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Restraint Usage Characteristics and Other Factors Associated with Safety of Children Involved in Motor Vehicle Crashes

Sunanda Dissanayake[1] and Niranga Amarasingha[2]

1. Department of Civil Engineering, Kansas State University, Manhattan KS 66506, USA

2. Department of Civil Engineering, Sri Lanka Institute of Information Technology, Malabe, Sri Lanka

Abstract: Involvement in road traffic crashes as vehicle occupants is a leading cause of death and serious injury among children. The objective of this study was to investigate crash severity factors and child safety restraint use characteristics in order to identify effective countermeasures to increase children's highway safety. Characteristics and percentages of restraint use among child passengers aged 4~13 years were examined using highway crash data from Kansas. The association between restraint use, injury severity and characteristics of children involved in crashes were investigated using OR (odds ratios) and a logistic regression model, which was used to identify risk factors. Results showed that children, who were unrestrained, were seated in the front seat, traveling with drunk drivers and on rural roads, and traveling during nighttime was more vulnerable to severe injury in the case of motor vehicle crashes. The most frequent contributing causes related to crashes involving children included driver's inattention while driving, failure to yield right-of-way, driving too fast, wet roads and animals in the road. Based on identified critical factors, general countermeasure ideas to improve children's traffic safety were suggested, including age-appropriate and size-appropriate seat belt restraints and having children seated in the rear seat. Parents and children must gain better education regarding these safety measures in order to increase child safety on the road.

Key words: Child safety, child restraint use, severity model, logistic regression model, crash data analysis.

1. Introduction

Motor vehicle crash involvement is the leading cause of death among children aged 4~13 years in the United States, according to the data reported by CDC (Centers for Disease Control and Prevention). From 2004 to 2007, a total of 3,809 fatalities due to injuries sustained in car crashes were reported among 4- to 7-year-old children and were the primary cause of death among this age group. According to CDC data, the leading cause of death among children aged 8~13 years was also traffic-related injuries, indicating a total of 5,234 fatalities. These motor vehicle crashes accounted for 51% of child deaths from unintentional injuries. Over the last few decades, the safety of child occupants in motor vehicle crashes has become a major concern. Despite efforts to improve child passenger safety, the continued improvement of children's traffic safety remains a national need.

Child restraints are expected to hold children in place and prevent them from being ejected from the vehicle or hitting the vehicle interior, while simultaneously avoiding dangerous levels of crash force on vulnerable areas of a child's body [1, 2]. Child restraint systems refer to the use of child safety seats restrained by seat lap belts as recommended by the *Federal Motor Vehicle Safety Standard* [2]. Children aged 4~7 years are restrained in the vehicle in booster seats. Proper restraining of children is the responsibility of parents or drivers since children do not have enough understanding of safety and typically are not aware of the risks associated with lack of safety

Corresponding author: Sunanda Dissanayake, Ph.D., P.E., professor, research fields: traffic engineering, highway safety, restraint usage and children's safety.

restraints. Older children might demonstrate a simpler understanding of why they wear seat belts, more so than the younger drivers. Typically, children are affected by parental influence and a desire to comply with the rules. Some children may express a desire not to wear their seatbelts and resist when parents tell them to buckle their safety belts. Hence, child passengers are different than other passengers, and it is important to give attention to this age group because this is when they begin to make independent decisions to wear their seat belts or not.

The main objective of this study was to investigate severity factors related with crashes involving children, with special focus on restraint usage, in order to identify effective countermeasures to increase children's highway safety. Objectives of this paper include the examination of various risk factors for children in crashes, such as failure to use restraint, riding with a drunk driver and child safety restraint usage characteristics. Seating position of the child passenger in the vehicle was also studied since seating position in the vehicle at a crash may contribute to injury risk. According to likelihood ratios of the developed model, potential actions that may improve safety of children involved in crashes are suggested.

2. Literature Review

Many researchers have evaluated the association between child restraint use and crash characteristics [1, 3]. The NOPUS (National Occupant Protection Use Survey), which collects detailed information regarding national-level shoulder belt and child restraint use levels as required by the NHTSA (National Highway Traffic Safety Administration), is often used by researchers to study child safety restraint characteristics of children under 12 years old. According to NOPUS data in 2009, observed seat belt restraint use among 4- to 7-year-old children in the US was 87%, which was slightly higher than 85% restraint use of children aged 8~12 years [4]. Child seat restraint system effectiveness has also been assessed using morbidity data taken from emergency departments or hospitals [1]. A few studies have been based on data from fatality databases, such as FARS (Fatality Analysis Reporting System) and state crash databases [4-6].

Agran et al. [7] investigated restraint use of children in fatal crashes in relation to vehicle and driver characteristics. Based on this study, restraint use of children was as low as 31% in older vehicles, 54% in rural areas and 23% between the hours of 3 a.m. and 6 a.m. The developed logistic regression models showed that restraint use declined with increasing number of occupants. As the age of children increased, the percentage of fatally injured children who were unrestrained also increased. Hence, child-occupant restraint use under all conditions of travel and all seating positions must be stressed by child-occupant protection counseling. Miller et al. [8] identified significant risk factors with the presence of a second adult in children-involved crashes involving a male driver, night driving, driving under the influence of alcohol, other moving or non-moving violations and the driver being unrestrained. Results showed that, as drivers got older, they were more likely to secure a baby in a child seat than ensure that the older children buckle up. Mature drivers in suburban areas were significantly more likely to restrain children than other drivers. A male driver, a young driver, a drunken driver and a nighttime trip each raised the likelihood of children being unrestrained when children were involved in crashes. The study pointed out that, other than programs promoting child safety and booster seats for the youngest children, few programs emphasize occupant restraint as the driver's responsibility.

