EFFECTIVENESS OF SEAT BELTS IN REDUCING INJURIES: A DIFFERENT APPROACH BASED ON KABCO INJURY SEVERITY SCALE

By

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ABSTRACT

Although many States use KABCO (K-fatal, A-incapacitating, B-non-incapacitating, C-possible, O-no-injury) injury scale in reporting highway crash injuries, many important information are available in terms of Abbreviated Injury Scale (AIS) such as seat belt effectiveness in preventing injuries. This study estimates the effectiveness of seat belts in reducing both fatal and nonfatal injuries to motor vehicle occupants in terms of KABCO injury scale. Multiple logistic regression method was used to estimate the seat belt effectiveness for two different vehicle groups: passenger cars, and other passenger vehicles. Crash data from Kansas Accident Reporting System database was used. According to results, the estimated seat belt effectiveness in reducing fatal injuries was 56% in passenger cars and 61% in other passenger vehicles. In passenger cars, seat belts are 53% and 55% effective in reducing incapacitating and non-incapacitating injuries respectively. In other passenger vehicles, these values are 52% and 51% respectively. The estimated seat belt effectiveness values for fatal injuries are somewhat higher compared to previous estimations. In addition, results showed that seat belts are more effective in preventing fatal injuries compared to nonfatal injuries.

INTRODUCTION

Ever since seat belts were made mandatory in auto designs by Highway Safety Act and the National Traffic and Motor Vehicle Safety Act in 1965, it has been estimated that seat belts have saved many lives and prevented severe injuries to occupants in motor vehicle crashes (*1*). Because of substantial safety benefits from seat belts, many States have legislated laws to enforce the use of seat belts in motor vehicles. Currently, all states in the USA except New Hampshire, have seat belt enforcement laws of which, 21 states have primary seat belt laws while other states have secondary laws (*2*).

However, the estimated benefits due to use of seat belts are largely dependent on the effectiveness of seat belts in reducing a particular level of injury severity. The effectiveness of seat belts can simply be defined as the reduction of risk (or probability) of being injured due to use of seat belts when involved in a crash. The current seat belt effectiveness values used by the National Highway Traffic Safety Administration (NHTSA) were estimated in 1984 and they were based on crash data before 1984 (*3*). Since, the automobile designs have undergone dramatic changes and improvements during the last two decades, those effectiveness values may need to be reassessed to check their validity for current vehicle conditions using more recent data. In addition, the NHTSA seat belt effectiveness values have been estimated based on Abbreviated Injury Scale (AIS) but many of the States use KABCO (K-fatal, A- incapacitating, B- non-incapacitating, C- possible, O- no-injury) injury severity scale in reporting highway crash severities. Because of this incompatibility in injury severity scales, state agencies in analyzing safety impacts of seat belts. Thus, the availability of seat belt effectiveness values for KABCO injuries would be useful for such agencies.

Although, many studies have conducted to estimate the effectiveness of seat belts using more recent crash data, many of them have been focused only on estimating the effectiveness in preventing fatalities. Prevention of fatal injuries is more important and always results in higher benefits. However, for a comprehensive benefit analysis on seat belt use, the effectiveness of seat belts in preventing nonfatal injuries is also important. For example, a person who suffers from severe but nonfatal injuries due to a crash may become permanently disabled and associated cost could be very high due to high costs associated with medical and rehabilitation expenses, productivity lost and other related factors. Thus, effectiveness of seat belts in preventing other types of injuries is also important in estimating total benefits resulted from seat belt use.

Thus, objective of this study was to estimate seat belt effectiveness values using more recent crash data for both fatal and non fatal injuries based on KABCO injury severity scale.

LITERATURE REVIEW

The Final Regulatory Impact Analysis conducted by NHTSA in 1984 is a comprehensive study, which estimated the effectiveness of restraint systems in reducing fatalities and injuries (*3*). This study considered both types of seat belts, manual (both lap and lap/shoulder) and automatic (two-point and three-point), in addition to the effect of air bags alone and the combined effect of both air bags and seat belts. Data from two databases, 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 passengers who were injured due to the crash. The results showed that, the effectiveness of lap/shoulder belts in preventing fatalities was 40-50 % and 45-55 % 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, one of the shortcomings of this method was the difficulty in controlling the seat belt use for different factors due to the insufficient availability of crash data during the study time period.

