Analysis of Trends and Correlation in Child Restraint Use and Seating Position of Child Passengers in Motor Vehicles: Application of a Bivariate Probit Model

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ABSTRACT

Motor vehicle crashes are a leading cause of death and injury for children under 8 years. While different states are showing increases in the proportion of child restraint device use, only around half of the children aged between 4 to 7 years are being properly restrained. This study was undertaken to identify the factors contributing to the proper child restraint use and child passenger's seating position through the direct observation surveys of more than 10,000 child passengers in 2015 and 2018 in Michigan. A bivariate probit model was developed to simultaneously identify the contributing factors for the proper restraint use and seating position of child passengers. The bivariate framework is able to account for correlation of the two dependent variables in the study. The results show that the two dependent variables are positively correlated, and this correlation is strongly significant. Also, the key factors simultaneously influencing proper child restraint use and appropriate seating position of the child passenger include the age of the child, number of the child passengers in the vehicle, driver belt use, driver gender, age, and race, vehicle type, stratum, weather, and the time of the day and week. However, factors such as county-specific population, income, and education, and the type of location did not have a significant association with either child restraint use or the seating position of the child passenger.

Keywords: Child Restraint Device Use, Seating Position, Child Passenger Safety, Bivariate Probit Model

INTRODUCTION

Motor vehicle crashes are a leading cause of death and injury for children under 8 years of age in the U.S. (*1*). Nationwide, between 2014 and 2018, a staggering total of 304,803 children under the age of 8 years died or suffered from vehicle occupant injuries (*2*). During the same time, only in Michigan, 72,094 children aged less than 8 years were involved in motor vehicle crashes combining all severities. This was a sharp increase (greater than 70 percent) from the number of children under the age of 8 years involved in traffic crashes between 2009 and 2013 (*3*). In Michigan, among the child occupants under the age of 8 years for whom restraint use information was recorded, less than 73 percent used child-specific restraint, either a child restraint device (CRD) or a belt-positioning booster seat (*3*). Data also shows that about 35 percent of the children, who died in a traffic crash, were not restrained in 2017 in the U.S. (*4*). At the state level, among the children aged less than 8 years that were either unrestrained or improperly restrained in Michigan, almost 5 percent suffered fatal or incapacitating injuries (*3*). This was significantly higher than the children who sustained fatal or incapacitating injuries but were properly restrained (0.12 percent) (*3*).

Over the past two decades, Michigan has experienced increases in the use of CRD among children under 4 years of age from 74.5 percent in 1997 to 98.2 percent in 2018 (*5*). On the other hand, following the enactment of statewide legislation in 2008, booster seat use was found to increase substantially in Michigan (*5*, *6*). However, despite these increases in CRD use, even less than 55 percent of children aged between 4 and 7 years used booster seats properly (*5*). Research has also demonstrated that children between the ages of 4 and 8 years are the least likely to be protected in the appropriate restraint (*7–9*). There are several potential explanations for the low booster seat use rate, including a lack of knowledge of the state law and best practice regarding the benefits of child appropriate restraints compared to seatbelts alone, as well as differences in risk perception among parents (*10–13*).

Children should be strapped in appropriate restraints based on their age, weight, or height. Michigan's Child Passenger Safety Law requires infant and convertible safety seats for children under the age of 4 and booster seats for children aged 4 until they fit in a seatbelt, which is usually at the age of 8 or 9 years (*5*, *14*). Research has clearly shown that the appropriate use of CRDs and booster seats can significantly reduce the risk of serious injury and death for children involved in vehicle crashes. Child safety seats reduce fatal injury by 71 percent for infants (under 1 year old) and by 54 percent for toddlers (1 to 4 years old) in passenger vehicles (*15*). The risk of serious injury for children 1 to 4 years old is 80 percent lower for children seated in forward-facing CRDs than children restrained in merely safety belts (*16*). Also, booster seat use reduces the risk for serious injury by 45 percent for children aged between 4 and 8 years, when compared with seatbelt use (*17*).

While the extant literature provides important insights into the child restraint use and the safety benefits of the proper restraint use, literature assessing proper use of restraint use simultaneously with the seating position of the child is scant. To this end, this study examines the factors that are associated simultaneously with appropriate child restraint use and proper seating position of the child passenger. The data was collected from 263 sites in 30 counties across Michigan in 2015 and 2018 as part of direct observation surveys. Data including the type of restraint use, drivers' demographic characteristics, and vehicle type along with county-level socio-demographic information were obtained in the process of data collection. The appropriateness of the restraint use was defined based on the child's age and the corresponding restraint use type. Similarly, the seating position is defined as appropriate, if the child was placed in a rear seat.