Incidence rates of incapacitating injuries and risk ratios have been used to evaluate differences in injury risks to various regions of the body, based on restraint use among children involved in crashes [9]. Results indicated that use of child safety seats effectively reduces incidence rates of incapacitating injuries for children involved in frontal, side impact or rollover crashes. In near-side impacts, unrestrained children were 8 times more likely to sustain incapacitating injuries than restrained children. Valent et al. [10] evaluated differences in injury risks to various regions of the body according to restraint use by investigating crash ratios. Compared with unrestrained children, properly restrained children had significantly lower overall injury risk, indicating a risk ratio of 0.37. The results demonstrated that misused restraints were less effective in reducing injury risk compared with properly-used restraints. The study recommended that educational initiatives should focus on ensuring that parents know appropriate age-dependent restraint methods and how to use those restraints properly.

The double-pair comparison method was also used by Starnes [6] to examine restraint-use patterns among child occupants involved in crashes, in which a child was fatally injured. According to results, restraint use of fatally-injured child passengers and their drivers were strongly correlated. Child passengers were far more likely to be unrestrained if the driver was also unrestrained. Olsen et al. [11] used generalized estimating equations to estimate relative risk for child, driver and crash characteristics for restrained drivers as compared to unrestrained drivers. Restrained drivers with restrained children were less likely to exhibit risky behaviors, including intoxication, speeding, prior traffic violations and involvement in injury crashes. The study identified overall associations between driver restraint use and lower risk of child emergency department evaluations. Vehicle and crash characteristics were associated with more severe outcomes in children. The recommendation was made that mechanisms to increase safe-driving practices of drivers transporting child passengers could potentially decrease the number of child passenger injuries from crashes. Quinlan et al. [12] examined the characteristics of crashes involving child passenger death and injuries associated with drunken drivers and identified opportunities to prevent such crashes. Approximately 64% of fatal crashes occurred when a child was riding with a drunken driver. Of drivers involved in a crash in which a child passenger died, drunken drivers were more likely to have been previously convicted of driving while intoxicated or to have had their licenses suspended or revoked. The study also showed that a majority of drunken-driver-related child passenger deaths occurred when the child was unrestrained. The recommendation was made that further reduction of unacceptable risks of child passenger injury and death associated with alcohol-impaired drivers could be accomplished through legal, medical and educational interventions.

3. Data

This study used highway crash data from the KCARS (Kansas Crash Analysis and Reporting System) database, which is comprised of all police-reported crashes in Kansas above a certain property damage threshold ($1,000 for the data set considered here). Data on children involved in crashes from 2004 to 2008 traveling by a motorized vehicle covered under the *Kansas Child Passenger Safety Act*, such as an automobile, van, pick-up truck or sport utility vehicle, were extracted for consideration and analysis. Children between 4~13 years old traveling with adult drivers were selected as the focus group, based on restraint-use requirements in Kansas. Two different sub-age group categories were also considered for analysis as follows:

- children between 4 and 7 years, who are supposed to be restrained in booster seats unless weighing more than 80 pounds and taller than 57 in.;
- children between 8 and 13 years, who are supposed to be seat-belted.

The KCARS database includes details about restraint use for all vehicle occupants, including non-injured occupants. Records also contain information regarding crash circumstances, such as weather conditions at the time of the crash, road and light conditions, vehicle-related information and driver-related information. Occupant information consists of age, gender, exact position within the vehicle, use of safety restraint and injury severity among many others. The KCARS database covering five years contained 50,155 records of children aged 4~13 years involved in crashes.

4. Methods

This section describes the methodology adopted to identify important characteristics affecting child passengers involved in crashes. First, percentages of restraint use among child passengers involved in crashes in each age group were examined using KCARS data, and RR (relative risk) ratios of the older child sub-group were calculated in comparison to younger child passenger sub-group. Second, drivers were paired with each crash-involved child in the vehicle according to the double-pair comparison method because driver characteristics could be stronger predictors of child restraint use [12]. This method has been commonly used in child passenger safety literature if the driver and at least one child occupant are in a vehicle involved in a crash. Two occupants in the vehicle are referred to as subject occupant and control occupant. Subject occupant is the person whose characteristics are used to determine injury risk or restraint use. The control occupant standardizes the conditions to investigate restraint usage effectiveness of the subject occupant. In this study, the control occupant is the driver of the child involved in a crash, while the subject occupant is the child passenger. For example, a driver with two crash-involved children in the vehicle was included in two separate driver-passenger pairs, once for each child with the driver. Accordingly, different driver characteristics were determined for child passengers' restraint use and injury risk.

4.1 Logistic Regression Analysis

Logistic regression analysis was used to determine the relative effect of child restraint system usage when children are involved in crashes. Injury severity was selected as the dependent variable in a model investigating characteristics of restraint use. The dependent variable (injury severity) has several discrete categories. The dichotomous nature of the dependent variable facilitates the application of logistic analysis, for which the probability of injury against no-injury categories is estimated by the maximum likelihood method [13]. In the logistic model, a dependent variable is formulated by the following expression:

$$g(x) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_j x_j + \ldots + \beta_p x_p \quad (1)$$

where:

$g(x)$ = independent variables formulated in the logistic model;

x_j = value of the jth independent variable;

β_j = corresponding coefficient of the jth independent variable;

p = number of independent variables.

