOGISTIC procedure of SAS software (SAS Institute Inc., 2004). One of the requirements that need to be satisfied when developing a logistic regression model is to make sure that multicollinearity does not occur in the model. Multicollinearity occurs when there are strongly correlated explanatory variables in the model. The problem with multicollinearity is that it is difficult to estimate the independent effects of those variables on the outcome (Allison, 1999). However, multicollinearity does not bias the estimated coefficients although it makes them unstable and more importantly the effects of multicollinearity only apply to those variables that are collinear in the model (Allison, 1999).

To diagnose the multicollinearity, the procedure suggested by Allison (1999) was used. First step in the procedure is to estimate the correlation coefficients of the selected explanatory variables. To compare the correlation between two variables (x and y) the Pearson product-moment correlation coefficient was estimated using the following equation;

$$r_{xy} = \frac{\sum_{i}^{n}((x_i - \bar{x})(y_i - \bar{y}))}{\sqrt{\sum_{i}^{n}(x_i - \bar{x})^2 \sum_{i}^{n}(y_i - \bar{y})^2}} \tag{3.13}$$

where,

r_{xy} = Pearson product-moment correlation coefficient

$\bar{x}$ = Mean of variable x

$\bar{y}$ = Mean of variable y

n = Sample size

The values of r_{xy} varies from -1 indicating a strong negative correlation between the two variables to 1 indicating a strong positive correlation. The correlation coefficients were estimated using CORR procedure of the SAS software (SAS Institute Inc., 2004). Although there is no strict cutoff, explanatory variables with an estimated correlation coefficient greater than 0.5 was identified as variables which are suspected to have multicollinearity effects. If such variables were found, the next step was to estimate the regression parameters using a linear regression model and estimate some diagnostic statistics. These statistics are called tolerance and Variance Inflation Factor (VIF) which is the reciprocal of tolerance. To estimate the tolerance for a particular variable, a linear regression model is developed with the selected variable as the dependent variable and other variables as explanatory variables and estimates the coefficient of determination R^2. Assume that for the explanatory variable x_i, the estimated coefficient of determination is R_i^2. The tolerance and VIF for the variable x_i, is estimated as follows;

$$tolerance = (1 - R_i^2) \text{ and } VIF = \left(\frac{1}{tolerance} \right) \tag{3.14}$$

If the estimated tolerance values for those suspected variables identified in the first step were very low (less than 0.40) then such variables were identified as highly correlated variables (Allison, 1999).

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 added one at a time based on the given level of significance. Once a variable is added, its significance into the model is checked with the variables which are already in the model. If the variable does not meet the given significance level, it is dropped from the model. The advantage of this method is that it selects the best model with the most significant variables towards the outcome.

3.3.3 Results

The model fitting information and the estimated logistic regression model parameters for fatal injuries based on passenger car occupants are shown in Table 3.3 and Table 3.4. As indicated in Table 3.3, the *AIC*, *SC*, and *-2 Log L* statistics for the fitted model with the selected explanatory variables are significantly lower than those values for the model without any covariates indicating a better fit of the model. The estimated *Sommer's D*, *Gamma* and *c* statistics have considerably higher values indicating a good prediction capability of the model. In addition, the model has an R^2 value of 0.42 which could be considered as reasonably higher. It should be noted that though the R^2 of the logistic regression model behaves quite similar to that value of a linear regression model, the same interpretation (i.e. the proportion of variation explained by the explanatory variables) cannot be applied to the logistic R^2. The estimated value of likelihood Ratio chi-square statistic is significant with degrees of freedom of 10. This leads to reject the null hypothesis that all the regression parameters could be zero in the model.

As shown in Table 3.3, total of 10 variables are significant in the model under 0.05 level of significance. The estimated regression parameter for the variable related to seat belt usage is -0.83 with an estimated standard error of 0.098. Since the estimated parameter is negative, it implies that when the restraint condition of the occupant changes from belted to unbelted, the risk of being fatally injured tend to reduce. This is reflected by the estimated odds ratio as it is less than one. In other words, the odds for a restrained occupant to be fatally injured are 0.44 times the odds for an unrestrained occupant to be fatally injured. The interpretation of estimated parameters for other variables is similar. Based on the estimated odds ratio, the seat belt effectiveness for fatal injuries in passenger cars is 0.56 (1-0.44) or 56%.

Table 3.3 Statistics for Assessing the Goodness-of-fit of the Model for Fatal Injuries based on Passenger Car Occupants

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	4465.64	3259.95
SC	4471.73	3326.94
-2 Log L	4463.64	3237.95

Association of Predicted Probabilities and Observed Responses

Percent Concordant	83.0	*Somers' D*	0.662
Percent Discordant	16.8	*Gamma*	0.663
Percent Tied	0.2	*Tau-a*	0.325
Pairs	2,612,637	*c*	0.831

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	p Value
Likelihood Ratio	1225.69	10	<.0001
Score	1076.46	10	<.0001
Wald	795.28	10	<.0001

Adjusted R^2 0.42

Table 3.4 Estimated Logistic Regression Parameters for Fatal Injuries based on Passenger Car Occupants

Variable	Estimated Parameter	Standard Error	Ch-square	p Value	Odds Ratio
ALCOHOL	-	-	-	-	-
ANGLE_CRASH	-	-	-	-	-
ARTERIAL	-	-	-	-	-
COLLECTOR	-	-	-	-	-
DR_AT_FLT	0.50	0.094	28.22	<.0001	1.65
DRIVER	0.64	0.096	44.84	<.0001	1.90
HDON_CRASH	-	-	-	-	-
INTERSTATE	-	-	-	-	-
INTR_SECN	-0.30	0.104	8.17	0.0043	0.74
LIGHT_CON	-	-	-	-	-
OCC_AGE	0.03	0.0023	231.13	<.0001	1.04
OCC_EJECT	1.68	0.135	153.43	<.0001	5.35
OCC_MALE	-	-	-	-	-
OCC_TRAPPED	1.96	0.104	354.63	<.0001	7.07
POSTED_SPEED	-	-	-	-	-
RD_CUR_GRAD	-	-	-	-	-
REAREND_CRASH	-	-	-	-	-
RURAL	-	-	-	-	-
SE_USED	-0.83	0.098	71.82	<.0001	0.44
SNG_VEH_CRASH	0.34	0.112	8.98	0.0027	1.40
URBSP	-	-	-	-	-
VEH_AGE	-	-	-	-	-
VEH_AT_FLT	-	-	-	-	-
VEH_DESTROY	1.53	0.307	24.83	<.0001	4.62
VEH_DISABLED	0.93	0.315	8.65	0.0033	2.53
VEH_STRAIGHT	-	-	-	-	-
VEH_TURN	-	-	-	-	-
WET_RD_SURF	-	-	-	-	-

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

Table 3.5 and Table 3.6 show the estimated model results for incapacitating injuries based on passenger car occupants. The model fitting statistics show better fit of the model with the selected covariates while global null hypothesis test shows that the estimated parameters are non-zero. The association statistics are considerably higher indicating satisfactory prediction capabilities of the model. However, association statistics and the R^2 value for this model are comparatively lower than those for the model for fatal injuries. Total of 16 variables are significant in the model and the estimated parameter for seat belt usage variable is -0.74 with an odds ratio of 0.48. Thus, the seat belt effectiveness for incapacitating injuries is 52%.

Table 3.5 Statistics for Assessing Goodness-of-fit of the Model for Incapacitating Injuries based on Passenger Car Occupants

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	24296.87	19891.38
SC	24304.650	20023.58
-2 Log L	24294.874	19857.38

Association of Predicted Probabilities and Observed Responses

Percent Concordant	77.2	*Somers' D*	0.546
Percent Discordant	22.6	*Gamma*	0.547
Percent Tied	0.2	*Tau-a*	0.271
Pairs	77,036,979	*c*	0.773

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	p Value
Likelihood Ratio	4437.50	16	<.0001
Score	3814.30	16	<.0001
Wald	2828.63	16	<.0001

Adjusted R^2 0.30

Table 3.6 Estimated Logistic Regression Parameters for Incapacitating Injuries based on Passenger Car Occupants

Variable	Estimated Parameter	Standard Error	Ch-square	p Value	Odds Ratio
ALCOHOL	-	-	-	-	-
ANGLE_CRASH	-0.10	0.044	11.88	0.0006	0.91
ARTERIAL	-	-	-	-	-
COLLECTOR	0.153	0.058	6.88	0.0087	1.17
DR_AT_FLT	-	-	-	-	-
DRIVER	0.312	0.040	60.72	<.0001	1.37
HDON_CRASH	0.155	0.076	4.18	0.0408	1.17
INTERSTATE	-	-	-	-	-
INTR_SECN	-	-	-	-	-
LIGHT_CON	-	-	-	-	-
OCC_AGE	0.013	0.001	187.33	<.0001	1.01
OCC_EJECT	1.578	0.142	124.26	<.0001	4.84
OCC_MALE	-0.732	0.035	428.70	<.0001	0.48
OCC_TRAPPED	2.474	0.117	445.35	<.0001	11.87
POSTED_SPEED	-	-	-	-	-
RD_CUR_GRAD	-	-	-	-	-
REAREND_CRASH	-	-	-	-	-
RURAL	-0.114	0.040	7.99	0.0047	0.89
SE_USED	-0.742	0.039	354.45	<.0001	0.48
SNG_VEH_CRASH	0.815	0.057	201.53	<.0001	2.26
URBSP	-	-	-	-	-
VEH_AGE	-	-	-	-	-
VEH_AT_FLT	-	-	-	-	-
VEH_DESTROY	1.456	0.059	600.14	<.0001	4.29
VEH_DISABLED	1.156	0.051	522.91	<.0001	3.18
VEH_STRAIGHT	0.085	0.037	5.27	0.0217	1.09
VEH_TURN	-	-	-	-	-
WET_RD_SURF	-0.175	0.039	20.44	<.0001	0.84

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

The estimated statistics and model parameters using the logistic regression model for non-incapacitating injuries in passenger cars are shown in Table 3.7 and Table 3.8. The model fitting information shows better fit of the model when the explanatory variables are in the model while the global null hypothesis test leads to reject the hypothesis that all the covariates are zero. The estimated association statistics and the R^2 value are comparatively lower for this model compared to those values for incapacitating injuries. The fitted model comprised of 17 variables and the estimated regression parameter for the seat belt usage variable is -0.80 with an error of 0.019 and the estimated odds ratio is 0.45. Thus, the seat belt effectiveness for non-incapacitating injuries is estimated to be 55%.

Table 3.7 Statistics for Assessing Goodness-of-fit of the Model for Non-incapacitating Injuries based on Passenger Car Occupants

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	131046.08	112276.74
SC	131055.55	112447.10
-2 Log L	131044.08	112240.74

Association of Predicted Probabilities and Observed Responses

Percent Concordant	74.6	*Somers' D*	0.494
Percent Discordant	25.2	*Gamma*	0.495
Percent Tied	0.2	*Tau-a*	0.244
Pairs	45,198,816	*c*	0.747

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	p Value
Likelihood Ratio	18803.35	17	<.0001
Score	16718.13	17	<.0001
Wald	13612.75	17	<.0001

Adjusted R^2 0.24

Table 3.8 Estimated Logistic Regression Parameters for Non-incapacitating Injuries based on Passenger Car Occupants

Variable	Parameter	Standard Error	Ch-square	p Value	Odds Ratio
ALCOHOL	0.28	0.040	49.06	<.0001	1.32
ANGLE_CRASH	-0.22	0.029	58.00	<.0001	0.81
ARTERIAL	-	-	-	-	-
COLLECTOR	0.07	0.023	8.33	0.0039	1.07
DR_AT_FLT	-0.18	0.015	136.44	<.0001	0.84
DRIVER	0.30	0.017	307.01	<.0001	1.36
HDON_CRASH	-	-	-	-	-
INTERSTATE	-	-	-	-	-
INTR_SECN	-	-	-	-	-
LIGHT_CON	-	-	-	-	-
OCC_AGE	0.01	0.000	215.41	<.0001	1.01
OCC_EJECT	1.63	0.227	51.51	<.0001	5.10
OCC_MALE	-0.67	0.015	2053.79	<.0001	0.51
OCC_TRAPPED	2.54	0.158	258.97	<.0001	12.62
POSTED_SPEED	0.003	0.001	25.20	<.0001	1.003
RD_CUR_GRAD	0.06	0.017	14.19	0.0002	1.07
REAREND_CRASH	-0.19	0.030	40.79	<.0001	0.83
RURAL	-	-	-	-	-
SE_USED	-0.80	0.019	1778.68	<.0001	0.45
SNG_VEH_CRASH	1.12	0.034	1062.61	<.0001	3.05
URBSP	-	-	-	-	-
VEH_AGE	-	-	-	-	-
VEH_AT_FLT	-	-	-	-	-
VEH_DESTROY	1.74	0.063	765.52	<.0001	5.68
VEH_DISABLED	1.22	0.058	437.77	<.0001	3.40
VEH_STRAIGHT	-	-	-	-	-
VEH_TURN	-	-	-	-	-
WET_RD_SURF	-	-	-	-	-

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

The estimated model fitting statistics for the logistic regression model for possible injuries based on passenger car occupants are shown in Table 3.9 while the estimated model parameters are shown in Table 3.10. The statistics indicate that the model fits better with the explanatory variables. The fitted model has total of 17 variables and an R^2 value of 0.20. The estimated coefficient for the seat belt usage variable is -0.50 and the error of estimation is 0.021. The estimated odds ratio is 0.61 indicating that seat belts are 39% effectiveness in preventing possible injuries.

Table 3.9 Statistics for Assessing Goodness-of-fit of the Model for Possible Injuries based on Passenger Car Occupants

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	164238.90	144886.46
SC	164248.58	145060.76
-2 Log L	164236.90	144850.46

Association of Predicted Probabilities and Observed Responses

Percent Concordant	72.2	*Somers' D*	0.447
Percent Discordant	27.5	*Gamma*	0.448
Percent Tied	0.3	*Tau-a*	0.223
Pairs	351,1243,188	*c*	0.724

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	p Value
Likelihood Ratio	19386.43	17	<.0001
Score	17587.06	17	<.0001
Wald	14851.17	17	<.0001

Adjusted R^2 0.20

Table 3.10 Estimated Logistic Regression Parameters for Possible Injuries based on Passenger Car Occupants

Variable	Parameter	Standard Error	Ch-square	p Value	Odds Ratio
ALCOHOL	-	-	-	-	-
ANGLE_CRASH	-	-	-	-	-
ARTERIAL	-0.07	0.016	17.83	<.0001	0.94
COLLECTOR	-	-	-	-	-
DR_AT_FLT	-0.87	0.014	3924.49	<.0001	0.42
DRIVER	0.25	0.016	249.53	<.0001	1.28
HDON_CRASH	-	-	-	-	-
INTERSTATE	-0.07	0.024	7.54	0.006	0.94
INTR_SECN	-	-	-	-	-
LIGHT_CON	-	-	-	-	-
OCC_AGE	0.01	0.000	254.42	<.0001	1.01
OCC_EJECT	1.51	0.404	13.91	0.0002	4.51
OCC_MALE	-0.85	0.013	4351.39	<.0001	0.43
OCC_TRAPPED	2.30	0.277	68.78	<.0001	9.98
POSTED_SPEED	-	-	-	-	-
RD_CUR_GRAD	0.04	0.015	6.08	0.0137	1.04
REAREND_CRASH	-	-	-	-	-
RURAL	-	-	-	-	-
SE_USED	-0.50	0.021	589.46	<.0001	0.61
SNG_VEH_CRASH	1.66	0.029	3389.84	<.0001	5.24
URBSP	-	-	-	-	-
VEH_AGE	-	-	-	-	-
VEH_AT_FLT	-0.63	0.069	84.62	<.0001	0.53
VEH_DESTROY	1.72	0.037	161.95	<.0001	5.61
VEH_DISABLED	1.23	0.052	1122.23	<.0001	3.44
VEH_STRAIGHT	-0.24	0.038	1056.08	<.0001	0.79
VEH_TURN	-0.09	0.015	255.72	<.0001	0.92
WET_RD_SURF	-	-	-	-	-

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

Estimated model parameters and model fitting statistics for logistic regression models based on occupants in other passenger vehicles are shown in Table 3.11 to Table 3.18 for all injury severity categories. It can be seen that the all models have comparatively higher R^2 values for all the models compared to those values for models for passenger cars. In addition, the association statistics are also higher for these models. As shown in Table 3.11, the model fitting statistics indicates better fit of the model for fatal injuries when the explanatory variables are included in the model. The estimated R^2 for this model is 0.55 which is considerably high indicating good prediction capabilities of the model. The estimated parameter for the variable related to seat belt usage is -0.948 and the error of estimation is 0.168. The odds ratio for this variable is 0.39 which indicates that seat belts are 61% effective in preventing fatal injuries to occupants in other passenger vehicles.