LITERATURE REVIEW

Prior studies have established that sitting in the rear seat of a vehicle is safer than sitting in the front seat in the event of a crash, and that the child safety seats perform better at reducing injuries (*18–21*). While some studies have separately examined the sitting behavior and restraint use among child passengers and have identified common risk factors for both these variables (*22–24*), some other studies have also found a significant relationship between the two variables (*25–27*). Using Fatality Analysis Reporting System (FARS) (*28*) data, a study determined that both child restraint use and rear seating were associated with statistically significant reductions in the likelihood of a child dying in a crash (*29*). Despite concerns around the sitting behavior and low restraint use among child passengers, few studies assessed the child restraint use and child's seating appropriateness simultaneously. However, if the interrelationship between a child's restraint use and sitting position is due to unobservable characteristics of the driver and the child passenger, then analyzing these two variables separately may produce bias estimates (*30*, *31*). A recent study from Ghana investigated sitting behavior and restraint use among child passengers and clearly indicated the existence of interrelationship between child passengers' seating position and restraint use. The key factors simultaneously influencing child passenger's sitting position and restraint use included vehicle type, driver's gender, driver's belt use, child's age, and the presence of other child or adult passenger. Also, the time of the day, and the day of the week influence only the child's sitting behavior. Female drivers were less likely to position child passengers at the front seat and were more likely to restrain them. However, the age of the driver and the gender of the child did not have a significant effect on either the child's seating position or the restraint use (*32*).

Existing research indicates that various sociodemographic, and vehicle characteristics are associated with the likelihood of using CRDs. Robinson et al. (2002) found that both ethnicity and parent age were significantly related to knowledge of neonatal car seat location. Results of their study indicated that African American parents and parents aged less than 22 years were least likely to know the correct child restraint use and seating position (*33*). Miller et al. (1998) reported that more children were found unrestrained if the driver was male, young, a drinking driver, and traveling at night (*34*). Conversely, a few other studies indicated that male drivers are more likely to properly restrain the child in a vehicle than their female counterparts (*11*, *13*, *35*). Agran et al. (1998) analyzed the restraint use of children aged under 9 years in fatal crashes and determined negative associations between child restraint use, and the age of children, number of vehicle occupants, older and larger vehicles, traveling during 3:00 AM to 6:00 AM, and traveling in rural areas. Driver restraint use was found to be the strongest predictor of child restraint use, and unrestrained and young (less than 18 years old) drivers were associated with lower restraint use of child passengers (*36*). In an interview-based study in Australia, Keay et al. (2013) showed that the inappropriate and non-use of restraint among children aged between 2 to 5 years were more likely when the driver was less than 36 years old, had a family with three or more children, or from a family where a language other than English was spoken at home (*37*).

A study from Michigan found that the highest number of children aged between 4 and 8 years riding completely unrestrained (44 percent) were those traveling in passenger vehicles. With unrestrained drivers, more than 90 percent of the children were riding completely unrestrained. Moreover, middle-aged drivers (30 to 59 years) had the highest rate of proper booster seat use (*35*). A similar study determined that the restraint use was low for older children in both pickup trucks and passenger cars (*38*). The strongest factor identified by a study that influenced child restraint use was the age of the child with the younger child being restrained more often. The other factors leading to increased child restraint use included cases where the driver was white, the parent was the driver, and there were three or fewer occupants in the vehicle. Interestingly, no significant relationships were found between the parent's age and the frequency of restraining the child (*39*). A study by Rangel et al. (2008) determined that the lowest rate of proper restraint use was among 4 to 8 year old children. The likelihood of any type of restraints being used was 2.3 times higher for Caucasian children than African American children. The compliance with restraint laws among African American children remains significantly lower than even the national average (*40*). A cross-sectional study in Iran showed the prevalence of child safety seat use was significantly associated with higher income among parents (*41*). In a study designed to investigate child safety seat knowledge in post-partum mothers, Spanier et al. (2002) determined that the higher level of education the mother had attained, the more knowledge she had regarding child passenger safety. Also, African American mothers and mothers from lower socioeconomic statuses performed worse on child passenger safety questions. However, this relationship seemed to be related to the education level in their study (*42*).

For most studies, driver restraint use was identified as one of the key predictors for child restraint use (*42*, *43*). Macy and Freed (2012) determined that the unrestrained drivers and traveling in a passenger car were predictors of a lower likelihood of CRD use. Additionally, children riding with a younger driver had lower odds of booster seat use. However, the child's and driver's gender were not associated with appropriate restraint use (*44*). Glassbrenner (2003) showed that when a driver is restrained, child passengers are restrained 92 percent of the time compared to 72 percent of the time when drivers are not restrained (*45*). However, a confounding study showed that there were no significant relationships between booster seat use and parental characteristics including parent's age, education level, and their self-reported seatbelt use (*46*).