With the independent variables, the conditional probability of a positive outcome is determined by:

$$\pi(x) = \frac{\exp\left(g(x)\right)}{1 + \exp\left(g(x)\right)} \quad (2)$$

where, $\pi(x)$ = conditional probability.

The maximum likelihood method is then employed to measure the associations by constructing the likelihood function as follows:

$$l(\beta) = \prod_{i=1}^{n} \pi(x_i)^{y_i} \left(1 - \pi(x_i)\right)^{1-y_i} \quad (3)$$

where:

$l(\beta)$ = likelihood function;

$\pi(x_i)$ = conditional probability of the dependent variable;

y_i = ith observed outcome, with the value of either 0 or 1 only;

i = 1, 2, 3,…, n, where n is the number of observations.

The log likelihood expression is considered to maximize the likelihood function in order to obtain the coefficients estimates:

$$LL(\beta) = \ln(l(\beta)) = \sum_{i=1}^{n}\left\{y_i \ln\left(\pi\left(x_i\right)\right)+\left(1-y_i\right)\ln\left(1-\pi\left(x_i\right)\right)\right\} \quad (4)$$

where:

$LL(\beta)$ = log likelihood function;

$l(\beta)$ = likelihood function;

$\pi(x_i)$ = conditional probability of the dependent variable;

y_i = ith observed outcome with the value of either 0 or 1 only;

i = 1, 2, 3,…, n, where n is the number of observations.

Maximization typically requires an iterative numerical method, which means that it involves successive approximations. Hence, the best estimate of β could be obtained by a numerical method using statistical software.

4.2 Goodness-of-Fit Measure

The goodness-of-fit of the predictive model could be assessed for significance and predictive power of the logistic regression model. To evaluate it, the change in deviance can be determined by comparing log likelihood functions between the unrestricted model and the restricted model, under the null hypothesis that coefficients for the predictive model are equal to 0, with the following expression [13]:

$$G = -2(LL(c) - LL(\theta)) \quad (5)$$

where:

$LL(c)$ = log likelihood function of the restricted model;

$LL(\theta)$ = log likelihood function of the unrestricted model;

G = goodness-of-fit value.

If G is significant at the 5% level, the null hypothesis would be rejected and the conclusion could be made that the proposed model generally fit well with the observed outcome.

The LR (likelihood ratio) test is the chi-square test where at least one of the predictors' regression coefficients is not equal to 0 in the model. The LR chi-square statistic can be calculated by:

$$LR = -2\log L(\text{null model}) - 2\log L(\text{fitted model}) \quad (6)$$

where:

L(null model) = intercept-only model;

L(fitted model) = intercept and covariates model.

The score chi-square test shows at least one of the predictors' regression coefficients is not equal to 0 in the model.

Another used goodness-of-fit measure is the AIC (Akaike information criterion), which is calculated as:

$$AIC = -2\log L + 2((k - 1) + s) \quad (7)$$

where:

L = likelihood of the model;

k = number of levels of the dependent variable;

s = number of predictors in the model.

The AIC is used for comparison of models from different samples or non-nested models. Ultimately, the model with the smallest AIC is considered the best. The SC (Schwarz criterion), which is also considered in evaluating goodness-of-fit, is defined as:

$$SC = -2\log L + ((k - 1) + s) \times \log(\Sigma f_i) \quad (8)$$

where:

L = likelihood of the model;

f_i = frequency values of the ith observation;

k = number of levels of the dependent variable;

s = number of predictors in the model.

Like AIC, SC penalizes for the number of predictors in the model, and the smallest SC is most desirable.

4.3 Multicollinearity

In some cases, logistic regression results may seem paradoxical, meaning the model fits the data well, even though no independent variables have a statistically-significant impact on predicting the dependent variable. In many situations, this occurs because of the correlation of two independent variables. Neither variable may contribute significantly to the model after the other one is included. However, model fit will be worse if both variables are removed from the model because the independent variables are collinear and the results show multicollinearity. The goal of traffic safety analysis is to understand how various independent variables impact the dependent variable; Hence, multicollinearity is a considerable problem [14]. One issue is that, even though the variable is important, model results show that it is not significant. The second problem is that the confidence intervals on model coefficients will be very wide. To assess multicollinearity, the correlation matrix of the independent variables can be investigated. If the element of correlation matrix has high value, model fit is affected by multicollinearity of the independent variable correspondent to that element. Also, each independent variable can be predicted from other independent variables. The model-fit statistics, such as individual R^2 value and a *VIF* (variance inflation factor), are high for any independent variable, and model fit is affected by multicollinearity.

4.4 Odds Ratios

To measure the strength of association between variables, OR (odds ratios) and 95% confidence intervals were calculated. The OR is a widely-used statistics in traffic safety studies to compare whether the probability of a certain event is the same for two groups [13]. An odds ratio greater than 1.00 indicates that the concerned attribute leads to a higher injury risk and vice versa. Univariate and multivariate techniques were used for analysis. Univariate techniques are those which utilize only a single independent variable, while multivariate techniques provide a linear combination of independent variables that satisfy statistical criteria.

