Effectiveness of Seat Belts in Reducing Injuries: A Different Approach Based on KABCO Injury Severity Scale

by Sunanda Dissanayake and Indike Ratnayake

This study uses the multiple logistic regression method to estimate the effectiveness of seat belts in reducing fatal and nonfatal injuries to occupants involved in motor vehicle crashes. Two vehicle groups - passenger cars, and other passenger vehicles that included vans and pickup trucks - were considered in estimating seat belt effectiveness values using highway crash data in Kansas. According to the results, the estimated effectiveness of seat belts in reducing fatal injuries is 56% for passenger car occupants and 61% for others. In passenger cars, seat belts are 53% and 55% effective in reducing incapacitating and non-incapacitating injuries, respectively. In the case of other passenger vehicles, corresponding values are found to be 52% and 51%.

INTRODUCTION

Ever since seat belts were made mandatory in auto designs by the 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 (Blincoe et al. 2002). Because of substantial safety benefits from seat belts, many states have laws to enforce the use of seat belts in motor vehicles. As of 2006, all states in the U.S. except New Hampshire have seat belt enforcement laws, of which 25 states have primary seat belt laws while other states have secondary laws (Glassbrenner 2006). Primary adult seat belt laws allow police officers to stop and cite a motorist for violation of the seat belt law. In the case of secondary seat belt laws, a motorist can be cited for violating the seat belt law only after having been stopped for an unrelated traffic violation.

The benefits of seat belts are estimated based on their ability to mitigate the impact due to a crash, thereby reducing the severity of injuries to the motorist, which is commonly referred to as the effectiveness of seat belts. In other words, the effectiveness of seat belts can be defined as the reduction of risk or probability of being injured due to the use of seat belts, when involved in a crash. The current seat belt effectiveness values used by the National Highway Traffic Safety Administration (NHTSA) (45% for fatal injuries and 60% effective for nonfatal injuries) have been estimated based on the Abbreviated Injury Scale (AIS) (NHTSA 2001). AIS is a method used to rank the injury severity based on a scale ranging from one (minor injuries) to six (fatal injuries). Intermediate injury severity categories based on AIS scale include moderate, serious, severe, and critical. However, many states in the USA use an injury severity scale, which uses five different levels to rank the injury severity (K-fatal, A- incapacitating, B- non-incapacitating, C- possible, O- no injury), in reporting injury severities due to highway crashes. This is commonly referred to as the KABCO injury severity scale. Because of this incompatibility in injury severity scales where they do not match except for fatal injuries, it might be difficult to use information from these two sources in safety analyses. For example, if a local or state agency utilizing the KABCO scale is interested in assessing the benefits of restraint use by motorists in terms of number of injuries prevented, the agency has to convert the local injury figures into the AIS scale. This might affect the accuracy of the estimation and may become challenging if the state does not have its own conversion factors based on local conditions. Since the availability of seat belt effectiveness values based on the KABCO injury severity scale would be very useful for such agencies, this study estimates the seat belt effectiveness values for both fatal and non-fatal injuries based on the KABCO injury severity scale.

LITERATURE REVIEW

The Final Regulatory Impact Analysis study conducted by NHTSA in 1984 estimated the effectiveness of restraint systems in reducing fatalities and injuries (NHTSA 1984). Both manual (lap and lap/shoulder) and automatic (two-point and three-point) seat belts were considered. Data from the National Crash Severity Study (NCSS) and National Accident Sampling System (NASS) for the period of 1979 to 1982 were used in the NHTSA study. The estimation method was based on rate of restrained and unrestrained occupants who were injured in highway crashes. The results showed that the effectiveness of seat belts in preventing fatal injuries was about 40-50%. Seat belts were estimated to be 45-55% effective in reducing nonfatal injuries. When lap/shoulder belts were combined with air bags, the estimated effectiveness was 45-55% for fatal injuries and 50-60% for nonfatal injuries. However, one of the shortcomings of this method was the difficulty in controlling for various other factors due to the insufficient availability of crash data during the study time period.