To summarize, several of these studies have attempted to determine child restraint usage rates, and the safety benefits of CRDs and booster seats. Yet there remains a dearth of research that simultaneously analyzes the appropriate child restraint use and proper seating position of the child passenger in motor vehicles. To address this knowledge gap, this study develops bivariate probit models to estimate the two variables simultaneously using the data from direct observation surveys in Michigan in 2015 and 2018.

METHODOLOGY

Site Selection

Study locations were selected to obtain CRD and booster seat use data from a representative sample of target-aged (0 to 7 year-old) child passengers in the state of Michigan. The specific observation sites were selected from a statewide sample of locations expected to yield high volumes of target-aged child passengers, including fast food restaurants, daycare centers, shopping centers, and recreational sites (e.g., zoos, museums, parks, etc.). Ultimately, a total of 263 sites in 30 different counties in Michigan were selected for data collection. The candidate counties were also classified into four strata based on the past safety belt use rates and vehicle miles traveled (VMT) (*31*). Stratum 1 consists of the counties with the highest historical safety belt use rates while Stratum 4 has exhibited the lowest belt use rate. Figure 1 shows the strata of the counties and the data collection locations. To allow for a direct comparison between the results of these surveys, the same sites were utilized each year, where feasible.

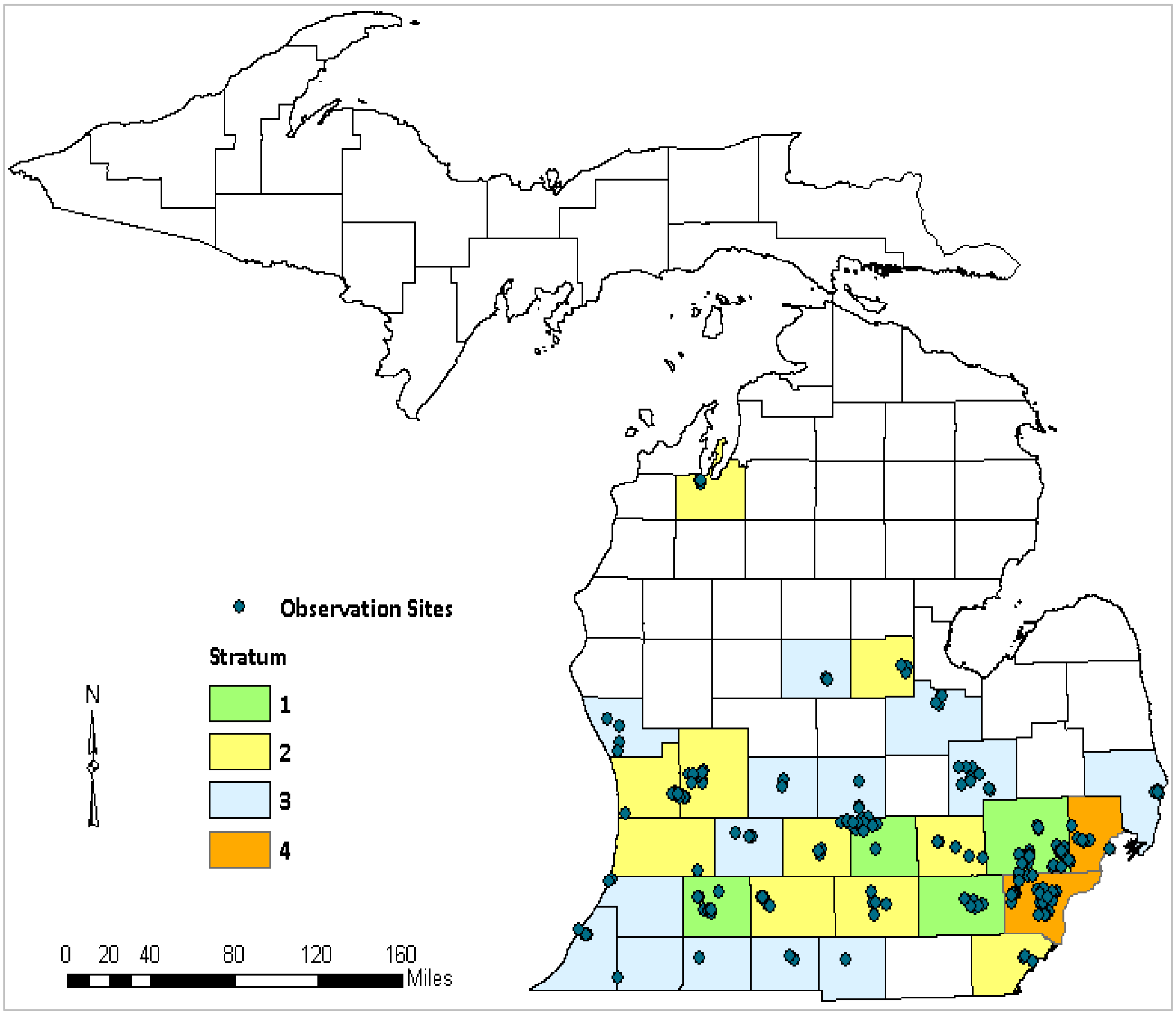

FIGURE 1: Data collection locations in different counties in Michigan

Data Collection

Data collection was performed by trained observers who received both classroom and field training before the actual observation survey. The observers positioned themselves on the roadside near the entrance or exit to each study location as vehicles would be either stopped or slowly moving ensuring a clear line of sight into the interior of each vehicle. At the primary observation sites where traffic volumes were relatively low, data were also collected from vehicles on the adjacent street. For all vehicles identified to have a 0 to 7 year-old child passenger, the driver and all target-age child passengers were observed for restraint use and non-use. A sample field observation form is shown in Figure 2. During the direct observation use surveys, several factors were assessed as part of the data collection including vehicle type (passenger vehicles, sport utility vehicles (SUVs), vans/minivans, or pickup trucks); driver restraint use, gender, age group and ethnicity; and child restraint use, age, and seating position. Driver restraint use was categorized as belted, not belted, or unknown. The seven restraint categories for each child were: belted, not belted, unknown, rear-facing child safety seat, front-facing child safety seat, high-back booster, or backless booster.