5. Results

According to restraint-use percentages of children in crashes based on injury severity, restraint use was very low among fatally-injured child passengers, whereas restraint use was higher in the not-injured group. Age distribution of drivers for children involved in crashes indicates that a majority of children were traveling with 25- to 44-year-old drivers at the time of a crash. Results in Table 1 show that the straight-following road was the predominant crash type for children involved in crashes. Vehicle maneuver observation is important because it offers reasons for movements and actions that a driver may have performed, in case of a crash. Collision with a vehicle was the primary crash type; Non-collisions and overturning of vehicles occurred less frequently. A majority of crashes occurred during daytime hours and during weekdays, where children are more likely to be traveling. Majority of children were involved in crashes occurring in the afternoon and evening. In relation to most characteristics, calculated RR values of 8- to13-year-old children compared to 4- to 7-year-old children were above 1.00, as shown in Table 1. Those numbers also show that children aged 8~13 years had higher risk for injuries in crashes compared to children aged 4~7 years.

Table 2 shows child passenger and driver characteristics of crashes involving children, as well as older passenger and driver characteristics for other crashes. Unrestrained children had significantly higher rates of incapacitating injuries in side impacts than restrained children. Driver-injury-severity distribution indicates the driver was not injured in most crashes involving children. Gender distribution shows female drivers ride more frequently with children at the time of crashes. The proportion of female drivers was higher in crashes where children aged 4~7 years were involved than children aged 8~13 years. A considerable number of violations, such as failure to use the safety belt, alcohol involvement and lack of a valid license, can be observed among drivers riding with children involved in crashes. The gender of the child passenger was somewhat equally distributed among children involved in crashes. In addition, a considerable percentage of children aged 4~7 years who were supposed to be in booster seats were restrained by only seat belts. Approximately 93% of child passengers were restrained at the time of the crash. According to observational studies in Kansas, seat belt usage rate was approximately 77% in 2011, significantly less than the rate determined by crash data. Furthermore, the

Table 1 Vehicle-related and environmental-related characteristics for crashes involving children.

Characteristic	Children (4~7 years)		Children (8~13 years)		All children (4~13 years)		Child (8~13 years) passenger RR*
	Number	Percentage (%)	Number	Percentage (%)	Number	Percentage (%)	
Vehicle maneuver							
Straight-following road	12,987	60	17,367	60	30,354	61	1.15
Turn or changing lanes	2,947	14	4,304	15	7,251	14	0.94
Avoiding maneuver	552	3	703	2	1,255	3	1.32
Stopped, parking or backing	4,918	23	6,592	23	11,510	23	1.39
Other	119	1	128	0	247	0	2.10
Accident class							
Collision with a vehicle	16,505	73	21,923	75	38,428	74	1.13
Collision with pedestrian/animal	2,872	13	4,357	15	7,229	14	0.88
Collision with an object	2,872	13	1,989	7	4,861	9	1.40
Other non-collision and overturned	516	2	912	3	1,428	3	1.34
Light conditions							
Daylight	15,960	75	20,936	72	36,896	73	1.17
Not daylight	5,285	25	8,181	28	13,466	27	1.21
Weather conditions							
No adverse conditions	18,055	85	24,768	86	42,823	85	1.18
Rain	1,908	9	2,667	9	4,575	9	1.13
Adverse conditions	1,255	6	1,646	6	2,901	6	1.10
Time of crash							
5:00~9:00	2,343	11	3,209	11	5,552	11	1.12
9:00~13:00	4,015	19	4,492	16	8,507	17	1.12
13:00~17:00	6,759	32	9,120	32	15,879	32	1.16
17:00~21:00	6,417	30	9,188	32	15,605	32	1.13
21:00~5:00	1,685	8	2,912	10	4,597	9	1.24
Day of week							
Weekdays	15,402	73	19,858	69	35,260	70	1.19
Weekend	5,824	27	9,066	31	14,890	30	1.13

*RR of 8- to 13-year-old children compared to 4- to 7-year-old children;
Unknowns are not listed.

older-child group demonstrated greater risk than the younger-child group by showing RR values greater than 1.00, in all characteristics except ejection from the vehicle.

As indicated in Table 3, most 4- to 7-year-old children were involved in crashes occurring on urban collectors, while a higher proportion of crashes occurred at non-intersections on roadways where children aged 8~13 years were involved. Many crashes took place under no adverse weather conditions and a significant number of crashes occurred in adverse conditions. Crashes on dry roads and straight and level surfaces were the most prevalent crash conditions for children involved in crashes. In most cases, the vehicle was functional after the crash, thus reflecting the findings of many children-involved crashes in Kansas as belonging to the “not injured” category. The investigation of restraint use among children involved in crashes revealed that restraint use decreases with an increased number of occupants in the vehicle. Use of restraints was substantially lower in older vehicles and crashes that occurred during late night and early morning hours. Driver restraint use strongly influenced restraint use of children, such that children were more likely to be restrained in vehicles with restrained drivers. When the driver was restrained, 93% of children

Table 2 Child passenger and driver characteristics for crashes involving children.