To estimate the effectiveness of automatic shoulder belt system, Rivara et al. used multiple logistic regression method (*4*). The odds ratios were estimated for restrained vs. unrestrained occupants while controlling for confounding effects of factors such as occupant age and gender, principle direction of force, automobile model year, change in the speed during the crash, and air bag deployment. The automatic seat belts were considered in two categories, which consisted of shoulder plus lap belts and shoulder belts alone, and manual shoulder and lap belts were considered in the other category. The effectiveness was estimated using data from Crashworthiness Data System (CDS) for the period of 1993 to1996 against fatalities and injuries which had an Abbreviated Injury Scale (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, which is called double pair comparison method, has been widely used by many researchers to estimate the effectiveness of seat belts (*5*). The rationale behind this method is that it compares injury risk to a subject occupant and other occupant under two conditions, restrained and unrestrained. Since the method compares two passengers in the same vehicle, it allows controlling for confounding effects of some variables such as traveling speed, vehicle type and make, age of the vehicle and crash type.

The double pair comparison method has been applied by many studies to estimate the seat belt effectiveness. Evans used this method to estimate the seat belt effectiveness in preventing fatal injuries based on crash data from Fatality Accident Reporting System (FARS) for the period of 1975 to 1983 (*6*). 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.

Evans 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 (*7*). The subject occupant was considered as the right or left rear seat occupant. The subject occupant was compared with other occupants such as driver, right front passenger and right or left rear passengers depending on the subject occupant under consideration. It was assumed that the rear seat passengers use only lap belts due to the lack of reliable information on exact restraint type in the database. The estimations showed that the average restraint effectiveness against fatalities for rear seat passengers (left and right passengers only) is between 9 to 27 %.

Kahane estimated the fatality and injury reducing effectiveness of lap belts for back seat occupants using double pair method (*8*). 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 and other injury severity levels. These injury severity levels were classified as, serious injuries (category “A” in KABCO scale or fatal), moderate to serious (category “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%.

Kahane 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 latest FARS data (*9*). An empirical tool was developed to adjust for the biases in double pair analyses of later FARS data. Results reconfirmed the NHTSA's earlier effectiveness estimates of 45% for passenger cars and 60% for light trucks against fatalities.

Cummings et al. study 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 (*10*). Mantel-Haenszel stratified method, the double pair comparison method and regression methods including conditional Poisson regression, and Cox proportional hazards regression methods 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. used matched-pair cohort methods to study the seat belt effectiveness in motor vehicle crashes (*11*). Conditional Poisson regression was used to estimate the effectiveness of seat belts while controlling for confounding variables such as occupant gender, seat position and age. 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 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 (*12*). 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).

The available literature on past studies indicates that many of the previous studies have focused only on estimating seat belt effectiveness in preventing fatalities. In addition, many of those studies have used matched-pair analysis techniques, thereby limiting the analysis only to vehicles containing one front seat passenger in addition to the driver. However, factors associated with vehicles containing only the driver may differ from vehicles containing driver and a front seat passenger. On the other hand, vehicles with two front seat passengers may not represent a considerable proportion of all vehicles involved in crashes. Sample size may further reduce as matched-pair methods consider only pairs in which at least one occupant had the outcome (the injury severity) hence increasing the sampling errors. For example, in Kansas during 10 year period from 1993 to 2002, there were only 23% of vehicles which were occupied by two passengers (including the driver) and involved in crashes, and this proportion reduced to 16% when vehicles with no reported occupant injuries were excluded. Thus, the use of seat belt effectiveness values estimated using matched-pair methods for all crashes may not be a very reasonable approach.

Many studies have examined the potential effect of unrestrained occupants on a subject occupant in a motor vehicle crash. MacLennan et al. studied the effect of unrestrained occupants on the injury risk of front seat occupants (*13*). They considered different subject occupants at risk based on different seating positions and initial direction of force. Results showed that belted occupants are at an increased risk of injury and death from unbelted occupants. Cummings and Rivara studied the association between death of a car occupant and the restraint use by other occupants (*14*). They found that a person's risk of death in a crash is associated with the restraint use of other occupants and the risk is lowest when all occupants were restrained. Mayrose et al. found that in the case of a head-on crash, a rear-seat unbelted occupant who is sitting right behind the driver increases the risk of fatal injuries to the driver (*15*). Thus, the presence of other unrestrained occupants in the same vehicle is an important factor in estimating seat belt effectiveness for the subject occupant.