❑ SAME VEHICLE AS PREVIOUS	❑ OBSERVED ON ADJACENT STREET

VEHICLE TYPE:			
❑ Passenger Car	❑ SUV	❑ Van/Minivan	❑ Pickup Truck

DRIVER			
RESTRAINT USE:	AGE:	GENDER:	RACE:
❑ Belted	❑ 16-29	❑ Male	❑ White
❑ Not Belted	❑ 30-59	❑ Female	❑ Black
❑ Unknown	❑ 60+	❑ Unknown	❑ Other
	❑ Unknown		❑ Unkown

CHILD PASSENGER					
RESTRAINT USE:		AGE:	SEATING POSITION:		
❑ Belted	❑ Rear-Facing CSS	❑ Under 2			
❑ Not Belted	❑ Front-Facing CSS	❑ 2 to 3	D	❑	❑
❑ Unknown	❑ High-Back Booster	❑ 4 to 7	❑	❑	❑
	❑ Backless Booster		❑	❑	❑

FIGURE 2 Data collection from

Statistical Methodology

This study analyzes the factors that are associated with proper child restraint use and proper seating position of the child passenger simultaneously. Because the dependent variables consist binary indicator variables (i.e., the child passenger was properly restrained or not, and the seating position was appropriate or not), discrete outcome models are an appropriate analysis framework. Given concerns as to potential correlation between these two variables of interest, bivariate probit models are well suited to the context of this study. The bivariate probit models were developed to account for the common unobserved factors that are simultaneously associated with the proper child restraint use and seating position of a child passenger. The bivariate probit regression is an extension of the univariate binary probit regression and is designed to model two binary dependent variables that may be simultaneously estimated (*47*). A bivariate probit model essentially discounts the correlation between the disturbances resulting in inefficiency in model estimations when the univariate probit models are separately developed (*48*). The generic form of a bivariate probit model can be expressed as:

$$y_{1i}^* = \beta_1 X_{1i} + \varepsilon_{1i} \quad (1a)$$

$$y_{2i}^* = \beta_2 X_{2i} + \varepsilon_{2i} \quad (1b)$$

where y_{1i}^* and y_{2i}^* are latent dependent variables; β_1 and β_2 are the vectors of estimable parameters; X_{1i} and X_{2i} are the vectors of explanatory variables; ε_{1i} and ε_{2i} are the disturbance terms assumed to be normally distributed with mean and variance are 0 and 1 respectively, and correlation of ρ. Dependent variables y_1 and y_2 are observed if the latent variables y_1^* and y_2^* are greater than 0:

$$y_1 = 1, \text{ if } y_1^* > 0, 0 \text{ otherwise} \quad (2a)$$

$$y_2 = 1, \text{ if } y_2^* > 0, 0 \text{ otherwise} \quad (2b)$$

The parameters of the bivariate probit can be estimated by maximum likelihood with the log-likelihood function expressed as (*30*):