NHTSA later conducted a series of studies to evaluate the above estimated seat belt effectiveness values using more recent crash data (NHTSA, 1996a, 1996b, 1999, 2001). These studies were conducted using the data from Fatality Analysis Reporting System (FARS) and NASS Crashworthiness Data System (CDS). According to the latest study of this series, the effectiveness of seat belts alone in preventing fatal injuries 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 values. In this method, the odds ratios between restrained and unrestrained occupants are estimated for the seat belt usage while various other factors are being controlled. Walker (1996) discussed the use of the logistic regression method to estimate seat belt effectiveness using data from the Crash Outcome Data Evaluation System (CODES) where its application in different aspects such as methodology, assumptions, limitations, and possible biases and errors were discussed. Johnson and Walker (1996) applied the logistic regression method to estimate the seat belt effectiveness using CODES data for seven states. Many other factors such as occupant characteristics (age, gender), type of occupant (driver, passenger), location of crash (rural, urban), crash type, and speed limit were controlled so the true effects of seat belts could be estimated. The injury severity was classified in four different levels: died (level 1), died or inpatient (level 2), died, inpatient, or transported (level 3), and any injury (level 4).[1] They found that seat belts are 89% effective in preventing level 1 injuries and 52% effective in level 4 injuries (NHTSA 1996a). Authors also discussed the effect of over-reporting of seat belt usage on the estimated seat belt effectiveness values.

In order to estimate the effectiveness of the automatic shoulder belt system, Rivara et al. (2000) used the multiple logistic regression method. The odds ratios were estimated for restrained vs. unrestrained occupants while controlling for other factors such as occupant age and gender, principle direction of force, automobile model year, change in speed during the crash, and air bag deployment. The effectiveness was estimated using data from the Crashworthiness Data System (CDS) for the period 1993 - 1996 for fatalities and injuries, which had an AIS score of 2 or higher. The results indicated that automatic shoulder belts alone (without lap belt) reduce the fatality risk by 29% in frontal crashes and 34% for fatalities in all types of crashes.

A method introduced by Evans (1986a) called double pair comparison, has been widely used by many researchers to estimate the effectiveness of seat belts. The rationale behind this method is that it compares injury risk to a subject occupant and other occupant under two conditions: restrained and unrestrained. Since the method compares two occupants in the same vehicle, it allows controlling for effects of some variables such as traveling speed, vehicle type and make, age of the vehicle, and crash type. Evans (1986b) used this method to estimate the seat belt effectiveness in preventing fatal injuries based on crash data from the Fatality Accident Reporting System (FARS) for the period 1975 - 1983. The results showed that the overall seat belt effectiveness in preventing fatal injuries to front seat occupants in passenger cars to be around 41% with an error margin of about 3%. Kahane (2000) also 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. An empirical tool was developed to adjust for double pair analyses of later FARS data from 1986 to 1999. Results reconfirmed NHTSA's earlier effectiveness estimates of 45% for passenger cars and 60% for light trucks.

Cummings et al. (2003) used the Conditional Poisson Regression[2] 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 seat passenger is reduced by 61% when using seat belts. In another study, Cummings (2002) applied the same method to compare the estimated seat belt effectiveness of preventing fatalities based on police reported data and data obtained through trained crash investigators. The risk ratios for front seat occupants were estimated using data from the CDS database for 1988 to 2000, which includes information on seat belt 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 yielded the same results.

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

In addition, vehicles with two front seat occupants may not represent a considerable proportion of all the vehicles involved in crashes. Sample size may further be reduced as matched-pair methods consider only pairs with at least one occupant having the outcome (the injury severity), hence increasing the sampling errors. For example, in Kansas during the 10-year period from 1993 to 2002, only 23% of vehicles involved in crashes had two front seat occupants. This proportion reduces to 16% when vehicles with no reported occupant injuries were excluded. Thus, the use of seat belt effectiveness values estimated using the matched-pair methods to estimate overall effectiveness for all the crashes may not be a very reasonable approach.

The logistic regression method could be expected to eliminate possible biases in matched-pair methods, since this method considers all possible cases (both single occupant and multi-occupant vehicles). Another advantage of the logistic regression method is that it gives the flexibility to control other factors, which may affect seat belt effectiveness (Walker 1996). Thus, this study uses the logistic regression method to estimate the effectiveness of seat belts in reducing injuries. Additionally, since this study uses the KABCO injury severity scale instead of the AIS scale used by the previous studies, state agencies will have the capability of directly connecting the effectiveness values with the available crash data.