Evans investigated the possible biases in double pair method due to non-coding of some surviving passengers, and driver/passenger impact during crashes (*16*). Evans found that fatality risk of an unbelted driver is decreased by striking passenger and passenger risk is increased by being struck by unrestrained driver in the case of a right-side impact.

The above studies provide evidence about the importance of considering the effects of other unrestrained occupants in estimating seat belt effectiveness of a subject occupant. The logistic regression method in which the odds ratios (or relative risk) between restrained and unrestrained occupants are estimated, could be expected to eliminate possible biases in matched-pair methods, since this method considers all possible cases (both single occupant and multi occupant cases). Another advantage of the logistic regression method is that it gives the flexibility to control for confounding effects of many factors which may affect the seat belt effectiveness. Thus, this study uses the logistic regression method to estimate the seat belt effectiveness.

METHODS AND DATA

Data

Kansas Accident Reporting System (KARS) database was used in this study to estimate the effectiveness of seat belts. Data related to all vehicles, which were involved in crashes during 1993 and 2002, were extracted from the database. Only front seat passengers of passenger cars, vans and pickup trucks were considered in the analysis. Since the data availability for vans was limited, especially in the case of fatal crashes, pickup trucks and vans were combined and considered as a single group. Thus, the estimations were based on two vehicle groups, passenger cars and other passenger vehicles. Occupants younger than 15 years were discarded from the data set as Kansas has a primary seat belt law for that age category compared to a secondary law for occupants older than 14 years. In addition, data related to crashes involving pedestrians, bicyclists, motorcycles and trains were discarded. The final data set contained crash data related to single-vehicle and multi-vehicle crashes.

The restraint usage comprised of 3 categories, both shoulder and lap belt, shoulder belt only and lapbelt only in addition to unknown and none-used categories. Records with unknown restraint use were discarded from the data set. However, KARS database did not have any information regarding the air bag deployment due to the crash and thus, that variable was not considered in the models. Based on the final data set, details of seat belt use by front seat passengers with the type of seat belts used are shown in Table 1.

TABLE 1 Seat Belt Usage by Front Seat Passengers based on KARS data from 1993 to 2002

Crash Type (Severity)	Occupant	Type of Seat Belt Used					Total Involved	% Seat Belt Use
		Lapbelt Only	Shoulder belt only	Lap & Shoulder belts	Total Used	None Used		
Fatal	Driver	30	1637	15	1682	2417	4099	41.03
	FRP*	12	574	4	590	825	1415	41.70
	Total	42	2211	19	2272	3242	5514	41.20
Incapacitating	Driver	309	13440	46	13795	7685	21480	64.22
	FRP	82	3826	15	3923	2833	6756	58.07
	Total	391	17266	61	17718	10518	28236	62.75
Non-incapacitating	Driver	2279	84232	171	86682	26838	113520	76.36
	FRP	538	21698	57	22293	9998	32291	69.04
	Total	2817	105930	228	108975	36836	145811	74.74
Possible	Driver	2646	122802	191	125639	18140	143779	87.38
	FRP	558	29912	34	30504	6429	36933	82.59
	Total	3204	152714	225	156143	24569	180712	86.40

** FRP –Front Right Passenger*

The injury severity is reported in 5 levels in the KARS database, which includes fatal injury, incapacitating injury, non-incapacitating injury, possible injury and no-injury. The crash severity was defined based on the highest reported injury severity of involved occupants. Thus, the data set contained data related to five different crash types depending on the crash severity. The level of risk involved in two different crash types may be different. For example, two occupants, who were recorded to have same personal injury severities, but involved in crashes with different severities, may not experience the same level of risk. Thus, considering these two occupants in two different crash categories would minimize any biases in estimated seat belt effectiveness.

Thus, the total data set was split into 5 different data sets based on crash severity and the data set related to property damage only crashes was discarded. Fatal crashes contained occupants with all 5 types of injury severities, non-incapacitating crashes contained 4 injury severities except fatalities, incapacitating category had 3 injury types and possible injury crashes only contained occupants with minor injuries and no injuries. These data sets were then used to estimate the seat belt effectiveness in reducing each injury severity level.