Table 3.11 Model Fitting Statistics for the Model for Fatal Injuries based on Occupants in Other Passenger Vehicles

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	2193.24	1378.86
SC	2198.61	1437.95
-2 Log L	2191.24	1356.86

Association of Predicted Probabilities and Observed Responses

Percent Concordant	88.2	*Somers' D*	0.765
Percent Discordant	11.7	*Gamma*	0.766
Percent Tied	0.1	*Tau-a*	0.379
Pairs	627120	*c*	0.882

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	p Value
Likelihood Ratio	834.38	10	<.0001
Score	697.36	10	<.0001
Wald	447.60	10	<.0001

Adjusted R^2 0.55

Table 3.12 Estimated Logistic Regression Parameters for Fatal Injuries based on Occupants in Other Passenger Vehicles

Variable	Parameter	Standard Error	Ch-square	p Value	Odds Ratio
ALCOHOL	-	-	-	-	-
ANGLE_CRASH	-	-	-	-	-
ARTERIAL	-	-	-	-	-
COLLECTOR	-	-	-	-	-
DR_AT_FLT	0.726	0.149	23.73	<.0001	2.07
DRIVER	0.877	0.163	28.84	<.0001	2.40
HDON_CRASH	-	-	-	-	-
INTERSTATE	-0.477	0.220	4.72	0.0298	0.62
INTR_SECN	-	-	-	-	-
LIGHT_CON	-	-	-	-	-
OCC_AGE	0.033	0.004	60.32	<.0001	1.03
OCC_EJECT	1.972	0.180	119.78	<.0001	7.18
OCC_MALE	-	-	-	-	-
OCC_TRAPPED	2.411	0.170	201.96	<.0001	11.14
POSTED_SPEED	-	-	-	-	-
RD_CUR_GRAD	-	-	-	-	-
REAREND_CRAS H	-	-	-	-	-
RURAL	-	-	-	-	-
SE_USED	-0.948	0.168	31.99	<.0001	0.39
SNG_VEH_CRASH	1.231	0.156	62.00	<.0001	3.42
URBSP	-	-	-	-	-
VEH_AGE	-	-	-	-	-
VEH_AT_FLT	-	-	-	-	-
VEH_DESTROY	1.402	0.445	9.92	0.0016	4.06
VEH_DISABLED	0.976	0.457	4.56	0.0328	2.65
VEH_STRAIGHT	-	-	-	-	-
VEH_TURN	-	-	-	-	-
WET_RD_SURF	-	-	-	-	-

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

Details of model fitting statistics and estimated regression parameters using logistic regression models for other injury severity levels are shown in Table 3.13 to Table 3.18. The interpretation of results is similar to those described for the other models in the previous sections.

Table 3.13 Model Fitting Statistics for the Model for Incapacitating Injuries based on Occupants in Other Passenger Vehicles

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	10096.33	7569.96
SC	10103.22	7659.63
-2 Log L	10094.33	7543.96

Association of Predicted Probabilities and Observed Responses

Percent Concordant	81.9	*Somers' D*	0.639
Percent Discordant	18.0	*Gamma*	0.640
Percent Tied	0.20	*Tau-a*	0.317
Pairs	13295865	*c*	0.819

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	p Value
Likelihood Ratio	2550.37	12	<.0001
Score	2193.42	12	<.0001
Wald	1523.43	12	<.0001

Adjusted R^2 0.39

Table 3.14 Estimated Logistic Regression Parameters for Incapacitating Injuries based on Occupants in Other Passenger Vehicles

Variable	Parameter	Standard Error	Ch-square	p Value	Odds Ratio
ALCOHOL	-	-	-	-	-
ANGLE_CRASH	-	-	-	-	-
ARTERIAL	-	-	-	-	-
COLLECTOR	-	-	-	-	-
DR_AT_FLT	-	-	-	-	-
DRIVER	0.518	0.070	55.11	<.0001	1.68
HDON_CRASH	-	-	-	-	-
INTERSTATE	-	-	-	-	-
INTR_SECN	-	-	-	-	-
LIGHT_CON	-	-	-	-	-
OCC_AGE	0.015	0.002	79.26	<.0001	1.01
OCC_EJECT	1.755	0.169	107.38	<.0001	5.78
OCC_MALE	-0.629	0.064	96.07	<.0001	0.53
OCC_TRAPPED	2.591	0.166	243.76	<.0001	13.34
POSTED_SPEED	-	-	-	-	-
RD_CUR_GRAD	-	-	-	-	-
REAREND_CRASH	0.323	0.077	17.79	<.0001	1.38
RURAL	-	-	-	-	-
SE_USED	-0.715	0.061	138.15	<.0001	0.49
SNG_VEH_CRASH	1.348	0.071	362.92	<.0001	3.85
URBSP	-	-	-	-	-
VEH_AGE	-	-	-	-	-
VEH_AT_FLT	-	-	-	-	-
VEH_DESTROY	1.557	0.092	284.59	<.0001	4.74
VEH_DISABLED	1.083	0.084	166.65	<.0001	2.95
VEH_STRAIGHT	-	-	-	-	-
VEH_TURN	-	-	-	-	-
WET_RD_SURF	-	-	-	-	-

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

Table 3.15 Model Fitting Statistics for the Model for Non-incapacitating Injuries based on Occupants in Other Passenger Vehicles

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	45868.70	36691.79
SC	45877.11	36834.77
-2 Log L	45866.70	36657.79

Association of Predicted Probabilities and Observed Responses

Percent Concordant	78.7	*Somers' D*	0.576
Percent Discordant	21.1	*Gamma*	0.578
Percent Tied	0.2	*Tau-a*	0.287
Pairs	274232172	*c*	0.788

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	p Value
Likelihood Ratio	9208.90	16	<.0001
Score	8159.97	16	<.0001
Wald	6162.37	16	<.0001

Adjusted R^2 0.32

Table 3.16 Estimated Logistic Regression Parameters for Non-incapacitating Injuries based on Occupants in Other Passenger Vehicles

Variable	Parameter	Standard Error	Ch-square	p Value	Odds Ratio
ALCOHOL	0.425	0.061	49.27	<.0001	1.53
ANGLE_CRASH	-0.285	0.029	96.88	<.0001	0.75
ARTERIAL	-	-	-	-	-
COLLECTOR	0.103	0.036	8.09	0.0045	1.11
DR_AT_FLT	-0.244	0.027	82.43	<.0001	0.78
DRIVER	0.212	0.032	43.20	<.0001	1.24
HDON_CRASH	-	-	-	-	-
INTERSTATE	-	-	-	-	-
INTR_SECN	-	-	-	-	-
LIGHT_CON	-	-	-	-	-
OCC_AGE	0.008	0.001	107.60	<.0001	1.01
OCC_EJECT	1.704	0.284	36.02	<.0001	5.49
OCC_MALE	-0.682	0.028	578.00	<.0001	0.51
OCC_TRAPPED	2.223	0.221	101.47	<.0001	9.23
POSTED_SPEED	-	-	-	-	-
RD_CUR_GRAD	-	-	-	-	-
REAREND_CRASH	-	-	-	-	-
RURAL	-	-	-	-	-
SE_USED	-0.722	0.030	563.45	<.0001	0.49
SNG_VEH_CRASH	1.533	0.041	1394.68	<.0001	4.63
URBSP	-	-	-	-	-
VEH_AGE	-	-	-	-	-
VEH_AT_FLT	-0.516	0.103	25.08	<.0001	0.60
VEH_DESTROY	2.133	0.118	324.53	<.0001	8.44
VEH_DISABLED	1.495	0.113	176.08	<.0001	4.46
VEH_STRAIGHT	-	-	-	-	-
VEH_TURN	-	-	-	-	-
WET_RD_SURF	-0.087	0.032	7.54	0.006	0.92

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

Table 3.17 Model Fitting Statistics for the Model for Possible Injuries based on Occupants in Other Passenger Vehicles

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	52221.17	44499.916
SC	52229.728	44653.837
-2 Log L	52219.17	44463.916

Association of Predicted Probabilities and Observed Responses

Percent Concordant	75.0	*Somers' D*	0.502
Percent Discordant	24.8	*Gamma*	0.503
Percent Tied	0.2	*Tau-a*	0.246
Pairs	357924290	*c*	0.751

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	p Value
Likelihood Ratio	7755.26	17	<.0001
Score	7028.10	17	<.0001
Wald	5536.94	17	<.0001

Adjusted R^2 0.25

Table 3.18 Estimated Logistic Regression Parameters for Possible Injuries based on Occupants in Other Passenger Vehicles

Variable	Parameter	Standard Error	Ch-square	p Value	Odds Ratio
ALCOHOL	-	-	-	-	-
ANGLE_CRASH	-	-	-	-	-
ARTERIAL	-0.111	0.028	15.40	<.0001	0.90
COLLECTOR	-	-	-	-	-
DR_AT_FLT	-0.931	0.025	1354.38	<.0001	0.39
DRIVER	0.206	0.030	47.17	<.0001	1.23
HDON_CRASH	-	-	-	-	-
INTERSTATE	-0.177	0.042	17.69	<.0001	0.84
INTR_SECN	-	-	-	-	-
LIGHT_CON	-	-	-	-	-
OCC_AGE	0.007	0.001	98.21	<.0001	1.01
OCC_EJECT	2.507	0.743	11.37	0.0007	12.26
OCC_MALE	-0.795	0.025	1022.97	<.0001	0.45
OCC_TRAPPED	2.053	0.443	21.52	<.0001	7.79
POSTED_SPEED	-	-	-	-	-
RD_CUR_GRAD	0.055	0.027	4.05	0.0441	1.06
REAREND_CRASH	-	-	-	-	-
RURAL	-	-	-	-	-
SE_USED	-0.421	0.033	164.38	<.0001	0.66
SNG_VEH_CRASH	1.971	0.047	1794.64	<.0001	7.18
URBSP	-	-	-	-	-
VEH_AGE	-	-	-	-	-
VEH_AT_FLT	-0.558	0.106	27.59	<.0001	0.57
VEH_DESTROY	2.020	0.096	444.37	<.0001	7.54
VEH_DISABLED	1.416	0.075	352.74	<.0001	4.12
VEH_STRAIGHT	-0.421	0.027	237.72	<.0001	0.66
VEH_TURN	-0.283	0.042	46.59	<.0001	0.75
WET_RD_SURF	-	-	-	-	-

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

The summary of estimated seat belt effectiveness values using logistic regression method are shown in Table 3.19.

Table 3.19 Estimated Seat Belt Effectiveness Values Using Logistic Regression Method

Vehicle Group	Seat Belt Effectiveness (%) (95% Confidence Interval)			
	Fatal Injuries	Incapacitating Injuries	Non-incapacitating Injuries	Possible Injuries
Passenger Cars	56 (39-73)	53 (46-60)	55 (52-58)	33 (28-38)
Other Passenger Vehicles	61 (35-87)	52 (41-63)	51 (45-57)	34 (26-42)

According to estimations, seat belts are 56% effective in preventing fatalities to front seat occupants in passenger cars. In other words, 56% of the 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%) in passenger cars. In addition, seat belts are 33% effective in reducing possible injuries to passenger car front seat occupants. In other passenger vehicles, seat belts are 61% effective in preventing fatal injuries to front seat occupants. For the same vehicle group, the estimated seat belt effectiveness in reducing incapacitating injuries is 52% while seat belts are 51% effective in reducing non-incapacitating injuries. Seat belt effectiveness in reducing possible injuries in this vehicle group is 34%, which is slightly higher than that value for passenger cars.

3.4 Matched-pair Analysis Methods

3.4.1 Introduction

Matched-pair analysis methods estimate risk ratios using information from two occupants in the same vehicle. In this study, the matched pair was the driver and right front seat passenger of a vehicle. Therefore, these methods are applicable only for vehicles which were occupied by at least two front seat occupants at the time of the crash and at least one them was injured due to the crash. Since these methods consider occupants in the same vehicle, it allows controlling for effects of some unobserved variables.

As these methods consider the information only from vehicles with at least two front seat occupants, data related to those vehicles were extracted from the data sets related to each crash category which were used for logistic regression models. The injuries resulted from each crash category, where the involved vehicles were occupied by at least two front seat occupants, and the restraint condition of the involved occupants (belted or unbelted) are shown in Table 3.20 to Table 3.23. As shown in Table 3.20, the seat belt usage among front seat occupants in other passenger vehicles which were involved in fatal crashes is significantly lower compared to that rate among passenger car occupants. This can be observed for other crash types as well although the difference is not as significant as that for fatal crashes. The seat belt usage rate of passenger car occupants is higher compared to the seat belt usage among occupants in other passenger vehicles in all crash categories. There is no significant difference between the seat belt usage rates of drivers and right front passengers in both vehicle groups. It can be seen that for a particular crash category, seat belt usage rate among occupants who sustained the highest level of injury severity is significantly lower compared to the seat belt usage rate among occupants who received other injuries. For example, in fatal crashes, seat belt usage by fatally injured occupants is ignorantly lower than that of survived occupants.