METHOD AND DATA

Data

Highway crash data from the Kansas Accident Reporting System (KARS) database was used for the analysis. Data related to vehicles involved in crashes between 1993 and 2002 were extracted from the database. Since the secondary enforcement seat belt law in Kansas is valid only for front seat occupants of passenger vehicles carrying fewer than 10 passengers, only front seat occupants of passenger cars, vans, and pickup trucks were considered in the analysis. Since the data availability for vans was limited, especially for fatalities, pickup trucks, and vans were combined and considered as a single vehicle group. Thus, the estimations were based on two vehicle groups: passenger cars and other passenger vehicles. Occupants younger than 15 years were discarded from the dataset since Kansas has a primary seat belt law for that age group, compared to a secondary seat belt law for occupants older than 14 years. In addition, data related to crashes involving pedestrians, bicyclists, motorcycles, and trains were also discarded. The final dataset included data related to single-vehicle and multi-vehicle crashes.

In the police reports, restraint usage is reported in three categories in addition to unknown and none-used categories: both shoulder and lap belt, shoulder belt only, and lap belt only. Records with unknown restraint uses were discarded from the dataset. The KARS database does not include any information regarding the air bag deployment due to the crash. Thus, the effect of air bags on seat belt effectiveness was not possible to be considered in the analysis. Based on the final dataset, details of seat belt use by front seat occupants are shown in Table 1.

Table 1: Seat Belt Usage by Front Seat Occupants Based on KARS Data From 1993 to 2002

		Number of Crashes						
Crash Type (Severity)	Occupant	Lap Belt Only	Shoulder Belt Only	Lap & Shoulder Belts	Total Used	None Used	Total Involved	% Seat Belt Use
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 Injuries	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

Personal injury severity is reported using five levels in the the KARS database: fatal injury, incapacitating injury, non-incapacitating injury, possible injury, and no-injury (property damage only). The crash severity was defined based on the highest reported injury severity sustained by an involved occupant. Based on this criterion, the dataset contained data related to five different crash types depending on crash severity. The level of risk involved in two different crash types might be different. For example, two occupants who were reported to have the same personal injury severity, but were involved in two different crashes with different crash 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 values.

Thus, the total dataset was split into four different datasets based on crash severity in such a way that the dataset related to fatal crashes included occupants with all five types of injury severities, the non-incapacitating crash dataset contained four injury severities except fatalities, the incapacitating category included three injury types, and the dataset for possible injury crashes only included occupants with possible injuries and unharmed (no-injury) occupants. These datasets were then used to estimate the effectiveness of seat belts in reducing each injury severity level.

Method

Details of the logistic regression method that was used to estimate seat belt effectiveness are discussed in this section. The response variable for the logistic regression model was the injury severity of an occupant, which was treated as a binary variable. If, the conditional probability that a particular injury severity level is present be denoted by $P(Y = 1 \mid X) = \pi(X)$ for a given set of p covariates (i.e. $X = x_1, x_2, x_3 \ldots x_p$), where π is a function of X, then the multiple logistic regression model of the log odds of π called the logit could be written in the following form (Hosmer et al. 2000, Agresti 2002);

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

and,

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

where,

β = Regression parameters to be estimated
α = Intercept parameter to be estimated
i = Covariate that varies from 1 to p

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

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

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

The 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 one when restrained and zero when unrestrained, gives the relative risk between restrained and unrestrained occupants to experience a particular injury severity. 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,

(4) $$E = (1 - OR) * 100$$

where,

E = Effectiveness of the restraint system (%)
OR = Odds Ratio between restrained and unrestrained occupants for a given injury severity, which explains the relative risk

For a particular crash category, the highest injury severity level was coded as the event with a value of one, while all other injury severity levels were coded as non-events (value zero). For example, in the case of a fatal crash, the response variable takes value one for occupants with fatal injuries, and takes value zero for occupants with nonfatal injuries. Four different models were developed for each injury severity level using the four datasets.