Method

Details of logistic regression method that was used to estimate the seat belt effectiveness are given in this section. The response variable for the logistic regression model was the injury severity of an occupant, which was considered as a binary variable. If the conditional probability that a particular injury severity level is present be denoted by $P(Y = 1 | X) = \pi(X)$ for a given set of p covariates (i.e. $X = x_1, x_2, x_3 \ldots x_p$), then the multiple logistic regression model could be written in the following form (*17, 18*);

$$\operatorname{logit}[\pi(X)] = \alpha + \sum_{i=1}^{p} \beta_i X_i \quad (1)$$

and,

$$\pi(X) = \frac{e^{[\sum_{i=1}^{p} \beta_i X_i]}}{1 + e^{[\sum_{i=1}^{p} \beta_i X_i]}} \tag{2}$$

where,

β = Regression parameters to be estimated

α = Intercept parameter to be estimated

Consider a dichotomous explanatory variable, x which takes value 1 or 0 representing two conditions. Then, the odds ratio for this particular variable can be defined as the ratio between odds for outcome being present when x=1 and x=0. This can be expressed in the following formula.

$$OR = \frac{\pi(1)/[1-\pi(1)]}{\pi(0)/[1-\pi(0)]} \tag{3}$$

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

Odds ratio explains the relative risk between two occupants, who are under two different conditions, to experience a particular injury severity. In this case, the odds ratio for the explanatory variable related to restraint use, which takes value 1 when restrained and 0 when unrestrained, gives the relative risk between restrained and unrestrained occupants for having a particular injury severity. If the restraint system is not effective, 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,

$$E = (1 - OR) * 100 \tag{4}$$

where,

E = Effectiveness of the restraint system (%)

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

The injury severity was considered in 4 different levels, fatal, incapacitating, non-incapacitating and possible injuries. For a particular crash category, the highest injury severity level was coded as the event (value 1), while all other injury severity levels were coded as non-events (value 0). For example, in the case of a fatal crash, the response variable takes value 1 for a passenger with fatal injuries and it takes value 0 for a passenger with nonfatal injuries. Total of four different models were developed for each injury severity level using the 4 data sets.

The potential explanatory variables were selected based on findings of previous studies and judgment. The selected candidate variables and their representation in the model are shown in Table 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 lack of available information. One such variable was the direction of initial force. Data related to this variable was only available for fatal crashes in the KARS database. However, the database consisted of data related to the manner of the collision of vehicles such as head-on, angle, sideswipe or rear-end, in cases where two or more vehicles were involved and therefore considered as a surrogate measure of the direction of impact.

TABLE 2 Selected Candidate Variables for Logistic Regression Models

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

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 control for vehicle mass in the models, it was assumed that controlling for different vehicle types would minimize this effect.

Logistic regression was performed using LOGISTIC procedure of the SAS software (*19*). For each injury severity level, two models were developed, a crude model with only one variable that is related to seat belt use and an adjusted model with controlling for all the explanatory variables. The idea was to examine the effect of those variables on seat belt effectiveness by comparing crude and adjusted odds ratios.

The adjusted models was developed using stepwise selection technique, which is an inbuilt feature provided in SAS's LOGISTIC procedure. In this method, the model building starts with no variable 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 toward the outcome. The quality of each model was assessed by using R^2 values and other model fitting statistics.

RESULTS AND DISCUSSION

Estimated regression parameters and odds ratios for logistic regression models for passenger cars are shown in Table 3.

TABLE 3 Estimated Logistic Regression Parameters and Odds Ratios for the Passenger Car Occupant Models