Table 3.20 Front Seat Occupant Injuries due to Fatal Crashes

Vehicle Type	Seating Position	Fatal Injuries				Other Injuries*				% Injured (Fatal)
		Belted	Unbelted	Belt Usage (%)	Total	Belted	Unbelted	Belt Usage (%)	Total	
Passenger Cars (668 Vehicles)	Driver	139	249	36%	388	116	164	41%	280	58%
	Right Front Passenger	151	273	36%	424	108	136	44%	244	63%
Other Passenger Vehicles (247 Vehicles)	Driver	33	112	23%	145	36	66	35%	102	59%
	Right Front Passenger	25	114	18%	139	26	82	24%	108	56%

** Include incapacitating injuries, non-incapacitating injuries, possible injuries, and no injuries*

Table 3.21 Front Seat Occupant Injuries due to Incapacitating Crashes

Vehicle Type	Seating Position	Incapacitating Injuries				Other Injuries*				% Injured (Incap.)
		Belted	Unbelted	Belt Usage (%)	Total	Belted	Unbelted	Belt Usage (%)	Total	
Passenger Cars (3,388 Vehicles)	Driver	1,087	999	52%	2,086	878	424	67%	1,302	62%
	Right Front Passenger	1,292	1,186	52%	2,478	554	356	61%	910	73%
Other Passenger Vehicles (1,100 Vehicles)	Driver	313	407	43%	720	212	167	56%	379	66%
	Right Front Passenger	317	447	41%	764	176	161	52%	337	69%

** Include non-incapacitating injuries, possible injuries, and no injuries*

Table 3.22 Front Seat Occupant Injuries due to Non-incapacitating Crashes

Vehicle Type	Seating Position	Non-incapacitating Injuries				Other Injuries*				% Injured (Non-incap.)
		Belted	Unbelted	Belt Usage (%)	Total	Belted	Unbelted	Belt Usage (%)	Total	
Passenger Cars (14,511 Vehicles)	Driver	6,120	3,097	66%	9,217	3,991	1,303	75%	5,294	64%
	Right Front Passenger	6,653	4,233	61%	10,886	2,701	924	75%	3,625	75%
Other Passenger Vehicles (4,909 Vehicles)	Driver	1,763	1,250	59%	3,013	1,311	585	69%	1,896	61%
	Right Front Passenger	2,018	1,730	54%	3,748	790	371	68%	1,161	76%

** Include possible injuries, and no injuries*

Table 3.23 Front Seat Occupant Injuries due to Possible Crashes

Vehicle Type	Seating Position	Possible Injuries				No Injuries				% Injured (Possible)
		Belted	Unbelted	Belt Usage (%)	Total	Belted	Unbelted	Belt Usage (%)	Total	
Passenger Cars (19,233 Vehicles)	Driver	9,815	1,908	84%	11,723	6,581	929	88%	7,510	61%
	Right Front Passenger	11,350	2,758	80%	14,108	4,400	725	86%	5,125	73%
Other Passenger Vehicles (4,969 Vehicles)	Driver	2,249	646	78%	2,895	1,680	394	81%	2,074	58%
	Right Front Passenger	2,785	970	74%	3,755	990	224	82%	1,214	76%

3.4.2 Double Pair Comparison Method

3.4.2.1 Introduction

The double pair comparison method is applicable to cases where the vehicle was occupied by at least two occupants (driver and front right passenger) with at least one occupant having the level of injury severity under consideration. From the selected datasets, cases where none of the occupants had the injury severity under consideration were 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 but 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. The following section consists of a brief description about the rationale behind the double pair comparison method and more detailed description can be found in publications by Evans (1986 a, 1986 b).

3.4.2.2 The Method

To illustrate the method, the hypothetical dataset related to driver and front right passenger fatalities in Table 3.24 is used. In this illustration, the passengers are disaggregated by their restraint condition. For other injury severities the procedure is similar.

Table 3.24 Hypothetical Dataset Used for Double Pair Estimation of Seat Belt effectiveness

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 injury risk ratios between two occupant groups: the ratio between restrained drivers and unrestrained passengers, and unrestrained drivers and unrestrained passengers. The injury risk ratio is the ratio between the number of injuries in each occupant group. In other words, if the fatality risk ratio between restrained drivers and unrestrained passengers is r_1, then r_1 can be estimated using the following equation.

$$r_1 = d / e \tag{3.15}$$

Similarly, the ratio of unrestrained drivers to unrestrained passengers, r_2 is given by,

$$r_2 = m / n \tag{3.16}$$

By using the ratios r_1 and r_2, the restrained drivers to unrestrained drivers fatality ratio, R_1 can be estimated using the following equation.

$$R_1 = r_1 / r_2 \tag{3.17}$$

The standard error in the estimate of R1, denoted by ΔR_1 is given by,

$$\Delta R_1 = R_1 \sqrt{\sigma^2 + 1/n + 1/d + 1/m + 1/e} \tag{3.18}$$

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.

$$\overline{R} = exp\left[\frac{\sum_{i=1}^{2}\{(R_i/\Delta R_i)^2 \, x \, log(R_i)\}}{\sum_{i=1}^{2}\{(R_i / \Delta R_i)^2\}}\right] \tag{3.19}$$

The standard error of the estimate of $\overline{R}$ is given by,

$$\Delta\overline{R} = \frac{\overline{R}}{\sqrt{\sum_{i=1}^{2}\{(R_i / \Delta R_i)^2\}}} \tag{3.20}$$

Finally, the seat belt effectiveness for drivers, ED can be estimated by,

$$E_D\,(\%) = 100(1 - \overline{R}) \tag{3.21}$$

Similarly, seat belt effectiveness for front right passengers, *Ep* can be estimated.

To estimate the overall seat belt effectiveness, the individual effectiveness values estimated in the above steps for driver and passenger should be weighted using some weight factors. The proportion of actual injury frequencies related to the two seating positions (driver and front right passenger) could be used as the weight factors. In this case, the injury frequencies are considered for all vehicles involved in crashes irrespective of occupancy. The estimation procedure is shown in Table 3.25.

Table 3.25 Estimation of Overall Seat Belt Effectiveness

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

Assume that the proportions of actual driver and front right passenger injuries are *a* and *b* respectively (*b* = 1- *a*). Also, assume that the percentages of driver and passenger injuries prevented by the use of seat belts are *C* and *D* respectively. Then quantities *C* and *D* can be estimated using the following equations.

$$C = a * E_D \% \tag{3.22}$$

$$D = b * E_P \% \tag{3.23}$$

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

$$E = (C + D)\% \tag{3.24}$$

The standard error of the overall seat belt effectiveness could be considered as same as the standard error of the effectiveness estimate for drivers (Evans 1986b).

3.4.2.3 Results

The double pair estimation procedure of seat belt effectiveness for fatal injuries for passenger car occupants is shown in Table 3.26 and Table 3.27. It can be seen from Table 3.26 that the seat belts are almost equally effective in reducing fatal injuries to drivers and front passengers in passenger cars as the estimated effectiveness values for drivers and front seat passengers are 53% and 54% respectively.

Table 3.26 Estimation of Seat Belt Effectiveness for Fatal Injuries for Occupants in Passenger Cars

Category	Driver Fatalities	FRP Fatalities	r	R	ΔR	$\overline{R}$	$\Delta\overline{R}$	E_D or E_P	Remarks
Driver Restrained, FRP* Unrestrained	23	49	0.47 (r_1)	0.53 (R_1)	0.22	0.47	0.10	0.53 (E_D)	Subject Occupant is the Driver
Driver Unrestrained, FRP Unrestrained	192	218	0.88 (r_2)						
Driver Restrained, FRP Restrained	127	141	0.90 (r_1)	0.41 (R_2)	0.18				
Driver Unrestrained, FRP Restrained	42	19	2.21 (r_2)						
FRP Restrained, Driver Unrestrained	19	42	0.45 (r_1)	0.40 (R_1)	0.17	0.46	0.10	0.54 (E_P)	Subject Occupant is the Front Right Passenger
FRP Unrestrained, Driver Unrestrained	218	192	1.14 (r_2)						
FRP Restrained, Driver Restrained	141	127	1.11 (r_1)	0.52 (R_2)	0.22				
FRP Unrestrained, Driver Restrained	49	23	2.13 (r_2)						

** FRP- Front Right Passenger*

Note: All the symbols used in this table have the same meanings as those are defined in the section 3.4.2.2.

Table 3.27 Overall Seat Belt Effectiveness for Fatal Injuries for Passenger Car Occupants

Subject Occupant	Actual Fatalities	Fraction of Actual Fatalities	Estimated Effectiveness (%)	% of Fatalities Prevented	Overall Effectiveness (%)
Driver	3,003	0.80	53	$C = 42$ (0.8*53%)	53
Front Right Passenger	770	0.20	54	D=11 (0.2*54%)	
Total	3,773	1		$E = 53$	

Table 3.28 shows the summary of estimated seat belt effectiveness values from double pair comparison method for different injury severities. According to double pair estimations, seat

belts are 53% and 57% effective in preventing fatal injuries in passenger cars and other vehicles respectively. Seat belt effectiveness in preventing incapacitating injuries is 52% in passenger cars and 47% in other passenger vehicles. For non-incapacitating injuries, seat belts are equally effective in both vehicle groups as the estimated seat belt effectiveness is 42%.

Table 3.28 Estimated Seat Belt Effectiveness Values Using Double Pair Comparison Method

Vehicle Type	Effectiveness (%) (95% Confidence Interval) (%)			
	Fatal	Incapacitating	Non-incapacitating	Possible
Passenger Cars	53 (43 - 63)	52 (41 - 63)	42 (29 – 55)	34 (19 - 59)
Other Passenger Vehicles	57 (39 - 75)	47 (33 - 61)	42 (28 - 56)	28 (10 - 46)

3.4.3 Cox Proportional Hazards Regression Method

3.4.3.1 Introduction

The Cox Proportional Hazards (CPH) regression method is widely used in survival time analysis studies to estimate the effects of different variables influencing the time-to-failure of a system. In traffic safety studies, this method can be applied with certain assumptions to estimate the effect of seat belts on injury risk to motor vehicle occupants in case of a crash. In general, motor vehicle crash reports use 30 day follow-up time period before reporting a fatal injury, if the person was not killed on the spot. In other words, the injury severity of an occupant is reported as fatal, if the occupant died within 30 days after involved in the crash and admitted to a hospital. Thus, time-to-death after the crash could be considered as the time-to-failure in survival analysis. However, the exact time to death are not provided in crash reports. Cummings et al. (2003) suggests that instead of considering exact time to deaths, it could be reasonable to estimate risk ratios for deaths within a 30-day interval in traffic safety studies. The argument in this case is that even if the occupants survived with severe injuries, in most of the cases they might be in intensive care unit under serious conditions during the rest of the time period before eventually dying (Cummings et al., 2003).

However, for nonfatal injuries information related to follow-up times is not available in crash database. Therefore, the above assumption is not applicable for cases with nonfatal injuries and this method cannot be applied to estimate seat belt effectiveness in reducing nonfatal injuries.

3.4.3.2 The Method

The procedure starts with defining a time dependent hazard function for a subject under consideration. The hazard function for an occupant at time *t* is defined as (Kalbfleisch and Prentice, 1980, Kleinbaum, 1996);

$$h\,(t, X) = h_0\,(t) e^{X\beta} \tag{3.25}$$

where,

$h\,(t, X)$ = Hazard function for the occupant at time t

$h_0(t)$ = The baseline hazard function for the occupant

X = Row vector of n measured covariates

β = Column vector of n regression parameters to be estimated

In other words, the hazard function of the occupant is assumed to be constant proportion of the baseline hazard function, since the quantity $e^{X\beta}$ is constant over time for an individual occupant. The baseline hazard function, $h_0(t)$ can be interpreted as the hazard function of the occupant when X=0 (or when there are no measured covariates). In the Cox PH model, $h_0(t)$ is considered as an undefined function (i.e. no probability distribution function is assumed for $h_0(t)$).

Assume that the covariate related to occupant's seat belt usage is represented by X_{SB} and X_{SB} = 1 if seat belt used and X_{SB} = 0 if not used. Let β_{SB} be the estimated regression parameter related to X_{SB}. By keeping all other covariates constant, the hazard ratio between restrained and unrestrained occupants can be estimated as follows;

$$HR = \frac{h\,(t, X_{SB} = 1)}{h\,(t, X_{SB} = 0)} = e^{\beta_{SB}} \tag{3.26}$$

where,

HR = Hazards ratio

$h\,(t, X_{SB} = 1)$ = Hazard function at time t when occupant is restrained

$h\,(t, X_{SB} = 0)$ = Hazard function at time t when occupant is unrestrained

It should be noted that, the base line hazard function is assumed to be constant for both restrained and unrestrained occupants and this may lead to biased estimations. This could be avoided up to a considerable extent by stratifying the model on vehicles and comparing two occupants in the same vehicle (within-vehicle comparisons).

Using the estimated hazard ratio, the seat belt effectiveness, E can be estimated as follows;

$$E = (1 - HR) * 100\% \tag{3.27}$$

The event or the outcome of the model is the occurrence of a fatal injury during the follow-up time of 30-day period. If an occupant survived after involved in a fatal crash, or the occupant did not die during the follow-up time of 30-day period, that observation is considered as a censored observation. A censored observation is defined as an observation with incomplete information. In this case, the information is incomplete because there was no event (fatal injury) present related to that particular subject (or the occupant) during the time (30-days period) that the subject was part of the study, and this is called a right censored observation.

The dependent variable of the model is the time to death or an arbitrary constant value in this case. The selected covariates or the explanatory variables included occupant's age, gender, seat belt usage, and the seating position (driver or passenger). Since the observations are stratified by vehicles, effects of many unobserved variables can be controlled in the analysis. In addition, many of those variables considered in multiple logistic regression models such as speed, vehicle related variables, and roadway and environmental related variables can be excluded in the analysis since they are common for both the occupants. The selected covariates are shown in Table 3.29.

The PHREG procedure of the SAS software was used to estimate the regression parameters of the Cox PH model (SAS Institute Inc., 2004). Since the dependent variable is constant this is a case with tied survival times and thus, the Efron method was used to handle the tied observations (Kalbfleisch and Prentice, 1980, Kleinbaum, 1996). To test the global null hypothesis about the explanatory variables, likelihood chi-square statistic, which has an approximate chi-square distribution, was used. The SAS's PHREG also provide some additional statistics called Score and Wald chi-square values, which have the similar properties as the likelihood chi-square statistic.

Table 3.29 Selected Covariates for the Cox PH Model

Variable	Description
DRIVER	=1 if the considered occupant was the driver, =0 otherwise
OCC_AGE	Age of the occupant in years
OCC_MALE	=1 if the occupant was male, =0 otherwise
SB_USED	=1 if the occupant was restrained, =0 otherwise

To check any lack of fit of the models, two different residuals are estimated by the PHREG procedure (SAS Institute Inc., 2004). These residuals are called Martingale and Deviance residuals. The Martingale residual for the Cox PH model with no time-dependent variables is estimated as follows;

$$M_i = \delta_i - h_0(t)\, e^{X\beta} \qquad (3.28)$$

where;

M_i = Martingale residual for the i^{th} observation

t = Event time (30 days in this case)

δ_i = Event status where δ_i=0 if the observation is censored and δ_i = 1 otherwise

The deviance residual is estimated using the following equation;

$$d_i = sign(M_i)\sqrt{2[-M_i - \delta_i \log(\delta_i - M_i)]} \qquad 3.28)$$

where,

d_i = Deviance residual for the i^{th} observation

$sign(M_i)$ = Sign of the martingale residual (positive or negative)

To obtain residual plots, Martingale and Deviance residuals are plotted against the linear predictor of the Cox model, $e^{X\beta}$. These plots are used to examine any lack of fit of the models.

3.4.3.3 Results

Table 3.30 shows the statistics for testing global null hypothesis. Table 3.31 shows the estimated regression parameters from the Cox PH model for the selected explanatory variables using fatal crash data for occupants in passenger cars. The statistics for testing global null hypothesis for regression parameters are significant indicating that covariates are nonzero. Figure 3.1 shows the plots of Martingale and Deviance residual with the linear predictor of the model. The residuals seem to be scattered evenly and there are no signs of any extreme observations indicating no lack of fit of the model.

As shown in Table 3.31, only two variables are significant in the model under 0.05 level of significance (which are shown in bold texts). The variable related to occupant's seat belt usage has a negative estimated parameter which indicates that hazard for an occupant to be fatally injured reduces when the occupant's restraint condition changes from unbelted (seat belt used) to belted (seat belt not used). The estimated hazard ratio for the variable related to seat belt usage of an occupant is 0.47 with a confidence limit ranging from 0.33 to 0.69. The estimated seat belt effectiveness using this method is therefore 53% (1-0.47) with a confidence interval of 33 - 69%.