The potential explanatory variables for the models were selected based on the findings of previous studies and judgment. The selected candidate variables and their representation in the models 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 the lack of data. One such variable was the direction of initial force during a crash. However, the database contained data related to the manner of collision 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 data on those variables. Due to the importance of controlling for those two variables, posted speed limit was used as a surrogate measure of the actual vehicle speed. Even though it was not possible to consider vehicle mass, it was assumed that controlling the seat belt use for different vehicle types would minimize this effect.

Logistic regression was carried out using the LOGISTIC procedure of the SAS software (SAS Institute Inc. 2004). For each injury severity level, two models were developed: a crude model with only one explanatory variable in the model that is seat belt usage, and an adjusted model with all the explanatory variables. The idea was to examine the effect of those variables on seat belt effectiveness. Before the model development, the explanatory variables were tested for their independence by assessing the correlation between variables. Correlation coefficients were estimated and highly correlated variables (i.e. variables with correlation coefficients greater than 0.5) were not treated together in the variable list (SAS Institute Inc. 2004). When there were two highly correlated variables, each one was considered separately while everything else remained the same and modeling proceeded with the variable giving better model fit. The idea was to minimize any bias of having highly correlated explanatory variables in the model thereby violating basic model assumptions.

The adjusted models were developed using the 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 a given level of significance. Once a variable is added, its significance is checked with the variables that 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 set of variables. 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. 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 non-fatal crashes are relatively low, more variables are significant in those models. The model results for the other passenger vehicle group also showed similar trends.

Signs of all the coefficients in Table 3 are consistent with theoretical expectations. For example, the fatal crash model indicates that there are two variables with negative coefficients, INTR_SECN and SE_USED. This means that intersection related crashes and the use of seat belts are reducing the chance of having fatal injuries in crashes. On the other hand, DR_AT_FLT, DRIVER, OCC_AGE, OCC_EJECT, OCC_TRAPPED, SNG_VEH_CRASH, VEH_DESTROY, and VEH_DISABLED

Table 2: Selected Candidate Variables for Logistic Regression Models

Variable	Mean	Std. 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 an angle crash, =0 otherwise
ARTERIAL	0.62	0.49	=1 if the crash occurred on an arterial roadway, =0 otherwise
BLACK_RD_TOP	0.79	0.31	=1 if the road happened on a paved roadway, =0 otherwise
COLLECTOR	0.12	033	=1 if the crash occurred on a collector road, =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 passenger was the driver, =0 otherwise
HDON_CRASH	0.03	0.16	=1 if a head-on crash, =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 the 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_TRAPPED	0.01	0.10	=1 if occupant was trapped inside the vehicle, =0 otherwise
OCC_MALE	0.55	0.45	=1 if the occupant was male, =0 otherwise
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 a rear-ended crash, =0 otherwise
RFP	0.22	0.41	=1 if the passenger was in the right front seat, =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
SIDESWIPE_CRASH	0.12	0.22	=1 if a sideswipe crash, =0 otherwise
SNG_VEH_CRASH	0.15	0.35	=1 if the crash was a single vehicle crash, =0 otherwise
POSTED_SPEED	40.7	12.18	Posted speed limit in mph
URBSP	0.13	0.18	=1 if there was at least one unrestrained passenger in 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
WEEK_DAY	0.71	0.22	=1if the crash happened on a weekday, 0=otherwise
WET_RD_SURF	0.21	0.41	=1 if the crash occurred on a wet road surface, =0 otherwise

all have positive coefficients. Accordingly, all these variables tend to increase the chance of having fatal injuries.

Table 4 shows the estimated seat belt effectiveness values calculated based on Equation 4, with corresponding error margins and R^2 values for both vehicle groups. All models seem to fit satisfactorily with the data as indicated by acceptable R^2 values, consistent with what is normally observed in models based on crash data. However, the errors of estimations are higher for the other passenger vehicle group. Significant changes in estimated seat belt effectiveness values can be observed when the seat belt use is adjusted for other explanatory variables.