Variable	Fatal		Incapacitating		Non-incapacitating		Possible	
	Parameter	Odds Ratio	Parameter	Odds Ratio	Parameter	Odds Ratio	Parameter	Odds Ratio
ALCOHOL	-	-	-	-	0.28	1.32	-	-
ANGLE_CRASH	-	-	-0.10	0.91	-0.22	0.81	-	-
ARTERIAL	-	-	-	-	-	-	-0.07	0.94
BLACK_RD_TOP	-	-	0.12	1.13	-	-	-	-
COLLECTOR	-	-	-	-	0.07	1.07	-	-
DR_AT_FLT	0.50	1.65	-	-	-0.18	0.84	-0.87	0.42
DRIVER	0.64	1.90	0.32	1.37	0.30	1.36	0.25	1.28
HDON_CRASH	-	-	0.20	1.22	-	-	-	-
INTERSTATE	-	-	-	-	-	-	-0.07	0.94
INTR_SECN	-0.30	0.74	-	-	-	-	-	-
OCC_AGE	0.03	1.04	0.01	1.01	0.01	1.01	0.01	1.01
OCC_EJECT	1.68	5.35	1.57	4.82	1.63	5.10	1.51	4.51
OCC_MALE	-	-	-0.74	0.48	-0.67	0.51	-0.85	0.43
OCC_TRAPPED	1.96	7.07	2.46	11.76	2.54	12.62	2.30	9.98
RD_CUR_GRAD	-	-	-	-	0.06	1.07	0.04	1.04
REAREND_CRASH	-	-	-	-	-0.19	0.83	-	-
RURAL	-	-	-0.11	0.90	-	-	-	-
SE_USED	**-0.83**	**0.44**	**-0.76**	**0.47**	**-0.80**	**0.45**	**-0.50**	**0.61**
SNG_VEH_CRASH	0.34	1.40	0.84	2.32	1.12	3.05	1.66	5.24
POSTED_SPEED	-	-	-	-	-	-	-	-
URBSP	-	-	-	-	-	-	-	-
VEH_AGE	-	-	-	-	-	-	-	-
VEH_AT_FLT	-	-	-	-	-	-	-0.63	0.53
VEH_DESTROY	1.53	4.62	1.46	4.32	1.74	5.68	1.72	5.61
VEH_DISABLED	0.93	2.53	1.16	3.20	1.22	3.40	1.23	3.44
VEH_STRAIGHT	-	-	-	-	-	-	-0.24	0.79
VEH_TURN	-	-	-0.14	0.87	-	-	-0.09	0.92
WEEK_DAY	-	-	0.18	1.19	-	-	-	-
R2	0.42		0.30		0.24		0.20	

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

The model for fatal crashes seems to fit better, since it has a comparatively higher R^2 value. Although, the R^2 values for models for low injury severity levels are relatively low, more variables are significant in those models. The model results for the other passenger vehicle group also showed similar trends.

Table 4 shows the estimated seat belt effectiveness values with their error margins and R^2 values for both vehicle groups. All models fit reasonably well with the data as indicated by higher R^2 values. However, the errors of estimations are higher for the other passenger vehicle group. A significant change in estimated seat belt effectiveness values can be observed when the seat belt use is adjusted for different factors. This change is comparatively higher for low severity models. Thus, it could be concluded that some of the considered variables have a significant effect on seat belt effectiveness.

TABLE 4 Estimated Seat Belt Effectiveness and Model R^2 Values for Each Vehicle Group

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

** E= seat belt effectiveness*

According to the results, seat belts are 56% effective in preventing fatalities to front seat occupants in passenger cars. In other words, 56% of fatalities could be prevented if all the front seat passengers are restrained. This value is higher compared to NHTSA's estimated value of 45% for fatal injuries. As far as nonfatal injuries are concerned, seat belts are more effective in reducing non-incapacitating injuries (55%) compared to incapacitating injuries (53%). It can be observed that the estimated seat belt effectiveness values for fatal injuries and severe nonfatal injuries (incapacitating and non-incapacitating injuries) are very close to each other. However, both of those values are higher than the effectiveness values used by NHTSA for nonfatal injuries (50%) defined as moderate to severe injuries (MAIS 2 -5). In addition, seat belts are 33% effective in reducing possible injuries to passenger car occupants and this value is significantly higher than that value recommended by NHTSA, which is 10%.

In other passenger vehicles, seat belts are 61% effective in preventing fatal injuries to front seat occupants which is very close to NHTSA's estimation of 60%. However, the error of estimated seat belt effectiveness for fatal crashes is higher compared to that error for passenger cars. This may be due to the use of smaller sample size used for other passenger vehicles compared to passenger cars. Seat belts are 52% effective in reducing incapacitating injuries and 51% effective in reducing non-incapacitating injuries. Again, both the values are less than the value estimated by NHTSA for nonfatal injuries (65%). The seat belt effectiveness for possible injuries in this vehicle group is 34%, which is slightly higher than that value for passenger cars.