Table 3.30 Statistics for Assessing Model Fitting

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	p Value
Likelihood Ratio	44.0	4	<.0001
Score	41.57	4	<.0001
Wald	37.84	4	<.0001

Table 3.31 Estimated Regression Parameters using Cox PH model for Passenger Car Occupants Involved in Fatal Crashes

Variable	Estimated Parameter	Standard Error	Chi-Square	Pr > Chi-Sq.	Hazards Ratio	95% Confidence Interval	
DRIVER	-0.059	0.075	0.62	0.4321	0.94	0.81	1.09
OCC_AGE	**0.031**	**0.007**	**21.04**	**<.0001**	**1.03**	**1.02**	**1.05**
OCC_MALE	-0.067	0.104	0.42	0.5181	0.94	0.76	1.15
SE_USED	**-0.747**	**0.191**	**15.24**	**<.0001**	**0.47**	**0.33**	**0.69**

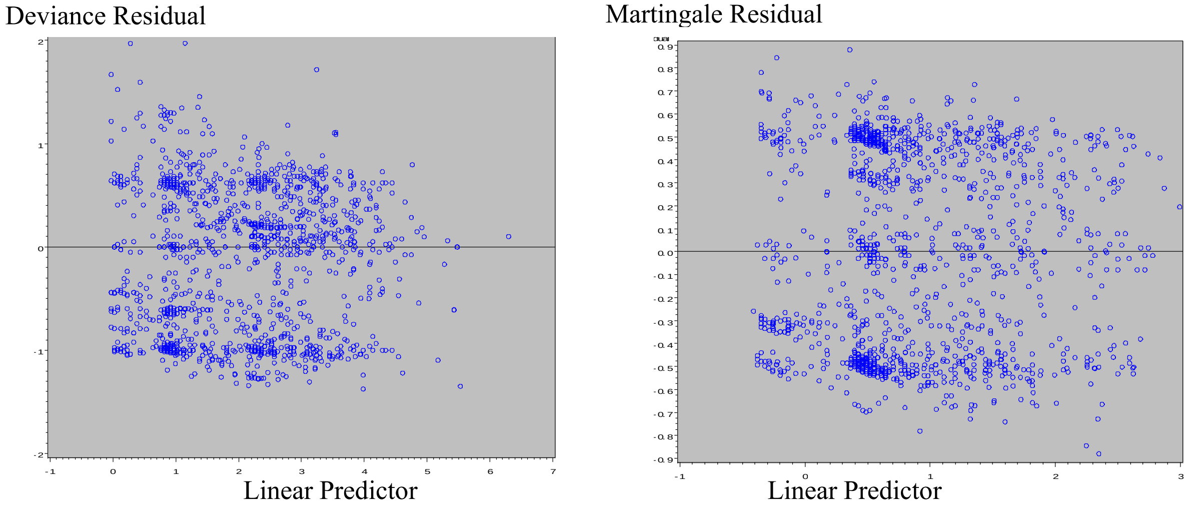


Figure 3.1 Residual Plots for the Fitted Model for Passenger Car Occupants

The Cox PH model outputs for occupants in other passenger vehicles are shown in Table 3.32 and Table 3.33. Since the estimated chi-square values shown in Table 3.32 are significant at 0.05 level of significance, it leads to the conclusion that the explanatory variables in the models can not be zero altogether. The residual plots for the fitted model are shown in Figure 3.2. It can be seen that both plots are scattered evenly and there are no signs of any outliers indicating no lack fit of the model. As shown in Table 3.33, only two variables are significant in the model. Since the estimated hazard ratio for the SE_USED variable is 0.40, the estimated seat belt effectiveness is 60% for this passenger vehicle group with a confidence interval ranging from 21 to 75% which is significantly a wider range.

Table 3.32 Statistics for Testing Global Null Hypothesis

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	p Value
Likelihood Ratio	19.82	4	0.0005
Score	19.06	4	0.0008
Wald	17.64	4	0.0015

Table 3.33 Estimated Cox PH Regression Parameters for Occupants in Other Passenger Vehicles Involved in Fatal Crashes

Variable	Estimated Parameter	Standard Error	Chi-Square	Pr > ChiSq	Hazards Ratio	95% Confidence Interval	
DRIVER	0.067	0.128	0.27	0.6005	1.07	0.832	1.38
OCC_AGE	**0.029**	**0.010**	**9.33**	**0.0022**	**1.03**	**1.01**	**1.05**
OCC_MALE	0.036	0.1937	0.03	0.853	1.04	0.71	1.51
SE_USED	**-0.927**	**0.327**	**8.04**	**0.0046**	**0.40**	**0.21**	**0.75**

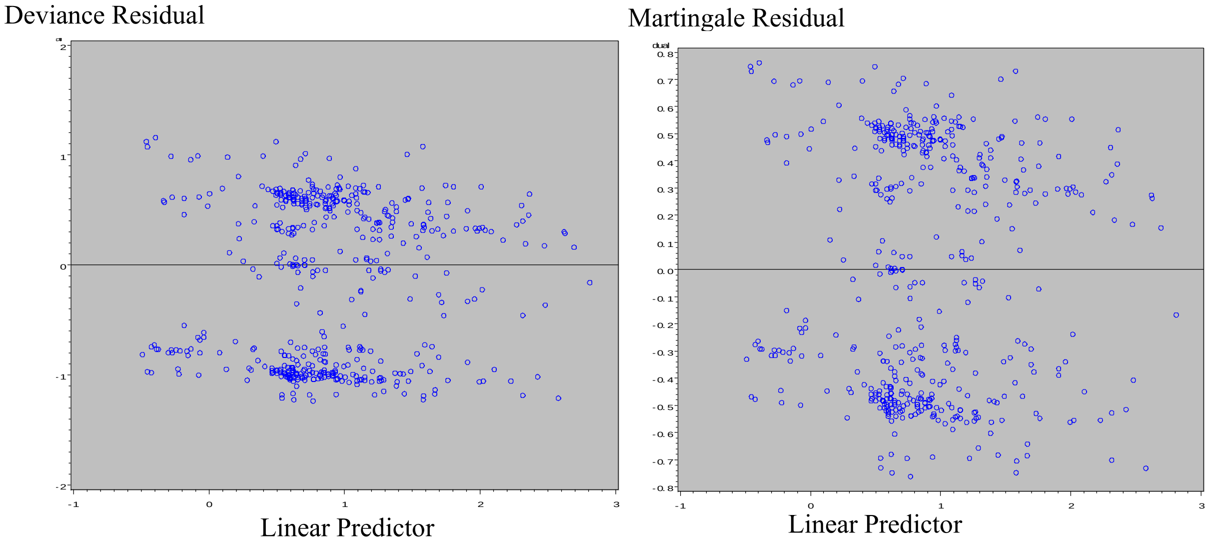


Figure 3.2 Plot of Residuals for the Fitted Model

3.4.4 Conditional Logistic Regression

3.4.4.1 Introduction

Conditional logistic regression method can be applied in matched cohort studies to estimate relative risks between two subjects by assuming odds ratios to be equivalent to risk ratios. In traffic crashes, this method can be applied to estimate risk ratios between two occupants in the same vehicle (i.e. by stratifying the subjects on vehicles) and thus to estimate seat belt effectiveness in preventing injuries. One of the advantages of this method compared to normal logistic regression method is that the effects of unobserved variables or the nuisance parameter can be eliminated by conditioning on the total outcomes.

3.4.4.2 The Method

First, consider the general form of the normal logistic regression model for an occupant in a vehicle with p covariates.

$$logit\,[\mathrm{P}(Y = 1)] = \alpha + \sum_{k=1}^{p} \beta_k X_k \tag{3.28}$$

All the symbols used in the equation (3.28) have the same meanings as those were defined in section 3.3.2. Now consider pair of occupants (i.e. driver and the front seat passenger) denoted by *t* (*t*=1 if the considered occupant is a driver and *t*=2 if it is a passenger) in the vehicle *i* (the subject). The logistic model for this case can be written as follows.

$$logit\,[\mathrm{P}(Y_{it} = 1)] = \alpha_i + \sum_{k=1}^{p} \beta_k X_{kit},\ t = 1, 2 \tag{3.29}$$

where,

$\mathrm{P}(Y_{it} = 1)$ = Probability that occupant *t* sustain injuries with a particular severity level

α_i = Nuisance parameter related to vehicle *i*

β_k = Regression parameter related to covariate *k*

X_{kit} = Row vector of p covariates related to occupant *t* (*t* = 1, 2)

It can be seen that the above model contains an unobserved parameter (nuisance parameter) and thus the next step is to eliminate this parameter from the model. This can be accomplished by conditioning the total pair-wise successive outcome into 1 (Agresti, 2002, Allison, 2005). To explain this, assume that y_{i1} represents the probability that the driver is injured or not (i.e. $y_{i1} = \mathrm{P}(Y_{i1} = 1)\ or\ \mathrm{P}(Y_{i1} = 0)$) and y_{i2} denotes the probability that the passenger is injured or not (i.e. $y_{i2} = \mathrm{P}(Y_{i2} = 1)\ or\ \mathrm{P}(Y_{i2} = 0)$) and,

$$S_i = y_{i1} + y_{i2} \tag{3.30}$$

where,

S_i = Total of the outcome probabilities of the pair

The distribution of y_{i1} and y_{i2} depend on regression parameters only when S_i =1. In other words, cases where S_i =0 (i.e. $y_{i1} = y_{i2}$ =0) or S_i =2 (i.e. $y_{i1} = y_{i2}$ =2) does not provide any information on the regression parameters. Therefore, by conditioning the analysis only to those cases where S_i =1 will not affect the final estimated regression parameters. Thus, only discordant pairs (i.e. cases where S_i =1 (i.e. y_{i1} =1 and y_{i2} =0 or y_{i1} =0 and y_{i2} =1) are important for the analysis. Assuming that the probability $y_{i1}=1$ is denoted by p_{i1} and probability $y_{i2}=1$ is denoted by p_{i2}, the above two cases can be formulated as follows;

$$\mathrm{P}(y_{i1}=0, y_{i2}=1 \mid S_i=1)=(1-p_{i1})p_{i2} \text{ and, } \mathrm{P}(y_{i1}=1, y_{i2}=0 \mid S_i=1)=p_{i1}(1-p_{i2}) \tag{3.31}$$

where, y_{i1} and y_{i2} are assumed to be independent. The logarithm of ratio between these two probabilities results the following formula.

$$log\left(\frac{\mathrm{P}(y_{i1}=0, y_{i2}=1)}{\mathrm{P}(y_{i1}=1, y_{i2}=0)}\right)=log\left(\frac{p_{i2}}{1-p_{i2}}\right)\text{-}\,log\left(\frac{p_{i1}}{1-p_{i1}}\right)=logit\,[\mathrm{P}(Y_{i2}=1)]-logit\,[\mathrm{P}(Y_{i1}=1)] \tag{3.32}$$

By substituting from equation 3.29, the equation 3.32 can be written as follows, which is the final model form.

$$log\left(\frac{\mathrm{P}(y_{i1}=0, y_{i2}=1)}{\mathrm{P}(y_{i1}=1, y_{i2}=0)}\right)=\beta(x_{i2}-x_{i1}) \tag{3.33}$$

where,

β = Column vector of regression parameters to be estimated

x_{i1} = Row vector of covariates related to driver

x_{i2} = Row vector of covariates related to passenger

It can be seen that the above model is free from nuisance parameter.

The odds ratio can be estimated using the following formula.

$$OR = e^{\beta_{SB}} \tag{3.34}$$

where,

OR = Odds ratio

β_{SB} = The estimated regression parameter for the variable related to seat belt usage

It should be noted that the assumption that the odds ratio being equal to the risk ratio between the two occupants is valid only if the outcome of interest is rare. Zhang et al. (1998) studied this scenario and found that the assumption that the odds ratio and the risk ratios being the same is valid only when the outcome of interest in the study population is less than 10%. However, in traffic crash studies, the outcome of interest, that is the injury severity, is not rare, especially when the risk ratios are estimated by considering different crash categories. For example, even in the data set related to fatal crashes which could be considered as the data set with least presence of the outcome (fatal injury), there were about 53% cases where at least one occupant was fatally injured. Therefore, the estimated odds ratios based on such a data set could significantly deviate from the risk ratio.

To approximate the odds ratio to the risk ratio, Zhang et al. (1998) proposed a method to adjust the odds ratio estimated from the conditional logistic regression. The adjusted odds ratio suggested by Zhang et al. (1998) has the following form;

$$RR = OR_{adjusted} = \left(\frac{OR}{(1-P_0)+(P_0 * OR)} \right) \tag{3.35}$$

where,

RR = Risk ratio

$OR_{adjusted}$ = Adjusted odds ratio

OR = Estimated odd ratio using conditional logistic regression method

P_0 = Incidence of outcome of interest in the non-exposed group (i.e. the proportion of injured occupants in the unrestrained group)

Once the risk ratio is estimated, the seat belt effectiveness can be estimated as follows;

$$E = (1-RR)*100\% \tag{3.36}$$

The selected covariates included variables related to occupant's restraint condition (belt used or not), age, gender, and ejection due to the crash. The selected candidate explanatory variables are shown in Table 3.34. The PHREG procedure of SAS software was used for model estimations (SAS Institute, Inc., 2005).

Table 3.34 Selected Covariates for the Conditional Logistic Regression Model

Variable	Description
DRIVER	=1 if the considered occupant was the driver, =0 otherwise
OCC_AGE	Age of the occupant in years
OCC_MALE	=1 if the occupant was male, =0 otherwise
SB_USED	=1 if the occupant was restrained, =0 otherwise

3.4.4.3 Results

Details of the estimated regression parameters and model fitting statistics from conditional logistic regression model for passenger car occupants who were involved in fatal crashes are shown in Table 3.35 and Table 3.36.

Table 3.35 Model Fitting Statistics

```
         Testing Global Null Hypothesis: BETA=0

           Test            Chi-Square   DF       p Value

         Likelihood Ratio      70.76     4       <0.0001
         Score                 62.62     4      <0.0001
         Wald                  51.82     4      <0.0001
```

Table 3.36 The Estimated Parameters for Passenger Car Occupants in Fatal Crashes

Variable	Estimated Parameter	Standard Error	Chi-Square	p Value	Odds Ratio		
					Estimated Value	95% Confidence Interval	
DRIVER	-0.119	0.098	1.49	0.2221	0.89	0.73	1.07
OCC_AGE	**0.050**	**0.010**	**27.86**	**<0.0001**	**1.05**	**1.03**	**1.07**
OCC_MALE	-0.134	0.138	0.95	0.3289	0.87	0.67	1.15
SB_USED	**-1.369**	**0.285**	**23.02**	**<0.0001**	**0.25**	**0.15**	**0.45**

Variables related to occupant's age and seat belt usage are significant in the model at 0.05 level of significance. Since the estimated likelihood ratio for the fitted model is significant, it could be concluded that all the covariates cannot be zero together. The estimated parameter for the variable related to seat belt usage is -1.369 and the estimated odds ratio is 0.25. This implies that the injury risk for a restrained occupant is only about 25% of that risk for an unrestrained occupant (i.e. the odds for being fatally injured is 4 times as high when occupants are unrestrained as compared to when they are restrained). The odds ratios shown in Table 3.36 are the unadjusted odds ratios and they should be adjusted using equation (3.35) to estimate the risk ratios. In the selected data set, about 22% of restrained passenger car occupants were fatally injured and thus the P_0 value is 0.22. Therefore, using equation (3.35) the adjusted odds ratio can be estimated as follows;

$$OR_{adjusted} = \left(\frac{0.25}{(1-0.22)+(0.22*0.25)} \right) = 0.31$$

Therefore the adjusted odds ratio (risk ratio) is 0.31 and the seat belt effectiveness in preventing fatal injuries to passenger car occupants is estimated to be 0.69 (1-0.31) and the 95% confidence limits are 0.49 and 0.82.