$$ln\ L = \Sigma \ln \Phi_2[q_{1i}\,\beta_1 X_{1i}\,, q_{2i}\,\beta_2 X_{2i}, q_{1i}\,q_{2i}\,\rho] \quad (3)$$

where ($\Phi_2[X_1, X_2, \rho)$ is the cumulative density function for the bivariate standard normal distribution with correlation ρ; such that $q_{1i} = 2y_{1i} - 1$; and q_{2i} =$2y_{2i} - 1$. Hence, $q_{ji} = 1$ if $y_{ji} = 1$ and $q_{ji} = -1$ if $y_{ji} = 0$, for j = 1, 2.

The correlation coefficient, rho (ρ), estimates the correlation between correct child restraint use and correct seating position of a child passenger after the effects of the independent variables in the model are accounted for. In the model results, the sign of the parameter estimates (βs), exhibits the effect of each variable on both child restraint use and seating position of the child. A positive parameter implies that the factor would increase the likelihood of proper restraint use or proper seating position of a child passenger and vice versa.

Preliminary Analysis

The statewide child restraint device use survey was performed between June and August of 2015 and 2018. During this observation period, a total of 12,567 observations of 0 to 7 year-old child passengers were obtained. Data were screened for missing values in different categories and a total of 10,137 complete observations were tabulated for further analysis. County-level demographic data including population, education level, and median household income were further added to the final data set. Descriptive statistics of the child restraint use survey are provided in Table 1.

For the purpose of this study, the "appropriate" child restraint use was defined based on the current Michigan law enacted in 2008 (*49*). Thus, the proper restraint for the children under the age of 4 years were children seated in a rear-facing or forward-facing child safety seat. Premature graduation to a booster seat or safety belt was classified as inappropriate restraint use for this age group. Similarly, appropriate restraint use for children ages 4 through 7 years included forward-facing restraint or booster seat (high back or backless). Premature graduation to safety belts without a booster was classified as inappropriate. Proper seating position was defined when the child was seated on the middle or back rows of a car, and conversely, when the child was seated at the front seat, it was considered an improper seating position.

The preliminary analysis in this study reveals that,

- The proper CRD use rates were 97.2 percent and 61.5 percent for children up to 3 years and 4 to 7 years, respectively, indicating a much lower CRD use rate for children aged 4 years or older.
- Only a small number of children were improperly seated (front seat), approximately 0.4 percent and 6.2 percent for children under 3 years and 4 to 7 years, respectively.
- Approximately, in one third of the observations, there were multiple child passengers in the vehicle.
- Overall, more than 97 percent of drivers were found to be properly belted and majority of the drivers were male. While the middle-aged (30 to 59 years) drivers account for almost three-quarter of the sample, followed by the young drivers (16 to 29 years), only less than 5 percent of the drivers were old (above 60 years). Also, majority of the drivers was white.
- Among the different vehicle types, passenger cars were most commonly observed, followed by SUVs and van/minivans, and lastly pickup trucks.
- With regard to the location types, shopping centers and fast food restaurants were most commonly observed. Moreover, these locations have comparable representations from all four strata.
- Lastly, majority of the observations were obtained during clear weather, during the weekdays, and in the mornings.

TABLE 1 Descriptive Statistics (n = 10,137)

Factor	Frequency	Percentage	Factor	Frequency	Percentage
Child Restraint Use			**Vehicle Type**		
Proper use	7,947	78.4	Passenger car	4,529	44.7
Improper use	2,090	21.6	Sport utility vehicle	3,395	33.5
Child Seating Position			Van or minivan	1,702	16.8
Proper	9,802	99.7	Pickup truck	511	5.0
Improper	335	0.3	**Location Type**		
Child Age			Shopping	4,245	41.9
Under 2 years	1,598	15.8	Fast Food	3,056	30.1
2 to 3 years	3,471	34.2	Recreation	2,119	20.9
4 to 7 years	5,068	50.0	Daycare	717	7.1
Number of children			**Geographic Location**		
One child	6,603	65.1	Stratum 1	2,439	24.1
Multiple children	3,534	34.9	Stratum 2	3,282	32.4
Driver Belt Use			Stratum 3	2,328	23.0
Driver belted	9,913	97.8	Stratum 4	2,088	20.6
Driver not belted	224	2.2	**Weather**		
Driver Gender			Clear	8,823	87.0
Male	8,718	86.0	Light fog/rain	1,314	13.0
Female	923	9.1	**Day of the week**		
Driver Age			Weekend	1,796	17.7
Under 30	2,344	23.1	Weekday	8,344	82.3
30 to 60	7,295	72.0	**Time of the day**		
Over 60	498	4.9	Morning	5,238	51.7
Driver Race			Afternoon	4,899	48.3
White	8,718	86.0			
African American	923	9.1			
Asian/ Hispanic/others	496	4.9			