According to the results, seat belts are more effective in reducing fatal injuries than nonfatal injuries, which is somewhat different from some previous findings that seat belts are more effective in reducing nonfatal injuries. There might be many possible reasons for these differences. One reason could be the use of different injury severity scale for defining injuries in this study. The accuracy of the police reported KABCO injury severities are often criticized for their accuracy over AIS injury severities, which are reported by experienced medical officials at a hospital. This is more critical in case of nonfatal injuries, as the police officer at the scene has to decide and report the level of the injury severity, which may be different from hospital reported injury severity which are based on thorough medical examinations by experienced medical officers. In addition, the decision taken by the individual officers at the crash scene may be dependent on personal judgment of each individual and thus the recorded data might not be accurate. Shinar et al. found that injury severity is one of the least reliable variables in police reported data and some times could extremely mislead the users (*20).*

Another concern is the accuracy of the data related to seat belt use, especially for low severity crashes, since the accuracy of the estimated seat belt effectiveness values depends on the accuracy of the data used. According to Table 1, the reported seat belt use in incapacitating crashes is 75 % and in possible injury crashes it is 86%, which are even higher than the Kansas average seat belt use during that period of time. Data related to seat belt use in a fatal crash, in which at least one dead occupant is involved, could be expected to be more accurate (*11*). The over reported seat belt use in low severity crashes may result in biased estimations of seat belt effectiveness.

Overall, the estimated seat belt effectiveness values against fatalities in passenger cars are higher compared to some previous estimations of 45% while that value for other vehicle groups is almost same (60% Vs 61%) (*3, 6, 9*). Although, this study estimates higher effectiveness value for fatal injuries in passenger cars, that value is still within the upper limit of the NHTSA estimation of 45-55% (*3*). Some other studies have also estimated higher seat belt effectiveness values for fatal injuries (*4, 11*). In cave of nonfatal injuries, the estimated values based on KABCO scale gives higher estimated seat belt effectiveness values compared to previous estimations based on AIS injury severity scale. For other passenger vehicles, the estimations based on KABCO injury severities are somewhat low compared to estimations based on AIS injuries. One reason for the change in estimations may be due to the effect of air bags, which was not possible to be considered in this study. Another reason may be the difference in study periods since there could be a lot of differences in the condition of the vehicles between those time periods.

It should be noted that, although the estimated seat belt effectiveness values based on two different injury severity levels are compared, it may not be a logical comparison especially in case of nonfatal injuries. The reason is that, the two injury severity scales have different levels and different procedures of reporting. For example, AIS has 5 different severity levels for nonfatal injuries, while KABCO scale only has 4 nonfatal injury levels.

CONCLUSIONS

Seat belt effectiveness was estimated using logistic regression method based on KABCO injury severity scale. Two vehicle groups were considered namely, passenger cars and other passenger vehicles (vans and pickup trucks). Seat belt use was controlled for different factors to account for possible confounding effects.

The estimated seat belt effectiveness in reducing fatal injuries was 56% in passenger cars and 61% in other passenger vehicles. In other words, 56% of fatalities could be prevented if all the front seat occupants use seat belts in passenger cars and 61% of fatalities related to other passenger vehicles could be prevented if all the front seat occupants are restrained. Seat belts are

53% and 55% effective in reducing incapacitating and non-incapacitating injuries in passenger cars while 33% effective for possible injuries. In other passenger vehicles, 52% of incapacitating injuries and 51% of non-incapacitating injuries could be prevented if all front seat passengers are restrained. Seat belts are 34% effective in reducing possible injuries in other passenger vehicles.

The estimated seat belt effectiveness values for fatal injuries are higher compared to previous estimations. In addition, results showed that seat belts are more effective in preventing fatal injuries compared to nonfatal injuries.

The logistic regression method could be considered to provide more accurate estimations compared to other methods, since logistic regression method considers all possible vehicles irrespective of the number of occupants involved, which could be considered as a well representative data sample. Another advantage of logistic regression method is that seat belt use can be controlled for possible confounding effects of certain factors. However, still there are concerns about the accuracy of the estimated seat belt effectiveness values due to the accuracy of the data used, especially data related to seat belt use.

The use of KABCO injury severities in estimating seat belt effectiveness may be a concern due to the issues related to the accuracy of the police reported data. Therefore, further assessments based on future research work are needed before finalizing the seat belt effectiveness values based on KABCO severity scale. Such research work may include the use of more accurate police reported data. This can be done by making necessary corrections to the original police reported data after comparing with hospital data. In addition, inclusion of more variables into the model such as speed of the vehicle, vehicle mass, direction of principle impact would also a possibility. Finally, the seat belt effectiveness values based on KABCO injury severities would be very useful for many agencies in assessing the effectiveness of restraint systems in motor vehicles.