The estimated seat belt effectiveness values for all injury severities in both vehicle groups are summarized in Table 3.37. The estimated set belt effectiveness in other passenger vehicle group for fatal injuries is 0.70 with a confidence interval of 0.36 to 0.87. For incapacitating injuries, the estimated seat belt effectiveness is 0.65 in passenger cars and 0.69 in other passenger vehicles. These two values are significantly higher compared to the estimated values from both multiple logistic regression and double pair comparison method.

Table 3.37 Estimated Seat Belt Effectiveness Values Using Conditional Logistic regression

Vehicle Group	Seat Belt Effectiveness (%) (95% Confidence Interval)			
	Fatal	Incapacitating	Non-incapacitating	Possible
Passenger Cars	69 (49 – 82)	65 (56 – 72)	44 (41 – 46)	39 (34 – 45)
Other Passenger Vehicles	70 (36 – 87)	69 (49 – 81)	47 (41 – 52)	35 (22 – 46)

3.4.5 Estimating Equation Approach

3.4.5.1 Introduction

One of the shortcomings of the conditional logistic regression method described in the previous section is that the method uses information only from outcome discordant pairs (i.e. pairs in which only one occupant was injured) and thus ignore outcome concordant pairs (i.e. cases where both occupants were injured or none of the occupants were injured). A case where none of the occupants was injured is not important in the analysis and therefore ignoring those pairs would not severely affect the estimated risk ratios. However, cases where both occupants were injured could be important for the analysis and ignoring such pairs become more critical when the presence of such cases in the considered dataset is significantly higher. For example, in the dataset used in this study related to fatal crashes included about 22% cases where both the occupants had died, which is a significant proportion. The estimating equation approach circumvents this problem by using a different approach for estimating the regression parameters.

3.4.5.2 The Method

The method starts with defining a risk ratio model for a matched pair. The probability that an occupant in the i^{th} vehicle being injured due to a crash is estimated by the following formula (Greenland, 1994):

$$\mathrm{P}(y=1 \mid X, i)=\exp(\alpha_i+X\beta) \tag{3.37}$$

where,

$\mathrm{P}(y=1 \mid X, i)$ = Probability that an occupant in the i^{th} vehicle being injured

X = Row vector of measured covariates

α_i = Nuisance parameter

β = Column vector of regression parameters to be estimated

It can be seen that the above model includes the unknown nuisance parameter and therefore need to be eliminated. For this purpose, a matched pair model is defined by considering risk ratio between two occupants (driver and the passenger). Consider a vehicle with two occupants (driver and front passenger) and assume that the probability that the driver being injured is $\mathrm{P}(y_{i1}=1)$ and that the passenger being injured is $\mathrm{P}(y_{i2}=1)$. Then the risk ratio model can be defined as:

$$\phi_i=\frac{\mathrm{P}(y_{i1}=1 \mid x_{i1})}{\mathrm{P}(y_{i2}=1 \mid x_{i2})}=\exp[(x_{i1}-x_{i2})\beta] \tag{3.38}$$

where,

ϕ_i = Risk ratio

x_{i1} = Row vector of covariates related to the driver

x_{i2} = Row vector of covariates related to the passenger

β = Column vector of regression parameters

Since the probability cannot exceed 1, β is subject to the following constraint:

$\phi_i = \mathrm{P}(y_{i1} = 1 \mid x_{i1}) \le \exp(x_{i1} - x_{i2})\beta \le \mathrm{P}(y_{i2} = 1 \mid x_{i2})$

Next step is to define an estimating equation for β. For this purpose, a pseudoscore vector for the i^{th} pair is defined for a given weight function as follows (Greenland, 1994):

$$s_i(\beta) = w(\phi_i)(y_{i1} - \phi_i y_{i2})d_i \tag{3.39}$$

where,

$s_i(\beta)$ = The pseudoscore vector

$w(\phi_i)$ = The given weight function

$d_i = (x_{i1} - x_{i2})'$ = Column vector of difference of covariates of driver and passenger

Greenland (1994) suggested that the expected value of $s_i(\beta)$ is equal to zero at the true value of β. Therefore, the following equation can be considered as an unbiased estimating function of β.

$$S(\beta) = \sum_{i}^{n} s_i(\beta) \tag{3.40}$$

where,

n = Total number of pairs (vehicles)

Although the choice of the form of the weight function is limited by that fact that the covariance matrix of $s_i(\beta)$ is a function of the nuisance parameter, Greenland (1994) suggested that the following form is a reasonable choice for the weight function.

$$w(\phi_i) = \frac{1}{(\phi_i + 1)} \tag{3.41}$$

Thus, the estimating equation has the following form:

$$S(\beta) = \sum_{i}^{n} s_i(\beta) = \sum_{i=1}^{n} \frac{(y_{i1} - \phi_i y_{i2})d_i}{(1 + \phi_i)} = 0 \tag{3.42}$$

where,

$\phi_i = \exp[(x_{i1} - x_{i2})\beta] = \exp(d_i^{'}\beta)$

It can be seen from the equation 3.42 that the information from pairs where both the occupants were injured is considered in the estimation process. Once the risk ratio is known, the seat belt effectiveness, *E* can be estimated as follows:

$$E = [1 - \exp(\beta_{SB})] * 100\% \qquad (3.43)$$

where,

β_{SB} = The estimated regression parameter for the covariate related to occupant's seat belt usage

The explanatory variables considered in the estimation process were similar to those used in conditional logistic regression method shown in Table 3.34. It should be noted that none of the available statistical analysis software packages provide any in-built procedures to directly estimate the regression parameters using equation (3.42). Greenland (1994) developed a Newton-Raphson algorithm with the aid of GAUSS matrix language (Aptech Systems, Inc., 2006) to estimate the regression parameter for a single covariate. This algorithm was modified to facilitate multiple covariates and used to estimate the regression parameters in this study. Models were fitted in two iterations with an accuracy of 0.005 units.

3.4.5.3 Results

The estimated parameters using the estimating equation approach for passenger car occupants involved in fatal crashes are shown in Table 3.38. The estimated parameter for the variable related to seat belt usage is -0.681. Thus, the seat belt effectiveness is estimated to be 50% (1- exp (-0.681)) with a confidence interval of 34 - 61% which is considerably a wider range.

Table 3.38 Estimated Parameters Using Estimating Equations for Passenger Car Occupants Involved in Fatal Crashes

Variable	Estimated Parameter	Standard Error	95% Confidence Interval	
DRIVER	-0.055	0.059	0.84	1.06
OCC_AGE	0.027	0.005	1.02	1.04
OCC_MALE	-0.058	0.080	0.81	1.10
SE_USED	-0.681	0.138	0.39	0.66

Table 3.39 summarizes the estimated seat belt effectiveness values from estimating equation approach for all injury severities. It can be seen that this method provides comparatively lower estimations of seat belt effectiveness values, especially for incapacitating and non-incapacitating injuries.

Table 3.39 Estimated Seat Belt Effectiveness Values Using Estimating Equation Approach

Vehicle Group	Seat Belt Effectiveness (%) (95% Confidence Interval)			
	Fatal	Incapacitating	Non-incapacitating	Possible
Passenger Cars	50 (34 - 61)	49 (43 - 55)	43 (39 - 46)	36 (31 - 40)
Other Passenger Vehicles	57 (30 - 74)	44 (32 - 55)	38 (32 - 44)	31 (22 - 40)

3.5 Summary of Results

Table 3.40 summarizes the estimated seat belt effectiveness values using all five methods while Figure 3.3 and Figure 3.4 show the variation in estimated seat belt effectiveness values from each method. It can be seen that the estimated seat belt effectiveness values using conditional logistic regression method are significantly higher than the estimated values from other methods for all injury severities in both vehicle groups, except for non-incapacitating injuries in which case, the highest seat belt effectiveness values are from multiple logistic regression method. Thus, conditional logistic regression method seems to overestimate the seat belt effectiveness compared to other methods, although certain adjustments were made to the estimated odds ratios. On the other hand, the estimating equation approach provides the lowest estimated seat belt effectiveness values compared to other methods for all injury severities except for possible injuries.

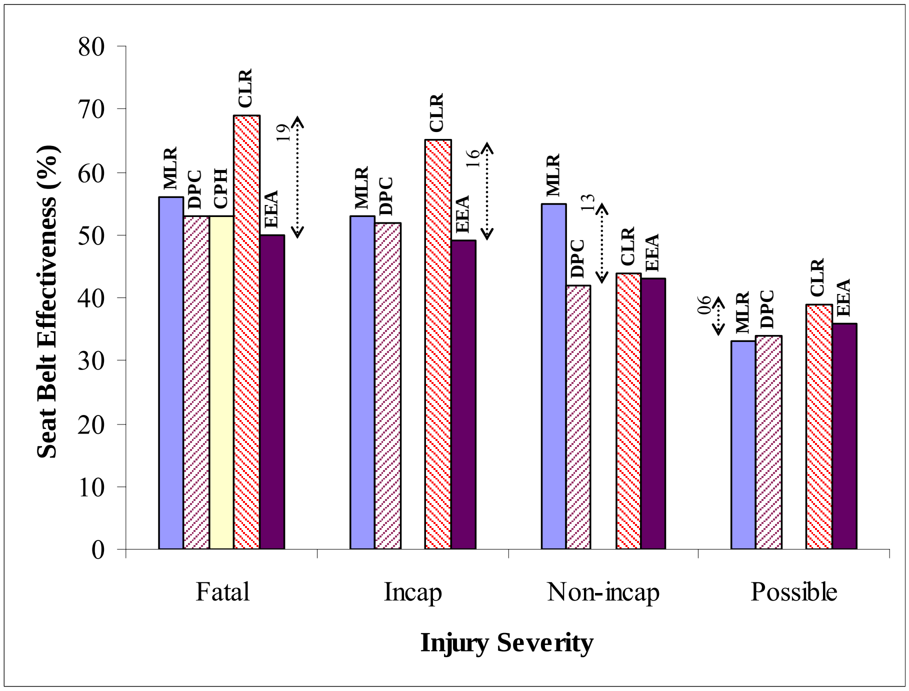
As shown in Figure 3.3 and Figure 3.4, the high variation in estimated seat belt effectiveness values is mainly due to the higher effectiveness values resulted from conditional logistic regression method. Comparing the results from other methods, it can be seen that there seem to be no significant variations among them. For example, the estimated effectiveness values from other four methods for fatal injuries vary from 50 – 56% in passenger cars and 57 – 61% in other passenger vehicles. The estimated seat belt effectiveness values using estimation equation approach are close to those values obtained from double pair comparison method.

Table 3.40 Summary of Estimated Seat Belt Effectiveness Using Selected Methods

Method	Vehicle Group	Seat Belt Effectiveness (%) (95% Confidence Interval)			
		Fatal Injuries	Incapacitating Injuries	Non-incapacitating Injuries	Possible Injuries
Multiple Logistic Regression	Passenger Cars	56 (39 - 73)	53 (46 - 60)	55 (52 - 58)	33 (28 - 38)
	Other Passenger Vehicles	61 (35 - 87)	52 (41 - 63)	51 (45 - 57)	34 (26 - 42)
Double Pair Comparison	Passenger Cars	53 (43 - 63)	52 (41- 63)	42 (29 - 55)	34 (19 - 49)
	Other Passenger Vehicles	57 (39 - 75)	47 (33 - 61)	42 (28 - 56)	28 (10 - 46)
Cox PH Regression	Passenger Cars	53 (33 - 69)	NA	NA	NA
	Other Passenger Vehicles	60 (21 - 75)	NA	NA	NA
Conditional Logistic Regression	Passenger Cars	69 (49 - 82)	65 (56 - 72)	44 (41 - 46)	39 (34 - 45)
	Other Passenger Vehicles	70 (36 - 87)	69 (49 - 81)	47 (41 - 52)	35 (22 - 46)
Estimating Equations	Passenger Cars	50 (34 - 61)	49 (43 - 55)	43 (39 - 46)	36 (31 - 40)
	Other Passenger Vehicles	57 (30 - 74)	44 (32 - 55)	38 (32 - 44)	31 (22 - 40)

NA- Not Applicable

Overall, for fatal injuries, the estimated seat belt effectiveness values range from 50 - 69% for passenger cars and 57 - 70% for other passenger vehicles. The highest variation in estimated seat belt effectiveness values can be observed for incapacitating injuries for other passenger vehicle groups (25% variation). The estimated seat belt effectiveness values for possible injuries have the lowest variation for both vehicle groups.



Note: MLR – Multiple Logistic Regression; DPC – Double Pair Comparison; CPH - Cox Proportional Hazards Regression; CLR- Conditional Logistic Regression; EEA- Estimating Equation Approach

Figure 3.3 Variation in Estimated Seat Belt Effectiveness Values for Passenger Cars

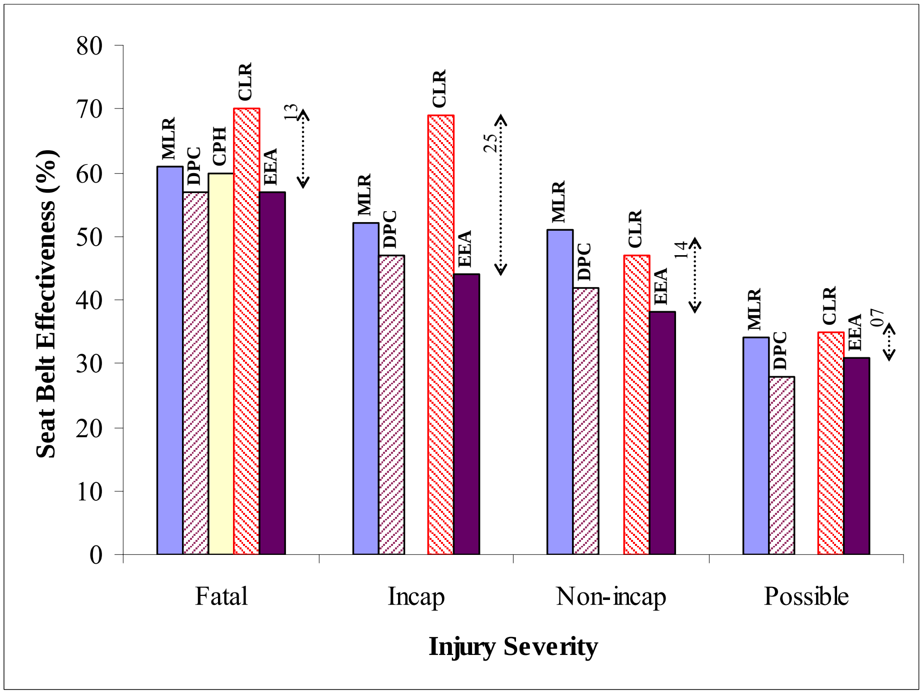
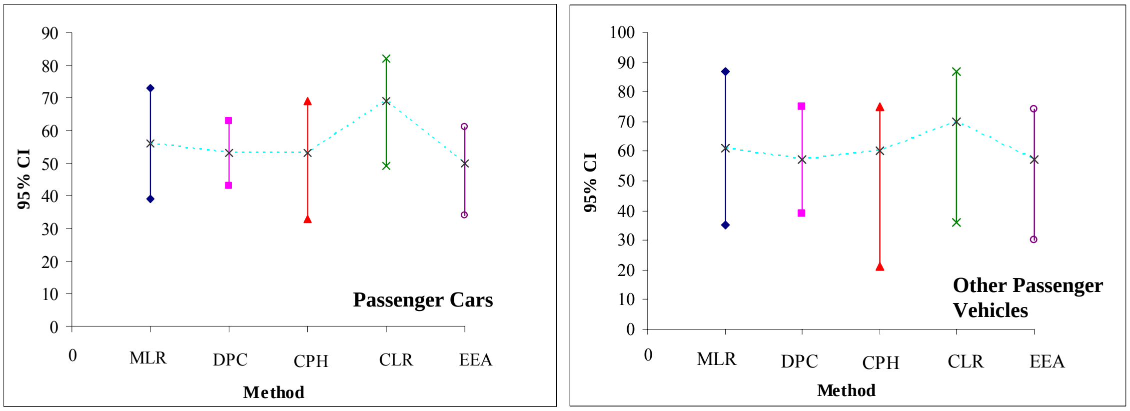


Figure 3.4 Variation in Estimated Seat Belt Effectiveness Values for Other Passenger Vehicles

Except for the results from conditional logistic regression, results from other three methods shows similar trends in variation of seat belt effectiveness among different injury severity levels (i.e. the highest effectiveness is for fatal injuries and it gradually decreases when the injury severity level decreases to have the lowest effectiveness for possible injuries). This can be observed for both vehicle groups. From Figure 3.5, it can be seen that there are no significant differences in the range of the confidence intervals from each method for fatal injuries, although multiple logistic regression and Cox regression models provide slightly wider confidence intervals for the estimated seat belt effectiveness values for other passenger vehicles.