RESULTS AND DISCUSSION

For this study, all observations, where at least one child passenger is present along with the driver in a motor vehicle, were analyzed. A total of 10,137 such observations were analyzed after removing all unknown data. As the likelihood of proper child restraint use (age-appropriate) is not independent of the likelihood of proper seating position (rear/middle seat) of the child passenger, it is important to understand this correlation between these two variables. Hence, to analyze the factors that simultaneously affect both proper child restraint use and proper seating position of the child passenger, a bivariate probit model was developed wherein the information related to the child passenger as well as the driver were included along with vehicle- and site-related factors. The dependent variables in all models are coded as a binary indicator implying proper and improper child restraint use and child passenger's seating position. The regression analysis in this study was carried out using R Studio.

Table 2 displays the results of the final bivariate probit model for both the dependent variables. The independent variables in all models included child passenger's age, number of child passengers in the vehicle, driver's age, gender, race, vehicle type, strata, weather, time of the day, and day of the week, each statistically significant at a 90 percent confidence level for predicting either child restraint use, or child's seating position, or both. County-specific socioeconomic factors including population, income, and education level did not have any significant association with either of the dependent variables and hence were further removed from the models. A significance level of 0.1 was used in this analysis.

As shown in Table 2, the results displayed comparable parameter estimates for most of the independent variables in child restraint use and child seating position models. The correlation parameter (ρ = 0.7002, p-value <0.001) is large and statistically significant, indicating the presence of common unobserved factors that may affect the proper use of child restraint and seating position of the child passenger. Also, the correlation coefficient is positive, indicating the use of proper child restraint is more likely to have the correct seating position of the child passenger as well. This finding is important and consistent with previous literature that identified a correlation between child passenger's restraint use and seating position (*32*).

Child Restraint Use

As can be seen from Table 2, the results reveal several interesting findings. First, the likelihood of proper child restraint use significantly reduces as the child's age increases, especially when the child is between 4 to 7 years old. This agrees with findings from other studies that determined a higher likelihood of proper restraint use for younger children compared to those 4 years or older (*27*, *50*). Moreover, having more than one child passenger in the vehicle increased the likelihood that the child would be properly restrained, although this association is not statistically significant. Similar to previous studies (*24*, *32*, *44*), the child is more likely to be properly restrained if the driver of the vehicle is properly belted. While middle-aged (30 to 59 years) drivers are found to be more likely to properly restrain the child passenger compared to the young drivers (16 to 29 years), old drivers are least likely to use the child restraint properly. This could be due to the fact that elderly drivers traveling with child passengers are likely to be the grandparents of the child. As grandparents are typically not the child's primary care-giver, it could be possible that they might not have adequate information on a CRD, and that may have resulted in low rate of correct installations.

Contrary to the general consensus that females are more responsible towards their children, the results of this study show that male drivers are more likely to properly restrain the child passenger, a finding that is consistent with multiple previous studies (*11*, *13*, *35*), although this association is not statistically significant. The white drivers are most likely to properly use the child restraint compared to its African American counterparts or drivers of other races. Drivers of passenger vehicles are the least likely to restrain their children properly, which has also been shown in other studies (*44*, *50*). Conversely, drivers of vans/minivans were the most likely to properly install their child passengers. Drivers in stratum 1, where historically driver's seat belt use is the highest in the state, are most likely to properly restrain the child passenger. On the other hand, drivers in stratum 4, which comprises of highly populated locations, are least likely to use the child restraint properly. Furthermore, the likelihood of proper child restraint use increases in light fog or rain compared to clear weather conditions. Finally, the use of proper restraint use for child passenger is higher over the weekends and in the afternoons.