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

Variable	Fatal		Incapacitating		Non-incapacitating		Possible Injury	
	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	-	-	-	-	-	-
LIGHT_CON	-	-	-	-	-	-	-	-
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	-	-	-	-
WET_RD_SURF	-	-	-	-	-	-	-	-
R^2	0.42		0.30		0.24		0.20	

Variables are not significant in the model under 95% confidence level (Variables with values are significant)

The results in Table 4 indicate that seat belts are 56% effective in preventing fatal injuries to front seat occupants in passenger cars involved in crashes. 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. 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 found to be slightly more effective in reducing non-incapacitating injuries (55%) as compared to incapacitating injuries (53%). The estimated seat belt effectiveness values for fatal injuries and severe nonfatal injuries (incapacitating and non-incapacitating injuries) are very close. Both of those values are only slightly higher than the effectiveness values estimated by NHTSA for nonfatal injuries (50%) defined as moderate to severe injuries (AIS 2 - 5). In addition, seat belts are 33% effective in reducing possible injuries to passenger car front seat occupants involved in crashes.

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. **Adjusted-model with all variables. ***Crude-model with only the seat belt use variable.

In other passenger vehicles, seat belts are 61% effective in preventing fatal injuries to front seat occupants, which is nearly identical to NHTSA's estimation of 60%. Seat belts are 52% effective in reducing incapacitating injuries and 51% effective in reducing non-incapacitating injuries in this vehicle group. Both these values are smaller 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 of passenger cars.

The use of police-reported state crash data to estimate seat belt effectiveness may raise some concerns regarding the accuracy of such data, especially related to important variables such as injury severity and seat belt usage. The accuracy of the police reported KABCO injury severities are often criticized for their accuracy relative to AIS injury severities, which are reported by experienced medical officials at a hospital. Particularly, in 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 officers. In addition, those reported severities may be subjective due to the differences in individuals' judgments. For example, Shinar et al. (1983) found that injury severity is one of the less reliable variables in police reported data and sometimes could mislead the users.

The accuracy of data related to seat belt usage, especially in nonfatal crashes, may also affect the accuracy of the estimated seat belt effectiveness. According to Table 1, the 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. The reason for this over-reporting of seat belt usage may be the occupants' unwillingness to disclose the actual state of seat belt use to prevent any adverse consequences such as increased insurance premiums or fines. The over-reported seat belt usage may result in higher estimated seat belt effectiveness 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 fatally injured occupant is involved, could be expected to be more accurate (Cummings et al. 2003).

CONCLUSIONS

Effectiveness of seat belts in reducing injuries to front seat occupants of motor vehicle occupants involved in crashes was estimated using logistic regression method based on the KABCO injury severity scale. Two vehicle groups were considered: passenger cars and other passenger vehicles, which included vans and pickup trucks. The estimated seat belt effectiveness in reducing fatal injuries is 56% for occupants of passenger cars and 61% for other passenger vehicles. In other words, 56% of unrestrained front seat fatalities could be prevented if all the front seat occupants wore their seat belts in passenger cars. Seat belts are 53% and 55% effective in reducing incapacitating and non-incapacitating injuries in passenger cars, while they are 33% effective for possible injuries.

In other passenger vehicles, the effectiveness of seat belts in preventing incapacitating and non-incapacitating injuries is 52% and 51% respectively. Additionally, seat belts are 34% effective in reducing possible injuries in the other passenger vehicle group. The estimated seat belt effectiveness values for fatal injuries are higher compared to previous estimations by NHTSA. In addition, results for both vehicle types showed that seat belts are more effective in preventing fatal injuries as compared to nonfatal injuries.

The logistic regression method could be considered to provide more accurate estimations compared to other methods such as the double pair method, since the 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 the logistic regression method is that the effects of various other factors can be controlled for so that more accurate seat belt effectiveness could be estimated. However, there could be some concerns about the accuracy of the estimates due to the accuracy of the data used, especially data related to seat belt use and injury severity in the police reported crash data. Therefore, further adjustments based on future research work might be required to improve the accuracy of estimated seat belt effectiveness values based on the KABCO injury severity scale. Such research work may include the use of more accurate injury severities, which might be done by making necessary adjustments to the original police reported data by comparing with hospital records. However, in the absence of such capability, the estimates are reasonably accurate and the effectiveness values based on KABCO injury severities would be useful for many local agencies in assessing the benefits of motor vehicle restraint systems.

Endnotes

1. Typical severity categories have been combined for analysis purposes. A fatality in highway safety means "death within 30 days of the crash as a result of injuries due to the motor vehicle crash" and accordingly an injured person could be first an inpatient prior to death.