Overall, the estimated seat belt effectiveness values for other passenger vehicles have wider confidence intervals compared to those intervals for passenger cars. This may be due to relatively smaller data samples used in the estimations for other passenger vehicle group. For nonfatal injuries, the confidence intervals for estimations from double pair comparison method are considerably wider than those intervals from other methods, especially for passenger cars. It can be seen that the multiple logistic regression method provides relatively narrower confidence intervals for almost all the nonfatal injury categories in both vehicle groups. Although, the estimated seat belt effectiveness values using conditional logistic regression method are comparatively higher, the confidence intervals are relatively narrower for nonfatal injuries, except for incapacitating and possible injuries in other passenger vehicles. The estimated seat belt effectiveness values using estimating equation method have relatively narrower confidence intervals for nonfatal injuries compared to fatal injuries.



Note: MLR – Multiple Logistic Regressions; DPC – Double Pair Comparison; CPH - Cox Proportional Hazards Regression; CLR- Conditional Logistic Regression; EEA- Estimating Equation Approach

Figure 3.5 Confidence Intervals for Estimated Seat Belt Effectiveness for Fatal Injuries

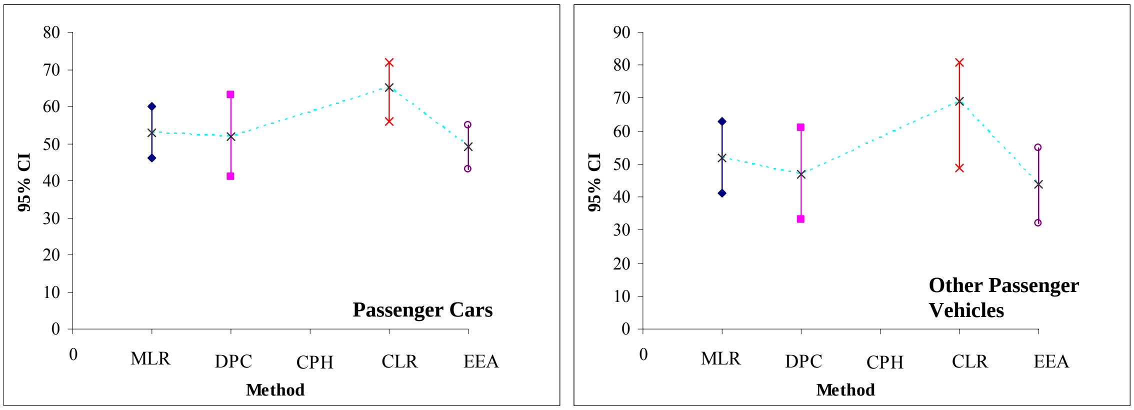


Figure 3.6 Confidence Intervals for Estimated Seat Belt Effectiveness for Incapacitating Injuries

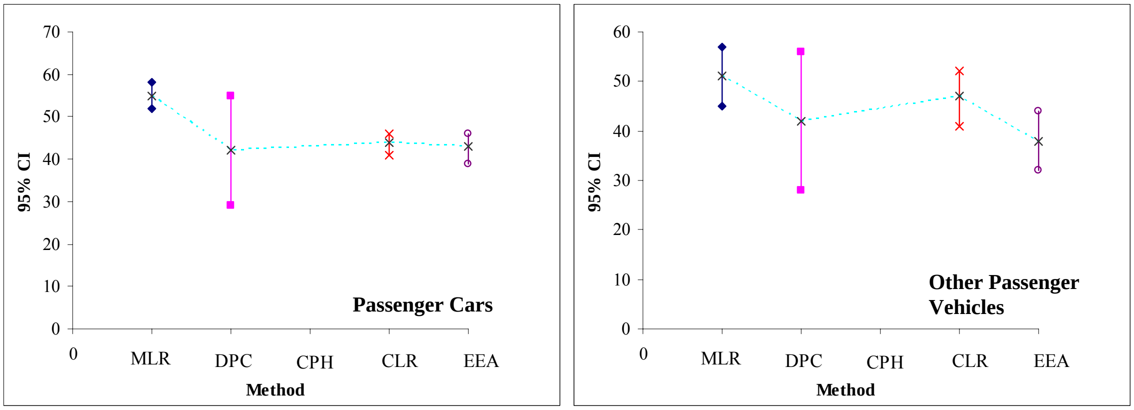


Figure 3.7 Confidence Intervals for Estimated Seat Belt Effectiveness for Non-incapacitating Injuries

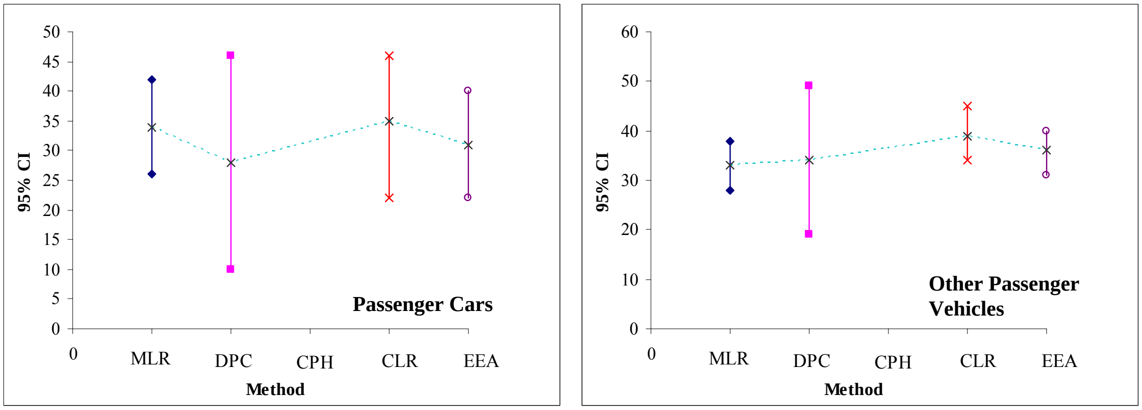


Figure 3.8 Confidence Intervals of Estimated Seat Belt Effectiveness for Possible Injuries

The distribution of estimated seat belt effectiveness values from multiple logistic regression method is shown in Figure 3.9. As shown in the figure, the top and bottom solid lines show the maximum and minimum limits of confidence intervals for the estimated seat belt effectiveness values from other methods. The estimated values from multiple logistic regression method with their confidence intervals are also shown in the Figure 3.9 . It can be seen that for almost all injury severity levels, the estimated seat belt effectiveness values from multiple logistic regression method lie between the estimated values from other methods, except for non-incapacitating injuries in passenger cars. Based on the above information, multiple logistic regression method could be considered to provide better estimations of seat belt effectiveness values compared to other methods for the selected dataset.

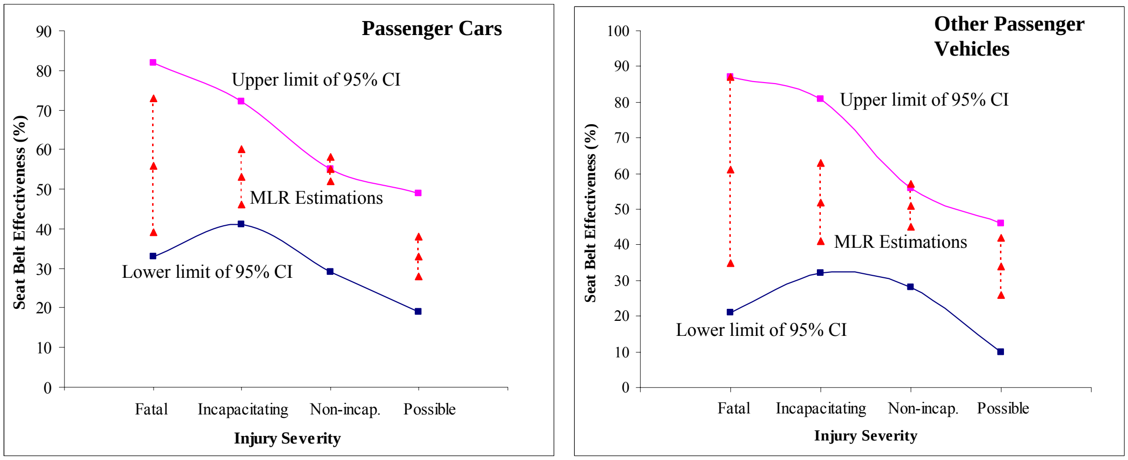


Figure 3.9 Distribution of Estimated Seat Belt Effectiveness Values from Multiple Logistic Regression Method

It should be noted that the use of State highway crash data to estimate seat belt effectiveness may raise some concerns regarding the accuracy of data, especially related to some important variables such as injury severity and seat belt usage. The accuracy of police reported KABCO injury severities are sometimes criticized for their accuracy over AIS injury severities, which are reported by experienced medical professionals at a hospital. Especially, in the case of nonfatal injuries the police officer at the scene has to decide and report the level of injury severity, which may be different from hospital reported injury severity based on thorough medical examinations by experienced medical professionals. In addition, the police reported severities may be subjective due to the differences in individuals' personnel judgments.

The accuracy of data related to seat belt usage, especially in nonfatal crashes, may also affect the accuracy of estimated seat belt effectiveness. According to Table 3.1, reported seat belt usage in non-incapacitating crashes is about 75 % and in possible injury crashes it is 86%, which are higher than the Kansas observed seat belt usage rates during that period of time. Reason for this over-reporting of seat belt usage may be the occupants' unwillingness to disclose the truth to prevent any adverse consequences such as increased insurance premiums, fines, etc. This may be more significant when there is a strong seat belt law in effect such as a primary seat belt. However, it should be noted that the observed seat belt usage rates obtained from surveys may not always accurately represent the actual seat belt usage patterns among the motorists. One of the main reasons is that those surveys are conducted only during day time and therefore it does not reveal any information on seat belt usage patterns during night time.

The over-reported seat belt usage may result in higher estimated seat belt effectiveness values than the 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., 2003). Some studies also have found that the estimated seat belt effectiveness for fatal injuries based on police reported data were not substantially different from estimated values based on data obtained from crash investigators, which are considered to be more accurate (Cummings, 2002).

Although, use of data from State crash databases to estimate seat belt effectiveness may have some concerns, the usefulness of seat belt effectiveness values based on KABCO injury scale should not be overlooked. Those values would be very useful for State highway agencies in evaluating their highway safety improvement programs, especially at a time when improving highway safety has become one of the prioritized goals in many States. Currently, seat belt effectiveness values are not available based on KABCO injury scale and thus, the estimated seat belt effectiveness values in this study could be expected to provide an initiative towards fulfilling that requirement.

CHAPTER 4 - ESTIMATION OF ECONOMIC BENEFITS

4.1 Introduction

The procedure developed in this study to estimate economic benefits associated with increased seat belt usage was based on two major steps. In the first step, the injury reductions that could be expected due to increased seat belt usage by motorists were estimated. The seat belt effectiveness values estimated in the first phase of the study was used for this purpose. To illustrate the estimation procedure, estimated seat belt effectiveness values using logistic regression method were used. Once the reduction in injuries is estimated based on each injury severity level, the next step of the procedure is to convert those injury reductions into economic values. For this purpose, the estimated injury reductions related to each injury severity category were multiplied by the corresponding economic costs associated with that particular injury severity.

4.2 The Procedure

The procedure used in this study was developed based on the methodology developed by Blincoe (1994). Necessary adjustments were made to the original procedure to suit for conditions occur in the State of Kansas. The following sections describe each major step of the procedure in details.

Step 1 – Obtaining injury frequencies

The procedure starts with determining frequencies of different injury severities resulting from motor vehicle crashes during the base year considered. The base year is the year for which the most recent crash data and seat belt usage 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 may be available. In such a case, the year for which the most recent crash data is available is defined as the base year. During the study period, the most recent year for which both crash data and seat belt usage rates were available for Kansas was year 2005. Therefore, the base year for this study was selected as 2005 and the current year was considered as 2006. The injury frequencies for each injury severity level (fatal, incapacitating, non-incapacitating and possible) for the base year (2005) were obtained from KARS database and the values are shown in Table

4.1. It should be noted that those frequencies are the front seat occupant injuries in passenger cars, vans, and pickup trucks due to multi-vehicle and single-vehicle crashes.

Table 4.1 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 – Estimation of 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 as overall usage rates. Thus, 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 types. The weight factors used in this study were the proportions of total injuries related to each vehicle type. The estimation procedure is illustrated in Table 4.2.

Table 4.2 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	

For example, to estimate the average effectiveness for fatal injuries, the percentages of fatalities related each vehicle type (i.e. the weight factors) are obtained and the values are shown in the 4th column of Table 4.2 (64% and 36% respectively). The estimated seat belt effectiveness values shown in the 5th column are 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, and the values are shown in the last column of Table 4.2.

Step 3 – Obtaining seat belt usage rates

The seat belt usage rates in fatal and nonfatal crashes in base year and current year as well as expected future rates were 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 69%. Therefore, base year seat belt usage rate in nonfatal crashes was assumed to be 69%.

The base year usage rate in potentially fatal crashes was estimated using the following formula,

$$U_t = \frac{[U_f/(1-e)]}{[U_f/(1-e)] + 1 - U_f} \tag{4.1}$$

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 by occupants who were fatally injured was estimated from the crash data. Although, seat belt usage by survivors was also available in the database, due to the concerns regarding the accuracy of such data, it was decided to use the equation (4.1) to obtain the overall seat belt usage in potentially fatal crashes.

According to the Blincoe's procedure, seat belt usage in the current year can be assumed to be equal to base year usage rate, unless there are enough evidences to believe any significant improvements in seat belt usage. Such evidence may include an introduction of a primary seat belt law. In such a case, seat belt usage rate in potentially fatal crashes should be estimated in the same manner as above using fatal crash data for the current year. However, crash data was not available for year 2006 during this study period. In addition, it was not possible to find any strong evidence to conclude any improvements in seat belt usage from the base year. Therefore, the current year seat belt usage rates were assumed to be equal to the base year usage rates in both fatal and nonfatal crashes.