Child's Seating Position

For child's proper seating position in terms of being seated in middle or rear seats, the age of the child is negatively associated with the proper seating position of the child passenger, implying that the higher the age of the child passenger is, the lower is the likelihood of the child being properly seated. Similar to the child restraint use, having more than one child passenger in the vehicle increased the likelihood that the child would be properly seated. Moreover, a properly belted driver significantly increases the likelihood of the child being properly positioned in the vehicle. Unlike the use of child restraint, driver age did not significantly influence the seating position of the child passenger. Furthermore, male drivers are more likely to properly position a child passenger compared to their female counterparts. Similar to child restraint use, white drivers are most likely to place the child passenger correctly compared to drivers of other races. The proper seating of a child passenger is the least in pickup trucks and most likely in passenger cars. Additionally, the likelihood of positioning the child passenger in the rear or middle seats is the highest in stratum 1, followed by strata 4, 3, and 2, respectively. The proper seating positioning increases during light fog or rain compared to clear weather. Also, the proper placing of a child passenger is greater during the weekends and in the afternoons. Lastly, the high correlation between the child passenger's seating position and the restraint use indicates that a child properly seated in a car is highly likely to be correctly restrained.

TABLE 2 Results of Bivariate Probit Models for Drivers and Passengers (*n* = 10,137)

Parameter	Proper child restraint use				Proper child seating			
	Estimate	**Std. Error**	**z-value**	**p-value**	**Estimate**	**Std. Error**	**z-value**	**p-value**
Intercept	1.939	0.167	11.63	<0.001	2.867	0.284	10.1	<0.001
Child age = up to 2 years	*Baseline*				*Baseline*			
Child age = 2 to 3 years	-0.892	0.130	-6.85	<0.001	-0.276	0.215	-1.28	0.199
Child age = 4 to 7 years	-2.439	0.125	-19.5	<0.001	-1.441	0.201	-7.16	<0.001
Number of children in the vehicle = 1	*Baseline*				*Baseline*			
Number of children in the vehicle > 1	0.018	0.036	0.49	0.621	0.607	0.070	8.72	<0.001
Driver belt use = Not properly belted	*Baseline*				*Baseline*			
Driver belt use = properly belted	0.552	0.097	5.71	<0.001	0.357	0.162	2.21	0.027
Driver age = 16 to 29 years	*Baseline*				*Baseline*			
Driver age = 30 to 59 years	0.072	0.042	1.7	0.089	0.048	0.072	0.66	0.509
Driver age = 60+ years	-0.018	0.083	-0.22	0.824	0.221	0.137	1.61	0.106
Driver gender = Male	*Baseline*				*Baseline*			
Driver gender = Female	-0.027	0.037	-0.73	0.467	-0.187	0.068	-2.73	0.006
Driver race = White	*Baseline*				*Baseline*			
Driver race = Black	-0.317	0.056	-5.68	<0.001	-0.129	0.105	-1.22	0.221
Driver race = Other	-0.256	0.073	-3.53	<0.001	-0.103	0.124	-0.83	0.405
Vehicle type = Passenger car	*Baseline*				*Baseline*			
Vehicle type = SUV	0.347	0.039	8.93	<0.001	-0.156	0.070	-2.22	0.027
Vehicle type = Van/minivan	0.674	0.053	12.63	<0.001	-0.124	0.090	-1.38	0.168
Vehicle type = Pickup truck	0.065	0.074	0.88	0.379	-1.023	0.093	-11.03	<0.001
Stratum 1	*Baseline*				*Baseline*			
Stratum 2	-0.164	0.048	-3.39	<0.001	-0.324	0.088	-3.69	<0.001
Stratum 3	-0.161	0.052	-3.12	0.002	-0.273	0.089	-3.09	0.002
Stratum 4	-0.169	0.051	-3.33	<0.001	-0.183	0.093	-1.97	0.048
Weekday	*Baseline*				*Baseline*			
Weekend	0.178	0.045	3.97	<0.001	0.104	0.073	1.42	0.155
Weather = Clear	*Baseline*				*Baseline*			
Weather = Light rain or fog	0.663	0.057	11.6	<0.001	0.405	0.099	4.1	<0.001
Time of the day = Morning	*Baseline*				*Baseline*			
Time of the day = Afternoon	0.114	0.035	3.26	0.001	0.016	0.060	0.27	0.789
Rho (ρ)	0.7002	0.027	26.67	<0.001				
Number of observations	10,137							
Log-likelihood	-4691.612							

In addition to the model estimated parameters (β) for each independent variable, the marginal effects for each variable are also of interest. The marginal effects provide a means of examining the magnitude of the effect of each independent variable on proper child restraint use or proper seating position of the child passenger in the context of the observed data collected for this study. Table 3 provides the marginal effects for the bivariate probit model including the estimates and their corresponding p-values. The marginal effects for each independent variable are also comparable between the two dependent variables, although, the extent or magnitude of these effects vary between the child restraint use and seating position.