2. Conditional Poisson Regression and Logistic Regression are two alternative model formats commonly used in case-control studies to estimate the effects of selected covariates on the presence of an outcome.

References

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

Blincoe, L., A. Seay, E. Zaloshnja, T. Miller, E. Romano, S. Luchter, and R. Spicer. *The Economic Impact of Motor Vehicle Crashes 2000.* Report No. DOT HS 809 446, National Highway Traffic Safety Administration, U.S. Department of Transportation, Washington, D.C., 2002.

Cummings, P., J. D. Wells, and F. P. Rivara. "Estimating Seat Belt Effectiveness Using Matched-Pair Cohort Methods." *Accident Analysis and Prevention* 35, (2003): 143- 149.

Cummings, Peter. "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* 8, (2002): 338-341.

Evans, Leonard. "Double Pair Comparison - A New Method to Determine How Occupant Characteristics Affect Fatality Risk in Traffic Crashes." *Accident Analysis and Prevention*18 (3), (1986a): 217- 227.

Evans, Leonard. "The Effectiveness of Safety Belts in Preventing Fatalities." *Accident Analysis and Prevention* 18 (3), (1986b): 229- 241.

Glassbrenner, D. *Safety Belt Use in 2005 - Use Rates in the States and Territories*. Report No. DOT HS 809 970, National Highway Traffic Safety Administration, U.S. Department of Transportation, Washington, D.C., 2006.

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

Johnson, S.W. and J. Walker. *The Crash Outcome Data Evaluation System (CODES).* Report No. DOT HS 808 338, National Center for Statistics and Analysis, National Highway Traffic Safety Administration, Washington, D.C., 1996.

Kahane, Charles 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*. Report No. DOT HS 809 199. National Highway Traffic Safety Administration, U.S. Department of Transportation, Washington, D.C., 2000.

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*10, (2004): 363-367.

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* 12 (2), (2005): 130-134.

National Highway Traffic Safety Administration, U.S. Department of Transportation. *Report to Congress: Benefits of Safety Belts and Motorcycle Helmets, Based on Data from the Crash Outcome Data Evaluation System (CODES)*. Washington, D.C., 1996a.

National Highway Traffic Safety Administration, U.S. Department of Transportation. *Fifth / Sixth Report to Congress: Effectiveness of Occupant Protection Systems and Their Use.* Report No. DOT HS 809 442, Washington, D.C., 2001.

National Highway Traffic Safety Administration, U.S. Department of Transportation. *Final Regulatory Impact Analysis Amendment to FMVSS No 208. Passenger Car Front Seat Occupant Protection*. Washington, D.C., 1984.

National Highway Traffic Safety Administration, U.S. Department of Transportation. *Third Report to Congress: Effectiveness of Occupant Protection Systems and Their Use.* Washington, D.C., 1996b.

National Highway Traffic Safety Administration, U.S. Department of Transportation. *Fourth Report to Congress: Effectiveness of Occupant Protection Systems and Their Use.* Washington, D.C., 1999.

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* 283 (21), (2000): 2826-2828.

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

Shinar, D., J. R. Treat, and S.T. McDonald. "The Validity of Police Reported Accident Data." *Accident Analysis and Prevention*15 (3), (1983):175-191.

Walker, J. *Methodology Application: Logistic Regression Using the CODES Data*. National Center for Statistics and Analysis, National Highway Traffic Safety Administration, Washington, D.C., 1996.

Dr. Sunanda Dissanayake *is an associate professor of civil engineering at Kansas State University. Her primary research interests include various aspects of traffic engineering, highway safety, crash data analysis, and access management. She has published extensively in technical journals in addition to numerous presentations at various transportation conferences. She obtained her B.Sc. (Eng), M.Eng., and Ph.D. degrees from the University of Moratuwa, Asian Institute of Technology, and University of South Florida respectively.*

Indike Ratnayake *was a graduate research assistant in the Department of Civil Engineering at the Kansas State University. He holds a B.Sc. in civil engineering from the University of Moratuwa (2001), an M.S. (2005) and a Ph.D. (2007) in civil engineering from the Kansas State University.*