To estimate future seat belt usage rate in potentially fatal crashes, Blincoe used the regression model developed by Partyka and Womble (1989), which predicts the number of lives saved based on the observed seat belt usage rate. This second order model was updated by Wang and Blincoe (2003) in 2003 with more recent data. The model format was changed to predict the seat belt usage in potentially fatal crashes as opposed to the amount of lives saved. In this update, Wang and Blincoe considered 6 different model types and found that the best model has the following form:

$$U_t = 0.43751 * U_0 + 0.47249 * U_0^2 \tag{4.2}$$

where,

U_t = Overall seat belt usage rate in potentially fatal crashes

U_0= Observed seat belt usage rate

This model had 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%.

However, the above model has been developed based on national data. Therefore, it was decided to update the above model based on Kansas data. A model based on Kansas data could be expected to provide more realistic predictions for prevailing conditions in Kansas.

To update the model, overall seat belt usage rates (U_0) and seat belt usage in fatal crashes (U_t) for the 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 significant changes in the conditions during that period of time. The U_0 values were obtained from the Kansas Safety Belt Education Office (KSBEO, 2006), which are based on State seat belt survey data. To obtain U_t values, first, seat belt usage rates among fatally injured occupants (U_f) were obtained from KARS database for the same period of time. Those U_f values were then substituted in equation (4.1) to estimate U_t values. The estimated U_t values and the observed U_0 values were then used to update the regression model for Kansas conditions. SAS software was used for model estimations (SAS Institute Inc., 2004).

Step 4 – Estimating expected safety improvements

The potential safety improvements that could be expected due to increased seat belt usage were estimated in this step. The following formula was used for this purpose (Blincoe, 1994).

$$IR = \frac{U_{n+1} - U_n}{(1/e) - U_b} \tag{4.3}$$

where,

IR = Injury reduction rate due to increased seat belt use

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

Un = Current seat belt usage rate

U_b = Base year seat belt usage rate

e = Average seat belt effectiveness

By using this formula, reduction rate in each injury severity category was estimated. The effectiveness values used were the average effectiveness values estimated in step 2.

Step 5 – Estimating Potential reduction in injuries

The estimated injury reduction rates in the step 4 were used to estimate the number of injuries that could be reduced due to increased seat belt usage. For example, the potential reduction in fatal injuries, FR can be estimated as,

$$FR = (IR)_{fatal} * F \tag{4.4}$$

Where,

$(IR)_{fatal}$ = Fatal injury reduction rate due to increased seat belt usage (from step 4)

F = Number of fatalities in the base year

Similarly, the potential reductions in other injury categories were also estimated.

Step 6 – Estimation of 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 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 as comprehensive costs, which is also referred to as willingness-to-pay cost, and the other way is to measure as human capitol costs. The human capitol costs include costs related to property damage, lost market productivity (or lost earnings), lost household production, medical including vocational rehabilitation, emergency services, travel delay, workplace costs, administrative, and legal. In fact, those are the cost elements involve with a highway crash, which can be practically defined in monetary terms. The comprehensive costs include both human capitol costs and costs related to pain and lost quality of life due to injuries suffered. In general, this value is very subjective and different studies have come up with different values.

Thus, to obtain more accurate estimations of expected comprehensive benefits from a State safety program, the above cost elements should be derived using 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. Although, some data elements 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 (KTR, 2007). Since Kansas is not involved in the CODES program in which many of the crash related information from different data sources are linked together, use of CODES database was also not a possibility. Therefore, this study used injury costs estimated based on national data with some adjustments to convert them into State economic conditions. Those adjustments are described in step 7.

Although such adjustments were made, the actual State injury costs may differ from national average costs. Therefore, the benefit estimations using national average data would be unable to provide precise dollar amounts of economic savings due to increase seat belt usage in the State. However, they could be considered to provide approximate figures, which would be very useful for the State highway safety agencies in evaluating the effectiveness of 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 agencies were published in the 1994 FHWA technical advisory (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) and the values are shown in Table 4.3. 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, a separate estimation based on these updated injury cost figures was also carried out. The injury costs developed by Blincoe et al. are shown in Table 4.4, which have been updated to 2006 dollars using CPI index.

Table 4.3 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)

Table 4.4 Cost of Injuries Developed by Blincoe et al. in AIS Scale (2006 Dollars)

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)

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, which is abbreviated as MAIS. In many cases, occupants may sustain multiple injuries and each injury is given an injury severity score based on different injured body regions. Out of these different scores, the maximum severity score is considered as the individual's overall injury severity, and expressed in terms of MAIS.

The injury costs given in Table 4.4 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 for this conversion. Those conversion factors are shown in Table 4.5 and the updated injury cost figures based on KABCO injury scale are shown in Table 4.6. It should be noted that the use of those conversion factors may affect the accuracy of estimated economic benefits since they are based on national data.

To estimate the total economic savings, the estimated injury reductions in step 5 were multiplied by corresponding injury cost values from Table 4.3 or Table 4.6.

Table 4.5 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

Table 4.6 Cost of Injuries Developed by Blincoe et al. in KABCO Scale (2006 Dollars)

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

Step 7 - Adjustments

The CPI was used to update the injury costs from base year to current year economic conditions. Using CPI indices for the base year and the current year considered, the injury costs are updated by using the following equation (KDOT, 2006);

$$C_{TY} = C_{BY}\left[\frac{CPI_{TY}}{CPI_{BY}}\right] \tag{4.5}$$

where,

CTY= Updated cost in targeted year's economic conditions (i.e. current year)

CBY= Cost in base year's economic conditions

CPITY= CPI for the month of January of the current year

CPIBY = CPI for the month of January of the base year

The CPIs are published for every month of the year by the Bureau of Labor Statistics of the US Department of Labor (BLS, 2006). For example, to update cost of a fatal injury from 1994 dollars to 2006 dollars, the CPIs for the month of January in 1994 and 2006 are required. From BLS publications (BLS, 2006), those two values are found to be 146.2 and 198.3 respectively. From equation (4.5), the corresponding costs in 2006 dollars, C2006 is,

$$\mathrm{C}_{2006} = 2{,}600{,}000[\frac{198.3}{146.2}] = \$3{,}526{,}539$$

The costs estimated in step 6 are based on national average economic conditions. To convert those costs into State economic conditions, a State cost factor can be used. The State cost factor was estimated by taking the ratio between the national and Kansas per capita personal incomes (Blincoe, 1994). The per capita income figures are published by US Bureau of Economic Analysis for every quarter of the year (US BEA, 2007). The US per capita income for the year 2006 was \$ 34,471 while that value for Kansas was \$ 32,866. Thus, the estimated State cost factor is estimated to be 0.95.

4.3 Results

Results from each step described in section 4.2 are discussed in the following sections.

Step 3

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 4.2, which is 0.58. Using the equation (4.1), 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%, which is significantly lower than the observed usage rate of 69% in year 2005. Since there is no significant evidence to prove any improvements in seat belt usage from the base year, seat belt usage in potentially fatal crashes in the current year is assumed to be equal to the base year usage rate of 59%.

Table 4.7 shows the observed seat belt usage rates in Kansas from 1998 to 2005, along with seat belt usage rate among fatally injured occupants. The last column of Table 4.7 shows the estimated overall seat belt usage rates in potentially fatal crashes (including survivors) by using equation (4.1). Figure 4.1 shows the comparison between three seat belt usage rates: U_0, U_f, and U_t. It can be seen that seat belt usage among fatally injured occupants are significantly lower.

Table 4.7 Seat Belt Usage Rates among Fatally Injured Occupants and Observed Usage Rates in Kansas

Year	Observed Seat Belt Usage Rate (U_0)	Seat Belt Usage Rate among Fatally Injured Occupants (U_f)	Average Seat Belt Effectiveness	Seat Belt Usage Rate 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

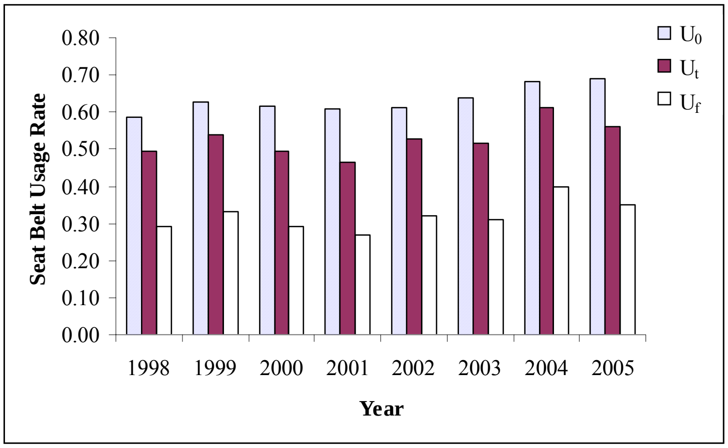


Figure 4.1 Comparison of Seat Belt Usage Rates

Based on U_0 and U_t values from Table 4.7, the estimated model form was found to be as follows;

$$U_t = 0.58869 * U_0 + 0.38075 * U_0{}^2 \tag{4.6}$$

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 predict U_t accurately at higher U_0 values. For example, theoretically, the model should predict a value of 100% for U_t when the value of U_0 is 100%. The model in equation (4.6) predicts U_t as 97% when U_0 is 100%.

The trend of increasing U_t at higher U_0 values may be different from what is observed at lower U_0 values. This is because, at higher observed seat belt usage levels, the remaining non-wearers could be considered as the highest risk takers and they are least likely to be convinced by any promotion programs or even by law enforcement programs. Therefore, use of same model for predicting U_t at all levels of U_0 may not be very accurate. Kansas has a current seat belt usage rate of 69% with a secondary seat belt law. The expected future seat belt usage rate through safety belt promotion programs or any other means could be considered to fall in the range of 80-85%. Therefore, this study considered a targeted maximum future usage rate of 85%, which was in fact the average seat belt usage rate in States with a primary seat belt law in year 2006 (Glassbrenner, 2007) . Thus, the targeted range of seat belt usage rate in this study is 69 – 85%. Within this range, the model developed in this study could be expected to provide accurate enough predictions of U_t. The predicted U_t values for the above range of U_0 are shown in Table

4.8. Table 4.9 summarizes the results from steps 1 to 3 which can be considered as the inputs for the next steps of the estimation procedure.

Table 4.8 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 4.9 Summary of Results 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

Steps 4 & 5

Assume that the observed seat belt usage rate will be increased by 1% from the present usage of 69%. From Table 4.7, the seat belt usage rate in potentially fatal crashes is 60% when the observed rate is 70%. Since the current seat belt usage rate in potentially fatal crashes is 58%, from equation (4.3), 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 seat belt usage rate increases by 1%. By using equation (4.4), the total reduction in fatalities, FR can be estimated as:

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

Thus, 1% increment in seat belt usage from the current year's usage level is estimated to save 2 additional lives. Similarly, the reduction in other injures can also be estimated. Table 4.10 shows the summary of estimated injury reductions due to 1% increment in overall seat belt usage. It can be seen that 1% increment in seat belt usage would result in 0.8% reduction in both incapacitating and non-incapacitating injuries. In other words, 11 incapacitating injuries and 60 non-incapacitating injuries could be prevented if 1% more motorists were restrained.

Table 4.10 Estimated Injury Reductions due to a 1% Increment in Seat Belt Usage

Injury Severity	Frequency (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

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 4.10 should be multiplied by corresponding injury cost values from either Table 4.3 or Table 4.6. To obtain the adjusted economic benefits for local conditions, the above estimations are multiplied by the State cost factor of 0.96. Adjusted and unadjusted estimated economic benefits due to 1% increment in seat belt usage rate are shown in Table 4.11 and Table 4.12 based on the two injury cost categories. It can be seen that the difference between total estimated benefits from two injury cost categories is about $ 0.5 million. Only the estimations based on FHWA injury costs will be referred in the following discussions.

Table 4.11 Estimated Economic Savings due to 1% Increment in Seat Belt Usage (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

Table 4.12 Economic Savings due to 1% Increment in Seat Belt Usage (based on Injury Costs Developed by Blincoe et al.)

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

The total economic savings due to 1% increment in seat belt usage is about $ 13 million in 2006 dollars annually. About 52% of the total benefits (6.7 million) are due to reduction in fatalities, while reductions in incapacitating and non-incapacitating injuries have almost equal contributions to the total benefits.

Similarly, benefits were estimated for each 1% increment in seat belt usage rate until the final anticipated seat belt usage rate of 85% is reached. The expected injury reductions due to different increments in seat belt usage are shown in Table 4.13. Assuming no economic benefits at current seat belt usage level, the estimated economic benefits are shown in Table 4.14 and Figure 6.8 shows the trend of economic savings for different increments in current year's seat belt usage rate.

Table 4.13 Estimated Injury Reductions for Different Expected 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

From Table 4.13, it can be seen that if the observed seat belt usage rate reaches the anticipated rate of 85%, which is the average seat belt usage rate in States with primary seat belt law, 47 additional lives could be saved. In addition, this would result in reduction of about 184 incapacitating injuries and 968 non-incapacitating injuries. The reduction in possible injuries could be expected to be about 523. The values shown in parenthesis in Table 4.14 are the possible ranges of estimated benefits. Those ranges were estimated based on the estimated 95% confidence intervals for the seat belt effectiveness values. According to the estimated economic benefits, if the overall seat belt usage reaches a level of 85% from its current level, the resulted economic savings could be in the range of $ 173-378 million in 2006 dollars. If the observed seat belt usage in Kansas was equal to the national average 81% (2006), about $ 191 million (could range from $ 128-280 million) could have been saved. In other words, the economic loss due to lower seat belt usage in Kansas compared to national average usage in year 2006 was about $ 191 million. This could also be interpreted as the annual economic loss to the State due to lower seat belt usage by Kansas motorists based on 2006 seat belt usage rate.

Table 4.14 Estimated Economic Savings for Different Expected Future Seat Belt Usage Rates

Expected Future Seat Belt Usage Rate (%)	Increment (%)	Economic Benefits * (Million Dollars) (FHWA Injury Costs)	Economic Benefits * (Million Dollars) (Costs by Blincoe et al.)
69	0	0	0
70	1	13 (9 - 21)	14 (9-22)
71	2	30 (21- 42)	31 (22-45)
72	3	46 (30-66)	48 (30-71)
73	4	62 (42-88)	66 (43-93)
74	5	79 (54-112)	83 (56-119)
75	6	95 (62-137)	101 (65-145)
76	7	108 (74-161)	118 (77-171)
77	8	125 (83-186)	135 (86-197)
78	9	141 (95-207)	153 (99-219)
79	10	158 (107-231)	170 (112-246)
80	11	174 (116-256)	187 (120-271)
81	12	191 (128-280)	205 (133-298)
82	13	207 (140-304)	222 (146-324)
83	14	227 (152-329)	240 (158-350)
84	15	243 (161-353)	257 (167-376)
85	16	260 (173-378)	275 (180-401)

** In 2006 dollars*

Note: Values in parenthesis show the range of estimated economic benefits based on 95% confidence interval for estimated seat belt effectiveness values

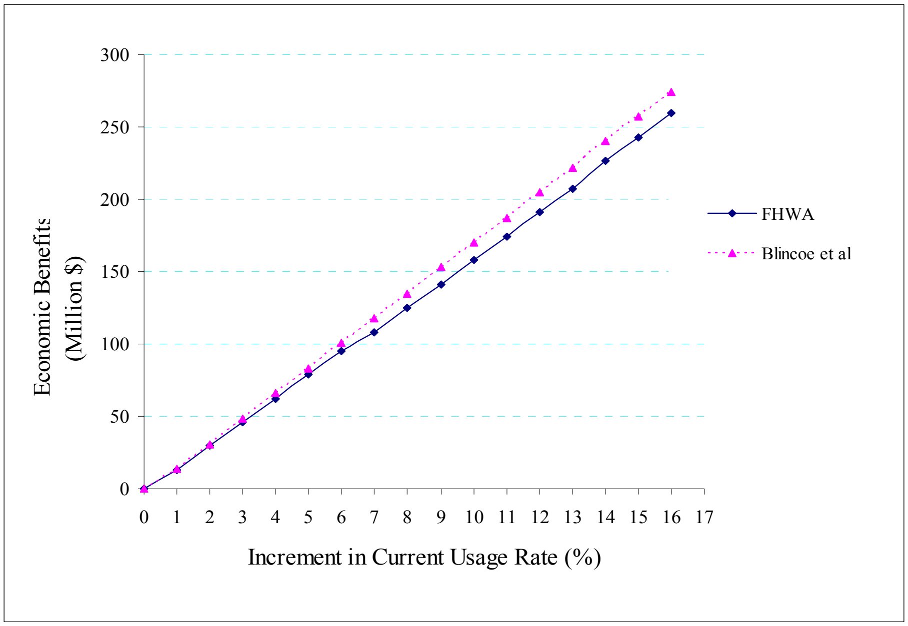


Figure 4.2 Estimated Economic Benefits due to Increased Seat Belt Usage

The estimated benefits in this study could be useful in many different applications. One such application would be to use them in benefit/cost analysis of seat belt promotion programs. For example, assume that the State of Kansas is planning to launch a safety belt promotion program which includes change of its secondary seat belt law to a primary law and a vigorous law enforcement program. Also assume that it is expected that this program would improve the current seat belt usage rate by 11%. Then the resulted benefits of the program could be directly obtained from Table 4.14 which could be in the range of $ 116-256 million in 2006 dollars. If the costs associated with the program are known, the benefit/coast ratios can be estimated.