Characteristic	Children (4~7 years)		Children (8~13 years)		All children (4~13 years)		Child (8~13 years) passenger RR*
	Number	Percentage (%)	Number	Percentage (%)	Number	Percentage (%)	
Child passenger injury severity							
Fatal injury	22	0	28	0	50	0	-
Disabled (incapacitating)	91	0	180	1	271	1	-
Injury, not incapacitating	786	4	1,358	5	2,144	4	-
Possible injury	1,200	6	1,771	6	2,971	6	-
Not injured	18,128	90	24,363	88	42,491	89	-
Child passenger gender							
Female	10,349	49	14,689	51	25,038	50	1.22
Male	10,877	51	14,448	50	25,325	50	1.11
Child passenger safety restraint							
Child/booster seat used	10,955	51	661	2	11,616	23	1.31
Seat belt used	8,965	42	25,938	90	34,903	70	1.07
None	709	3	1,246	4	1,955	4	1.19
Child ejection							
Ejected	36	0	122	0	158	0	1.11
Not ejected	19,934	99	27,376	99	47,310	99	1.15
Trapped	79	0	74	0	153	0	1.93
Driver injury severity							
Fatal injury	34	0	46	0	80	0	1.74
Disabled (incapacitating)	146	1	226	1	372	1	2.88
Injury, not incapacitating	1,077	5	1,570	6	2,647	5	1.39
Possible injury	1,548	8	2,008	7	3,556	7	1.12
Not injured	17,367	86	23,776	86	41,143	86	1.27
Driver gender							
Female	14,245	67	18,265	63	32,510	64	1.18
Male	7,025	33	10,901	37	17,926	36	1.17
License compliance							
Valid license	19,778	94	27,271	94	47,049	94	1.17
Not licensed or invalid license	1,295	6	1,660	6	2,955	6	1.31
Driver safety belt used	20,569	97	27,269	94	47,838	95	1.14
Alcohol related	140	1	185	1	325	1	1.35
Driver ejection							
Ejected	59	0	65	0	124	0	0.96
Not ejected	20,022	99	27,301	99	47,323	99	1.16
Trapped	48	0	136	0	184	0	1.19

*RR of 8- to 13-year-old-children compared to 4- to 7-year-old children;
Unknowns are not listed.

aged 4~7 years were restrained. When the driver was unrestrained, 56% of children passengers were restrained. In the older-child group, the percentage of unrestrained children increased whether they were traveling with unrestrained drivers or restrained drivers. In the older-child age group, 58% of children were not restrained when the driver was unrestrained, while 94% of children were restrained when riding with a restrained driver. Child restraint use was lower in rural areas compared to urban areas. Driver alcohol use was associated with lower restraint use, most likely indicative of high-risk drivers who are less likely to

Table 3 Road-related and vehicle-related characteristics for crashes involving children.

Characteristic	Children (4-7 years)		Children (8-13 years)		All children (4-13 years)		Child (8~13 years) passenger RR*
	Number	Percentage (%)	Number	Percentage (%)	Number	Percentage (%)	
Functional class							
Rural roads	1,318	6	4,178	14	5,496	11	1.21
Urban interstate	1,270	6	108	0	1,378	3	0.57
Urban arterial	111	1	9,515	33	9,626	19	1.15
Urban collector	7,503	35	1,892	7	9,395	19	1.19
Urban local street	3,865	18	3,574	12	7,439	15	1.11
Unknown	7,159	34	9,662	33	16,821	34	1.17
Crash location							
Non-intersection-on roadway	10,854	51	15,034	52	25,888	51	1.20
Intersection-on roadway	9,734	46	13,128	45	22,862	45	1.10
Off roadway	687	3	1,020	4	1,707	3	1.52
Road surface condition							
Dry	17,191	81	23,576	81	40,767	81	1.16
Wet	2,532	12	3,493	12	6,025	12	1.17
Debris	1,493	7	2,017	7	3,510	7	1.27
Work zone	605	0	780	0	1,385	0	1.25
Road surface character							
Straight and level	15,952	75	21,828	75	37,780	75	1.14
Straight not level	4,020	19	5,583	19	9,603	19	1.15
Curved	1,187	6	1,605	6	2,792	6	1.61
Vehicle damage							
None	537	3	727	3	1,264	3	1.32
Damage	6,036	29	8,251	28	14,287	28	1.22
Functional	8080	38	11,028	38	19,108	38	1.09
Disabling	5,597	26	7,649	26	13,246	26	1.16
Destroyed	918	4	1,387	5	2,305	5	1.37
Vehicle body type							
Automobile	9,100	43	12,523	43	21,623	43	1.10
Van	5,022	24	6,140	21	11,162	22	1.24
Pickup-truck	2,217	10	3,705	13	5,922	12	1.11
Sport utility vehicle	4,890	23	6,680	23	11,570	23	1.30
Other	48	0	106	0	154	0	0.76

*RR of 8- to 13-year-old-children compared to 4- to 7-year-old children;
Unknowns are not listed.

restrain children.

Approximately 94% of children were restrained by valid driver license holders, but only 83% of children were restrained by invalid license holders or drivers that were not licensed. Only 11% of crash-involved children were in the middle seating position of the rear seat, but almost 66% of children travelled in the rear seat. According to percentages of restrained children by seating position, children traveling in the front seat were less likely to be restrained than children traveling in the rear seats. Children who travelled in left and right rear-seating positions indicated a high percentage of restraint use. Restraint use among children involved in crashes decreased with increased age.

Table 4 shows the odds of univariate and multivariate analysis. Child passengers traveling with valid licensed and restrained drivers were lower in injury risk. Investigating odds of child-passenger-related

Table 4 Odds ratios for injury of children involved in crashes.