TABLE 3 Marginal Effects of Predictors (*n* = 10,137)

Parameter	Proper child restraint use		Proper child seating	
	Estimate	p-value	Estimate	p-value
Child age = 2 to 3 years	-0.165	<0.001	-0.005	0.186
Child age = 4 to 7 years	-0.450	<0.001	-0.025	<0.001
Number of children in the vehicle > 1	0.003	0.621	0.011	<0.001
Driver belt use = Not properly belted	0.102	<0.001	0.006	0.030
Driver age = 30 to 59 years	0.013	0.089	0.001	0.513
Driver age = 60+ years	-0.003	0.824	0.004	0.107
Driver gender = Female	-0.005	0.468	-0.003	0.005
Driver race = Black	-0.059	<0.001	-0.002	0.222
Driver race = Other	-0.047	<0.001	-0.002	0.404
Vehicle type = SUV	0.064	<0.001	-0.003	0.029
Vehicle type = Van/minivan	0.125	<0.001	-0.002	0.160
Vehicle type = Pickup truck	0.012	0.379	-0.018	<0.001
Strata 2	-0.030	<0.001	-0.006	<0.001
Strata 3	-0.030	0.002	-0.005	0.004
Strata 4	-0.031	<0.001	-0.003	0.058
Weekend	0.033	<0.001	0.002	0.164
Weather = Light rain or fog	0.122	<0.001	0.007	<0.001
Time of the day = Afternoon	0.021	0.0011	0.0003	0.7892

CONCLUSIONS

This study simultaneously analyzes the factors that are associated with the child restraint use and seating position of child passengers of motor vehicles. For this study, the analysis was carried out on the data that has been collected from 263 sites across 30 counties in Michigan in 2015 and 2018 as part of direct observation surveys. The categories for the child restraint use included in this analysis were properly restrained indicating age-appropriate child restraint use, and not properly restrained that includes using some restraint but not child restraint device (CRD). Similarly, the other dependent variable was the proper seating position, which is essentially the rear or middle seats of the vehicle, and improper seating position implying the front seats. Additional data considered in this analysis included child passenger's age, number of child passengers in the vehicle, driver's age, gender, and race, vehicle type, strata, weather, time of the day, and day of the week.

Overall, a total of 10,137 observations were analyzed where at least one child passenger was present in a vehicle. A bivariate probit model was developed that simultaneously estimated both the use of CRD as well as the seating position of the child passenger in a vehicle. The use of the bivariate model accounts for the correlation between the two dependent variables and provides increased efficiency compared to the separate univariate probit models. The correlation parameter (ρ) of the final bivariate model was found to be large and highly significant implying the presence of common unobserved factors affecting the use of child restraint as well as the seating position of the child passenger. Also, the positive correlation parameter indicated that the proper use of CRD is more likely to have the child passenger correctly seated in the vehicle and vice versa.

Factors including child's age, the number of child passenger in a vehicle, driver's age, gender, and race, vehicle type, strata, weather, time of the day, and day of the week were all found to be significantly associated with either child restraint use, or child's seating position, or both. In general, the effects of different factors associated with the two dependent variables were mostly similar. County-specific socioeconomic factors including population density, income, and education level did not have any significant association with proper child restraint use and child's proper seating position.

The results reveal that the proper child restraint use, and proper child seating position are less likely with the increase in age of the child passenger. When more than one child is present in the vehicle the likelihood for proper restraint use and seating of a child passenger is greater, and this is particularly significant for the appropriate seating position of the child. Young drivers are, in general, found to be least responsible in using proper child restraint or placing the child in the correct seats. While male drivers were more likely to use the CRD and place the child correctly, white drivers were found to be most likely to do the same. Also, proper child restraint use was least likely in passenger vehicles, but it is more common to have the child correctly seated in passenger cars. Furthermore, the proper use of child restraint and seating position of the child passenger is most likely in stratum where the occupant seatbelt use is historically the highest in the state. Lastly, for both the dependent variables, traveling in light rain or fog, in weekends, and in the afternoons increased the likelihood of proper use of CRD as well as proper placement of the child passenger in a motor vehicle.

Overall, the results of this study support the previous research findings and provide more evidence that the interaction of various demographics, vehicle, and site-related characteristics are significantly associated with the use of CRD and the seating position of the child passenger, in addition to. More importantly, the study contributes to the limited body of knowledge regarding the correlation between CRD use and child passenger's seating position.

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AUTHOR CONTRIBUTION STATEMENT

The authors confirm contribution to the paper as follows: study conception and design: Meghna Chakraborty, Timothy Gates; analysis and interpretation of results: Meghna Chakraborty, Md. Shakir Mahmud; draft manuscript preparation: Meghna Chakraborty, Md. Shakir Mahmud, and Timothy Gates. All authors reviewed the results and approved the final version of the manuscript.

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