The benefit estimation procedure illustrated in the above sections was based on seat belt effectiveness values obtained from multiple logistic regression method. To study the effects of different seat belt effectiveness values used in the estimation process on the resulted economic benefits, different estimations were carried out using the seat belt effectiveness values obtained from different methods. The estimated benefits are shown Table 4.15 and the variation in the estimated benefits is shown in Figure 4.3.

Table 4.15 Estimated Economic Benefits Based on Different Seat Belt Effectiveness Values

Future Usage (%)	Increment (%)	Estimated Economic Savings			
		MLR	DPC	CLR	EEA
69	0	0	0	0	0
70	1	13	12	17	11
71	2	30	28	38	22
72	3	46	39	55	37
73	4	62	55	75	48
74	5	79	67	96	62
75	6	95	83	116	73
76	7	108	98	137	88
77	8	125	110	154	102
78	9	141	125	175	114
79	10	158	141	195	128
80	11	174	153	216	139
81	12	191	168	236	154
82	13	207	184	256	168
83	14	227	196	277	179
84	15	243	211	298	194
85	16	260	227	318	208

Note: MLR – Multiple Logistic Regression; DPC – Double Pair Comparison; CLR- Conditional Logistic Regression; EEA- Estimating Equation Approach

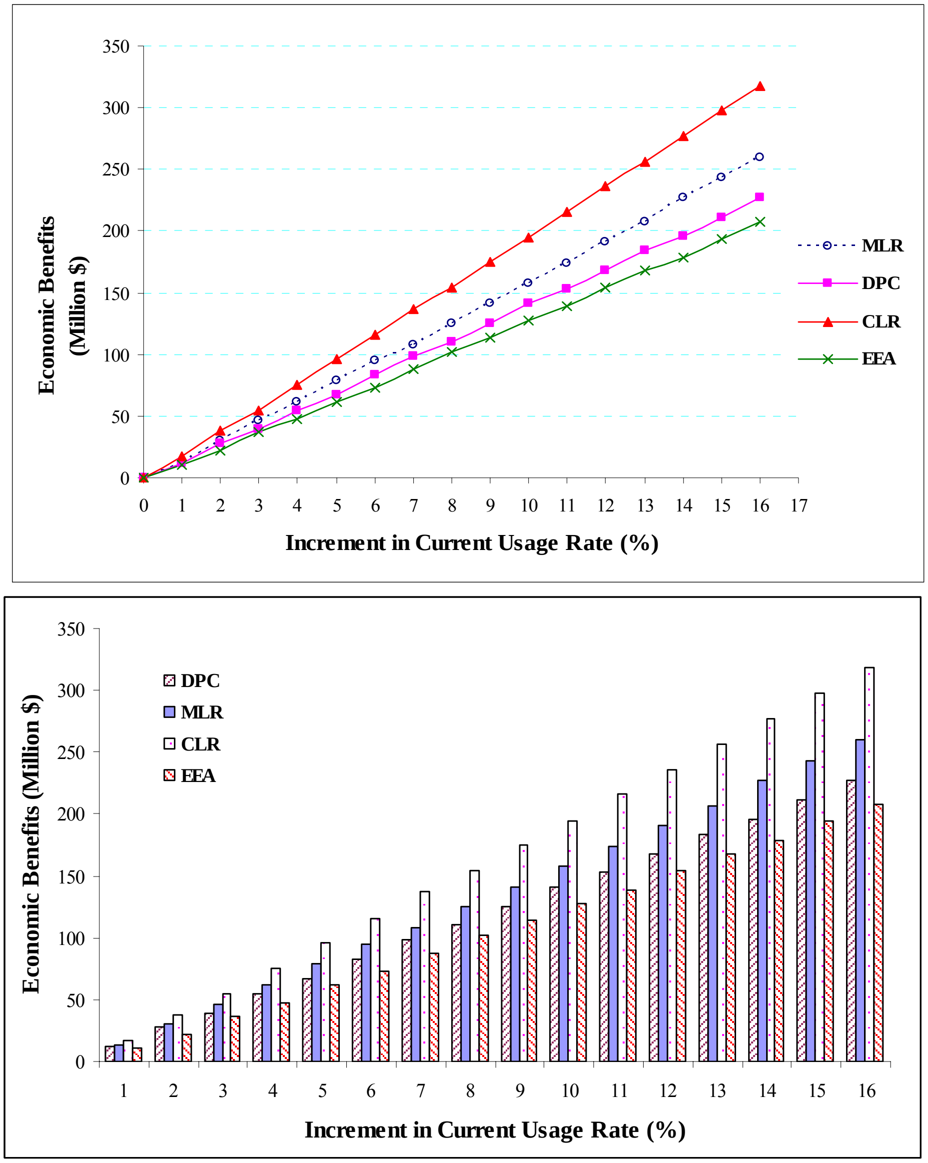


Figure 4.3 Variation in Estimated Benefits Using Different Seat Belt Effectiveness Values

It can be seen that the differences among the estimated benefits increases and become significant when the seat belt usage rate increases. For example, considering a future seat belt usage rate of 81%, the difference between the minimum and the maximum estimated benefits is about $82 million. Thus, it could be concluded that the seat belt effectiveness values used in the estimation process may have considerable effects on the estimated benefits, especially when the difference between current and future expected seat belt usage rate is high.

It should also be noted that the economic benefits estimated in this study only provide approximate figures and the exact benefits may vary. For example, this study did not consider rear-seat passengers in the analysis and that might have underestimated the total benefits that could be expected due to increased seat belt usage. In addition, there may be some concerns about the accuracy of data used in the analysis, especially data related to seat belt usage and injury severities, which may have affected the final estimations as well.

CHAPTER 5 - SUMMARY AND CONCLUSIONS

This study developed a procedure to estimate potential economic benefits associated with increased seat belt usage. A two-phased procedure was utilized. In the first phase, seat belt effectiveness in reducing injuries to motor vehicle occupants was estimated using different methods available. These methods included multiple logistic regression, double pair comparison method, Cox proportional hazards regression, conditional logistic regression, and risk ratio model using estimating equation approach. Results from each method were evaluated to identify strengths and limitations. Crash data from Kansas Accident Reporting System (KARS) database was used, and the estimations were based on KABCO injury scale. Two vehicle groups were considered: passenger cars, and other passenger vehicles, which included pickup trucks and vans. Only front seat occupants who were older than 14 years of age were considered in the analysis. In the second phase of the study, the potential economic benefits that could be expected due to increased seat belt usage by motorists were estimated. The estimated seat belt effectiveness values using logistic regression method were used to estimate potential injury reductions and those injury reductions were converted into economic values by using costs associated with each injury severity level. The injury costs used in this study were the FHWA recommended costs based on national data.

The conditional logistic regression method was found to overestimate seat belt effectiveness compared to other methods, as the estimated seat belt effectiveness values were significantly higher than those values from other methods. On the other hand, the lowest estimated seat belt effectiveness values were resulted from estimating equation approach, except for possible injuries. Significant variations were observed among the estimated seat belt effectiveness values using the selected methods for some injury severity categories. For fatal injuries, the estimated seat belt effectiveness values ranged from 50 - 69% for passenger cars and 57 to 70% for other passenger vehicles. The range of seat belt effectiveness values for incapacitating injuries was 47-65% for passenger cars and 44-69% for other passenger vehicles. The highest variation in estimated seat belt effectiveness values were observed for incapacitating injuries in other passenger vehicle group. The estimated seat belt effectiveness values for possible injuries had the lowest variation for both vehicle groups (33-39% for passenger cars and 28% 35 for other vehicles). It was found that the multiple logistic regression method provide relatively narrow confidence intervals for almost all the nonfatal injury categories in both vehicle groups. Based on the results, multiple logistic regression method was found to provide better estimations of seat belt effectiveness compared to the other methods.

According to the estimations using logistic regression method, seat belts are 56% effective in preventing fatal injuries when used by passenger car front seat occupants. In other passenger vehicles, seat belts are 61% effective in preventing fatalities. The seat belt effectiveness in reducing incapacitating injuries was found to be 53% in passenger cars and 52% in other passenger vehicles. In addition, seat belts are 55% effective in reducing non-incapacitating injuries to passenger vehicle occupants, while they are 51% effective in other passenger vehicles.

Based on the economic benefit estimations, it was found that, 1% increment in current seat belt usage could result in about $13 million savings to the State of Kansas. If seat belt usage in Kansas reaches the national average rate of 81% (2006), the resulted annual economic benefits is estimated to be about $ 191 millions (in the range of $ 128-280 millions) in 2006 dollars. In other words, due to lower seat belt usage among Kansas motorists compared to national usage rate, the annual estimated economic loss is about $ 191 millions. In addition, about 34 additional lives could be saved, if the 2005 usage rate of 69% could reach 81% level. It was also found that the seat belt effectiveness values used in the estimation process may have considerable effects on the estimated economic benefits, especially when the difference between current and future expected seat belt usage rate is high.

Different methodologies that are used to estimate seat belt effectiveness have different limitations and weaknesses and thus have advantages and disadvantages depending on the situation. Following is a summary of advantages and disadvantages of matched pair analysis methods in general.

Advantages:

- Capable of controlling for effects of many unobservable variables by considering occupants in the same vehicle

Disadvantages:

- Consider only vehicles with at least two passengers there by neglecting information from vehicles with a single occupant
- Difficult to apply in some cases where the data availability is limited (e.g. in fatal crashes)

In addition to the above mentioned points, the following section lists the advantages and disadvantages of the methods that are used to estimate seat belt effectiveness.

Multiple Logistic Regression Method:

Advantages:

- Consider information from all possible vehicles irrespective of the number of occupants involved
- The effects of many observed variables can be considered
- Can be applied to even small data samples
- Many available software applications can be used for the estimations

Disadvantages:

- The effects of variables related to differences between vehicles (nuisance parameters) can not be considered
- The estimations would be biased if the measured variables (covariates) are limited

Double Pair Comparison Method:

Advantages:

- Estimation procedure is straight forward
- No need of any special software applications (even a spread sheet application can be used)

Disadvantages:

- Effects of other variables can not be considered (some effects could be considered but require large data samples)
- The method cannot be applied to cases where there are no pairs with either both occupants are belted or not belted.

Cox PH Regression Method:

Advantages:

- Effects of some variables (such as occupant’s age, gender, seating position) can be considered
- Estimations could be more accurate since this is a nonparametric method especially when the probability distribution of injury risk is uncertain
- Many available commercial software packages can be used for the estimations

Disadvantages:

- The validity of the equal follow-up times may not be accurate in many cases
- Cannot be applied to estimate seat belt effectiveness for nonfatal injuries

Conditional Logistic Regression

Advantages:

- Effects of some occupant variables can be considered
- Many available commercial software packages can be used for the estimations

Disadvantages:

- Information from outcome concordant pairs (both occupants are injured) are not used in the estimation process
- Could overestimate the effectiveness

Estimating Equation Approach:

Advantages:

- Effects of some occupant variables can be considered
- Information from both outcome discordant and concordant pairs are used in the estimation

Disadvantages:

- Special computer programs need to developed since the available software packages can not be used for the estimation

Based on the above information, it could be concluded that the selection of a particular method to estimate seat belt effectiveness should be based on careful evaluation of crash data to be used and other relevant factors. Therefore, it is recommended to analyze the crash data to check if there are any extreme distributions of vehicle occupancy such as higher percentage of vehicles with single occupant, crash distributions (single vehicle vs. two-vehicle crashes), different vehicle distributions, and any other important factors. In addition, the availability of observed variables is also an important factor in selecting a suitable method

One of the main objectives of this study was to provide an initiative towards utilizing vital information that could be extracted from State highway crash databases in important safety analysis programs such as estimation of benefits associated with seat belt usage. One of the important requirements to launch such an initiative would be the availability of required information used in the estimation process. One such information is the seat belt effectiveness values based on injury severity scale used in local highway crash databases (i.e. KABCO scale). Currently, the seat belt effectiveness values are not available based on KABCO injury scale and thus the estimated seat belt effectiveness values in this study could be expected to provide a significant contribution in fulfilling that requirement.

None of the previous studies have compared seat belt effectiveness values using different methodologies for nonfatal injuries. Therefore, the results of this study could provide important information about those methodologies especially their limitations and weaknesses. In addition, this could be the first study that the estimating equation approach is applied to estimate seat belt effectiveness in reducing all types of injury severities.

The economic benefits estimated in this study are based on data (crash data and seat belt usage data) for year 2005. However, if these values are to be used in any future analysis and if crash data is available for more recent year than 2005, then that year should be considered as the base year and all the values should be updated using the new data. In addition, the injury costs should also be updated if any changes have been made to the original injury costs used in this study.

Since this study used injury related costs estimated based on national data to estimate economic benefits, they may not represent the actual State economic conditions although certain adjustments were made. Therefore, it is recommended using State specific cost values whenever they are available. Another noteworthy point at this level is that an important assumption made in the benefit estimation process. This study assumed that by wearing a seat belt the occupant is going to end up unharmed compared to an unrestrained occupant rather than assuming that the restrained occupant ends up with less severe injuries. For example, when estimating reductions in incapacitating injuries due to seat belt usage, it is assumed that those who were survived without being injured were unharmed (no injuries) and estimate the resulted benefits. However this is not the case in reality. Those who survived from receiving incapacitating injuries may still sustain some minor injuries (i.e. severity is lower than incapacitating such as non-incapacitating or possible injuries) and there might be some costs involved with these cases. Therefore, the real economic savings should be the net savings of those two (i.e. economic savings from the reduction of severe injuries due to the use of seat belt minus the costs related to minor injuries). However, this type of analysis require great deal of information related to crash victims and such information is rarely available.

It should be noted that the economic benefits estimated using the procedure developed in this study provide only approximate figures and the exact economic benefits that could be expected due to increased seat belt usage could be different from those estimated values. Therefore, it is recommended to round off the final estimations to reflect the fact that the estimated values are only approximations but not the precise dollar amounts.

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