Characteristic		Univariate OR (odds ratio)	Multivariate Analysis		
			Odds ratio	95% confidence interval	
				Lower bound	Upper bound
Driver-related characteristics					
Male		0.994	0.993	0.904	1.091
Valid licensed		0.538	0.851	0.734	0.987
Safety belt used		0.174	0.621	0.541	0.712
Alcohol-related		5.035	1.932	1.292	2.889
Ejected		17.245	0.829	0.285	2.398
Child-related characteristics					
Child seat		0.682	0.293	0.243	0.354
Seat belt		0.640	0.334	0.286	0.390
Ejected		60.684	24.968	11.760	53.013
Rear seat		0.789	0.917	0.832	1.011
Environmental-related characteristics					
Not daylight		0.939	0.861	0.736	1.007
Weather	No adverse conditions	1.063	0.686	0.330	1.426
	Rain	0.998	0.792	0.368	1.629
	Adverse conditions	0.812	1.000	-	-
Time	5:00~9:00	1.006	0.946	0.824	1.086
	9:00~17:00	1.000	1.000	-	-
	17:00~21~00	0.971	0.993	0.888	1.109
	21:00~5:00	1.200	1.194	0.951	1.499
Week days		0.973	1.042	0.944	1.151
Road-related characteristics					
Rural roads		1.472	1.082	0.967	1.211
Location	Non-intersection-related	1.230	0.888	0.796	0.991
	Intersection-related	1.000	1.000	-	-
	Off roadway	3.339	1.012	0.807	1.268
Road surface condition	Dry	0.604	0.736	0.371	1.461
	Wet	0.608	0.865	0.426	1.755
	Debris	1.000	1.000	-	-
Surface character	Straight and level	0.875	0.888	0.796	0.991
	Straight not level	1.150	1.012	0.807	1.268
	Curved	1.000	1.000	-	-
Vehicle-related characteristics					
Vehicle damage	None	1.000	1.000	-	-
	Minor damage	0.709	0.775	0.310	1.934
	Function	1.107	1.152	0.463	2.865
	Disabling	5.347	4.720	1.902	11.717
	Destroyed	22.383	16.072	6.422	40.223
Vehicle	Automobile	0.489	0.821	0.232	2.902
	Van	0.262	0.546	0.154	1.937
	Pick-up truck, camper recreational vehicle	0.299	0.555	0.157	1.961
	Sport utility vehicles	1.000	1.000	-	-

variables, restrained children showed significantly lower risk than unrestrained. The odds ratio of rear seating was less than 1.00, indicating rear seating reduced injury risk for child passengers. An important risk factor was ejection, which may be due to failure to restrain. The odds ratios of environmental-related variables were not statistically significant at the 95% confidence interval. Injury risk on rural roads in which a child passenger was involved in crashes was higher than on urban roads in Kansas. Off-roadways showed a higher injury risk for children, and injury risk on dry roads was lower than wet roads when child passengers were involved in crashes. Also, riding on straight, level road surfaces was a significantly lower injury risk than travelling on curved or unleveled road surfaces. In the case of a crash, the child would be at a higher injury risk if the vehicle was disabled or destroyed, compared to a vehicle which did not sustain damage.

5.1 Logistic Regression Model

A logistic model was developed to further investigate child passenger injury and the dependent variable. Injury severity is defined as a binary variable depending on whether the child is injured or not injured. All other crash, vehicle, roadway, environment, driver and passenger attributes were used as independent variables. According to estimated coefficients in Table 5, male children were less likely to be injured when involved in crashes than female children. If the child was in a child seat, injury severity was less. Children using seat belts were less likely to suffer injuries when involved in crashes. If the child passenger was ejected or trapped, or if the vehicle was destroyed or disabled, the child had a high chance of injury. If the driver had a valid driving license, the vehicle was newer, and it did not get damaged, had minor damage, or was functional at the time of crash, child passengers were less likely to suffer injuries. Alcohol involvement of the driver, travelling on rural roads, travelling by automobile or pick-up trucks or travelling at high speeds showed high injury risk for child passengers.

5.2 Contributory Causes

Many factors combine to produce circumstances leading to a traffic crash; A single cause is rare. Contributing causes related to children involved in crashes are provided in Table 6. Inattention and failing to give enough time and attention to the driving task were the most frequent driver factors in child-involved crashes. When the contributory cause was distraction, reckless/careless/aggressive driving, alcohol involvement or restricted driver license, child-restraint use was significantly low. There were occasions when the driver had to react to unexpected events. Therefore, road conditions and surrounding conditions must be considered as primary factors, important for safe driving. Roadway-related contributory causes include wet, debris or icy roads as main factors. Child-restraint use was lower in rain, snow, smog or cloudy environmental contributory crashes. Tires and brakes were the most common vehicle-contributing causes for crashes involving children. Presence of one or more of these contributory causes does not prove that a child is being harmed or is at risk of harm, but it can alert to the possibility that a child may be at risk.

6. Countermeasures

The developed logistic regression model identified risk factors which increase injury severity. Safety-restraint use is one of the most highly significant variables that could reduce child-injury risk. Hence, age-appropriate and size-appropriate restraints can be used as an effective strategy for reducing injury severity of children involved in crashes and reducing costs associated with those crashes. Many efforts have been taken to increase age-appropriate and size-appropriate restraints for children. This analysis showed that many children are still transported without appropriate restraints. Therefore, continued efforts are needed to increase child-safety-restraint usage, especially in rural areas and during nighttime. Different strategies are necessary to increase child restraint use compared to adult seat belt use, as issues associated with increasing child restraint use are different than those for increasing adult seat belt use.