REFERENCES

1. Blincoe, L., A. Seay, E. Zaloshnja, T..Miller, E. Romano, S.Luchter, and R.Spicer. *The Economic Impact of Motor Vehicle Crashes, 2000.* Publication DOT HS 809 446. NHTSA, U.S. Department of Transportation, 2002.

2. National Highway Traffic Safety Administration, U.S. Department of Transportation, http://www.nhtsa.dot.gov/people/outreach/state_laws-belts04/safeylaws-states.htm, Accessed, April, 2006.

3. *Final Regulatory Impact Analysis Amendment to FMVSS No 208. Passenger Car Front Seat Occupant Protection*. NHTSA, U.S. Department of Transportation, 1984.

4. Rivara, P., T.D. Koepsell, D.C.Grossman, and C. Mock. Effectiveness of Automatic Belt Systems in Motor Vehicle Crashes, *The Journal of American Medical Association*, Vol.283, No.21, 2000, pp.2826-2828.

5. Evans L. Double pair comparison - A New Method to Determine How Occupant Characteristics Affect Fatality Risk in Traffic Crashes, *Accident Analysis and Prevention,* Vol.18, No. 3, 1986, pp 217- 227.

6. Evans L. The Effectiveness of Safety Belts in Preventing Fatalities, *Accident Analysis and Prevention,* Vol.18, No. 3, 1986, pp 229- 241.

7. Evans L. Rear Seat Restraint System Effectiveness in Preventing Fatalities, *Accident Analysis and Prevention,* Vol.20, No. 2, 1988, pp 129- 136.

8. Kahane, C.J. Fatality and Injury Reducing Effectiveness of Lap Belts for Back Seat Occupants. SAE Paper 870486. Society of Automotive Engineers, Warrendale, PA, 1987.

9. Kahane, C. J. *Fatality Reduction by Safety Belts for Front Seat Occupants of Cars and Light Trucks, Updated and Expanded Estimates Based on 1986 – 99 FARS Data*. Publication DOT HS 809 199. NHTSA, U.S. Department of Transportation, 2000.

10. Cummings, P., B. McKnight, and N.S. Weiss. Matched-pair Cohort Methods in Traffic Crash Research, *Accident Analysis and Prevention,* Vol.35, 2003, pp. 131- 141.

11. Cummings, P., J.D. Wells, and F.P. Rivara. Estimating Seat Belt Effectiveness Using Matched-pair Cohort Methods, *Accident Analysis and Prevention,* Vol.35, 2003, pp. 143-149.

12. Cummings, P. Association of Seat Belt Use with Death: A Comparison of Estimates Based on Data from Police and Estimates Based on Data from Trained Crash Investigators, *Injury Prevention*, Vol.8, 2002, pp.338-341

13. MacLennan,P.A., G. McGwin Jr, J. Metzger, S. G. Moran, and L. W. Rue III. Risk of Injury for Occupants of Motor Vehicle Collisions from Unbelted Occupants, *Injury Prevention*, Vol.10, 2004, pp.363-367.

14. Cummings, P., and F.P. Rivara. Car Occupant Death According to the Restraint Use of Other Occupants: A Matched Cohort Study, *The Journal of American Medical Association*, Vol.291, No.21, 2004, pp.343-349.

15. Mayrose, J., D. Jehle, M. Hayes, D. Tinnesz, G. Piazza, and G.E. Wilding. Influence of the Unbelted Rear-seat Passenger on Driver Mortality: The Backseat Bullet, *Academic Emergency Medicine*, Vol.12, No.2, 2005, pp.130-134.

16. Evans, L. Examination of Some Possible Biases in Double pair Comparison Estimates of Safety Belt Effectiveness. *Accident Analysis and Prevention*, Vol.20, 1998, pp.215-18.

17. Hosmer, D.W., and S.Lemeshow. *Applied Logistic Regression,* 2nd ed. John Wiley & Sons, Inc., New York, 2000.

18. Agresti, A. Categorical Data Analysis, 2nd ed. John Wiley & Sons, Inc., New Jersey, 2002.

19. *SAS/STAT 9.1 User's Guide*, SAS Institute Inc., Cary, NC, 2004.

20. Shinar, D., J.R. Treat, and S.T. McDonald. The Validity of Police Reported Accident Data, *Accident Analysis and Prevention*, Vol.15, No.3, 1983, pp.175-191.