Table 5 Models fit statistics and maximum likelihood estimates.

Label	Parameter definition	Coefficient	*p*-value
Intercept	Intercept	−8.66	0.946
AGE	If 4~7 years, *AGE* = 1; 8~13 years, *AGE* = 0	−0.024	0.587
DRMALE	If driver is a male, *DRMALE* = 1, otherwise 0	−0.049	0.206
CHIMALE	If child is a male, *CHIMALE* = 1, otherwise 0	−0.199	< 0.0001*
SEAT	If front seating, *SEAT* = 1, otherwise 0	0.069	0.395
	If rear seating, *SEAT* = 1, otherwise 0	−0.026	0.716
VALID	If valid license, *VALID* = 1, otherwise 0	−0.124	0.045*
SEATB	If seat belt used, *SEATB* = 1, otherwise 0	−1.291	< 0.001*
	If child seat used, *SEATB* = 1, otherwise 0	−1.439	< 0.001*
AIRB	If airbag used, *AIRB* = 1, otherwise 0	1.219	< 0.001*
ALCO	If alcohol-related, *ALCO* = 1, otherwise 0	0.033	0.036*
DARK	If dark or night, *DARK* = 1, otherwise 0	0.074	0.243
WTHER	If good weather, *WTHER* = 1, otherwise 0	−0.062	0.83
	If rain, *WTHER* =1, otherwise 0	−0.553	0.851
	If adverse condition, *WTHER* = 1, otherwise 0	−0.212	0.475
TIME	If 5:00~9:00 a.m., *TIME* = 1, otherwise 0	−0.074	0.679
	If 9:00 a.m.~1:00 p.m., *TIME* = 1, otherwise 0	−0.104	0.555
	If 1:00~5:00 p.m., *TIME* = 1, otherwise 0	−0.043	0.803
	If 5:00~9:00 p.m., *TIME* = 1, otherwise 0	−0.04	0.813
	If 9:00 p.m.~1:00 a.m., *TIME* = 1, otherwise 0	−0.082	0.638
WEEK	If weekday, *WEEK* = 1, otherwise 0	−0.022	0.578
RDFUNC	If rural roads, *RDFUNC* = 1, otherwise 0	−0.095	0.108
	If urban interstate, *RDFUNC* = 1, otherwise 0	−0.208	< 0.001*
	If urban collector/local, *RDFUNC* = 1, otherwise 0	−0.219	0.001*
NEW	If vehicle made later than the year of 2000, *NEW* = 1, otherwise 0	−0.142	< 0.001*
SPD LIM	On-road speed limit	0.006	0.001*
Likelihood Ratio		7,337	< 0.001*
Score		9,016	< 0.001*
−2log*L*		23,170	-
CLASS	If non-collision or overturned, *CLASS* = 1, otherwise 0	9.967	0.938
	If collision with pedestrian or animal, *CLASS* = 1, otherwise 0	70.176	0.955
	If collision with vehicle=1, otherwise 0	0.591	0.94
	If collision with fixed object=1, otherwise 0	0.684	0.94
WZONE	If work zone, *WZONE* = 1, otherwise 0	−0.132	0.245
DAMEGE	If vehicle does not damage, *DAMEGE* = 1, otherwise 0	−0.601	0.029*
	If minor damage, *DAMEGE* = 1, otherwise 0	0.997	< 0.001*
	If driver and four passengers, *DAMEGE* = 1, otherwise 0	0.014	0.899
	If driver and five passengers, *DAMEGE* = 1, otherwise 0	−0.128	0.221
BODY	If automobile, *BODY* = 1, otherwise 0	0.35	< 0.001*
	If van, *BODY* = 1, otherwise 0	0.047	0.423
	If pick-up truck or camper rv, *BODY* = 1, otherwise 0	0.216	0.001*
MANEU	If straight-following road, *MANEU* = 1, otherwise 0	−0.544	0.002*
	If turn or changing lanes, *MANEU* = 1, otherwise 0	−0.67	< 0.001*
	If avoiding maneuver, *MANEU* = 1, otherwise 0	−0.579	0.003*
	If stopping, parking or backing, *MANEU* = 1, otherwise 0	−0.349	0.048*

(Table 5 continued)

EJECT	If child eject, *EJECT* = 1, otherwise 0	2.45	< 0.001*
	If child did not eject, *EJECT* = 1, otherwise 0	−0.841	< 0.001*
	If child trapped, *EJECT* = 1, otherwise 0	1.831	< 0.001*
ROADCHA	If straight and level, *ROADCHA* = 1, otherwise 0	−0.364	0.095
	If straight not level, *ROADCHA* = 1, otherwise 0	−0.303	0.171
	If curved, *ROADCHA* = 1, otherwise 0	−0.274	0.23
ROADWY	If off roadway, *ROADWY* = 1, otherwise 0	−0.26	0.905
	If non-intersection on roadway, *ROADWY* = 1, otherwise 0	−0.349	0.872
	If intersection on roadway, *ROADWY* = 1, otherwise 0	−0.085	0.969
AIC		23,286	-
SC		23,789	-

*Significant at 95% confidence level.

Table 6 Driver contributory factors for children involved in crashes.

Contributory causes		Number of children-involved crashes	Child restraint system used	
			Frequencies	Percentages (%)
Driver causes	Inattention	8,652	8,154	94
	Failed to yield right of way	3,999	3,786	95
	Too fast	2,492	2,268	91
	Improper turn/passing/backing/signal	2,203	2,113	96
	Followed too closely	2,027	1,939	96
	Disregard traffic signs or signal	1,291	1,204	93
	Distraction	746	663	89
	Avoidance or evasive action	708	651	92
	Reckless/careless/aggressive driving	332	245	74
	Under influence of alcohol/drugs	315	249	79
Road causes	Wet	32,702	30,829	94
	Debris or obstruction	886	860	97
	Icy or slushy	534	499	93
	Ruts, holes or bumps	167	163	98
Environmental causes	Animal	4,102	4,068	99
	Rain, snow, mist or drizzle	1,047	1,010	96
	Vision obstructed	407	386	95
	Strong winds	128	117	91
	Rain, snow, smog or cloudy	77	65	84
Vehicle causes	Tires	146	129	88
	Brakes	98	96	98
	Wheel(s)	63	58	92

6.1 Child Restraint Laws

Child restraint laws require children traveling in motor vehicles to be restrained in equipment appropriate for the child's age and size. Transitioning children from child seats to booster seats, instead of directly to seatbelts, provides more safety benefit for children at least through age of eight. NHTSA [15] stated that use of booster seats reduces injury risk of children in crashes by 45%, compared to use of vehicle safety belts only. Also, laws requiring children to use restraints whenever and wherever they sit in vehicles are needed. According to results of this study, children in the front seat are more vulnerable for injury when involved in crashes. Nevertheless, a significant proportion of children involved in crashes were sitting in front seats. Currently, children are strongly recommended to be restrained in the rear center seat. In order to increase child safety, legislation could be changed to require all children less than 8 years old be restrained in the rear seat.

6.2 Enforcement

More enforcement of child restraint laws for booster seat use for children aged 4~7 years is needed. Previous enforcement efforts increased correct use of booster seats and use of safety belts by older children. Therefore, law enforcement officers should continue to increase enforcement of child passenger restraint use laws. Highly-publicized, high-visibility enforcement of child restraint laws is one of the most effective countermeasures for increasing child restraint use, as reported by NHTSA [15]. Our findings suggest that driver characteristics play an important role in child passenger crashes. According to the developed model, avoiding alcohol-involved driving is an important factor in reducing child injury risk, which is also a factor in reducing crash involvement. Hence, enforcement against drunk driving is needed, especially at locations where high alcohol use is expected. Further results showed that driver restraint use is closely associated with child restraint use. Enforcement officers should pay more attention to increasing driver restraint use, thus increasing child passenger restraint use, reducing ejection at time of crash and reducing child injury risk. Enforcement activities should be more targeted and improved toward vulnerable drivers who do not have valid driving licenses and at more critical locations where high posted speed limits exist or in rural areas as identified from the developed model. Also, reckless, careless and aggressive driving should be reduced by enforcement activities because those drivers are less likely to buckle a child into proper restraints. Investigation of attitudinal or motivational factors to increase safety restraint use would be helpful in identifying critical areas for enforcement programs.

6.3 Publicity and Education

Restraint-use campaigns and education programs focusing on the negative impact of restraint non-use and addressing issues related to low habitual seat belt use by children are effective activities to increase child restraint use. According to NHTSA [15], community-wide information in addition to enhanced enforcement campaigns and child restraint distribution in conjunction with education programs are effective activities for increasing restraint use among children. Educational programs should focus on the main contributory causes that increase child passenger risk. Drivers should try to engage less in inattentive driving, failure to yield right-of-way, driving too fast, following too closely, distracted driving, disregarding traffic signs and signals, reckless, careless, aggressive driving and travel wet roads. In particular, parents should not allow to children to ride with an alcohol-impaired driver.

Education programs at schools are effective in improving safety restraint use by children aged 8~13 years [15]. Parents need to know that they are the most influential factor in child safety and children's use of safety restraints. Older children simply forget to fasten a seat belt or feel that seat belts are uncomfortable. In such situations, parents need to mention the importance of restraint and help them buckle up. Previous researchers revealed that some parents have limited knowledge on height and weight recommendations applicable to their children in regards to restraint use. Therefore, parental education programs are a good strategy to increase restraint use among children.

7. Conclusions

In order to identify risk factors associated with children aged 4~13 years who are involved in crashes, the logistic regression model was developed. The objective of this model was to study the effect of variables contributing to higher injury risk for children involved in crashes. Based on the model, restrained children traveling with a valid driver's license holder, in a newer vehicle or on urban roads, are at lower risk of increased severity. Traveling with a drunk driver, traveling in an automobile or pick-up truck or traveling at high speeds increases the possibility of an injury crash. The most frequent contributing causes related to crashes involving children in Kansas are inattention, failing to give time and attention to the driving task, driving too fast, wet roads and animals on the travel lanes. When a contributory cause is distraction, reckless/careless/aggressive driving, alcohol involvement or restricted driver's license, child restraint use was significantly low. Based on identified factors, improving child traffic safety requires many countermeasures, including age-appropriate and size-appropriate seat belt restraints and properly restraining children in the rear seat. Parents and children must gain better education regarding these critical factors which are necessary to increase child safety on the road. Enforcement efforts to increase correct use of child restraints should also be required.

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