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16. Abstract

NHTSA recommends different child restraint systems for child occupants from birth to age 13. This evaluation separated child occupants into different age groups: 1- to 3-year-old, 3- to 5-year-old, 4- to 8-year-old, 5- to 8-year-old, and 7- to 8-year-old to examine the effects of child restraint systems on reducing fatalities and injury severity. For the 1- to 3-year-old and 3- to 5-year-old child occupants, car seats reduced more child fatalities than booster seats in non-rollover crashes (excluding rollovers) and all crashes (including rollovers) based on data from the Fatality Analysis Reporting System. The following shows the effectiveness of car seats:

For 1- to 3-Year-Old Child Occupants:

Fatalities in Non-Rollover Crashes	52.3%
Fatalities in All Crashes	47.3%

3- to 5-Year-Old Child Occupants:

Fatalities in Non-Rollover Crashes	39.1%
Fatalities in All Crashes	43.1%

For the 5- to 8-year-old child occupants, booster seats reduced more injuries with Maximum Abbreviated Injury Scale (MAIS) ≥ 2 and injuries with MAIS ≥ 3 than seat belts in non-rollover crashes and all crashes based on data from the National Automotive Sampling System-Crashworthiness Data System (NASS-CDS). The following shows the effectiveness of booster seats:

Injuries (MAIS ≥ 2) in Non-Rollover Crashes	74.9%
Injuries (MAIS ≥ 2) in All Crashes	65.5%
Injuries (MAIS ≥ 3) in Non-Rollover crashes	74.3%
Injuries (MAIS ≥ 3) in All Crashes	67.3%

For the 7- to 8-year-old child occupants, booster seats reduced more injuries with MAIS ≥ 2 than seat belts in non-rollover crashes based on NASS-CDS. The following shows the effectiveness of booster seats:

Injuries (MAIS ≥ 2) in Non-Rollover Crashes	85.6%

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List of Abbreviations

AIS: Abbreviated Injury Scale

CRS: child restraint system

CV: coefficient of variation

FARS: Fatality Analysis Reporting System

GVWR: gross vehicle weight rating

MAIS: Maximum Abbreviated Injury Scale

NASS-CDS: National Automotive Sample System - Crashworthiness Data System

PCR: police crash report

PSU: Primary Sampling Unit

PJ: police jurisdiction

ROC: receiver operating characteristic

Executive Summary

The National Highway Traffic Admission recommends that children up to age 8 should be restrained in a child restraint system appropriate for their age, weight, and height. Child restraint systems include the categories of car seats and booster seats. The car seat category is comprised of rear-facing car seats and forward-facing car seats. In 2010[1] NHTSA produced effectiveness estimates for booster seats using data from the National Automotive Sampling System-Crashworthiness Data System.

This evaluation examined the effectiveness of different types of CRSs against both nonfatal injuries and fatalities. Specifically:

1. Injury crashes involving:
    a. moderate-to-critical injuries (injuries with Maximum Abbreviated Injury Scale ≥ 2);
    b. serious-to-critical injuries (injuries with MAIS ≥ 3); and
2. Fatal crashes involving child occupants age 1 to 8. The fatality data for the child occupants was analyzed across the following age groups: 1 to 3, 3 to 5, 4 to 8, and 7 to 8.

After an exploratory data analysis, the evaluation considered crashes in two broad classes: crashes *excluding* rollovers and crashes *including* rollovers. This dual examination was warranted because the data demonstrated that the distribution of occupant injury severity was different between rollover and non-rollover crashes. NASS-CDS data from 1998 to 2015 was used to estimate the effects of CRSs on moderate/serious to critical injuries. NHTSA's Fatality Analysis Reporting System data from 2009 to 2016 was examined to estimate the effects of CRSs in fatal crashes.

The results of this analysis are presented in the following tables. Note that not every type of child restraint demonstrated a statistically significant effect.

The first sets of tables demonstrate where CRSs had statistically significant effects. For example, the table below shows the effects of booster seats on reducing moderate/serious to critical injuries of 5- to 8-year-old occupants.

5- to 8-Year-Old Occupants	
	Estimated Effect of Booster Seats
Moderate to Critical Injuries in *Non-Rollover Crashes*	74.9%
Moderate to Critical Injuries in *All Crashes*	65.5%
Serious to Critical Injuries in *Non-Rollover crashes*	74.3%
Serious to Critical Injuries in *All Crashes*	67.3%

The following table shows the effect of booster seats on reducing moderate to critical injuries of 7- to 8-year-old occupants.

[1] Sivinski, R. (2010, July). *Booster seat effectiveness estimates based on CDS and State data* (Report No. DOT HS 811 338). National Highway Traffic Safety. Available at https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/811338.

7- to 8-Year-Old Occupants	
	Estimated Effect of Booster Seats
Moderate to Critical Injuries in Non-Rollover Crashes	85.6%

The following table shows the effects of car seats on reducing fatalities of 1- to 3-year-old occupants.

1- to 3-Year-Old Occupants	
	Estimated Effect of Car Seats
Fatalities in Non-Rollover Crashes	52.3%
Fatalities in All Crashes	47.3%

The following table shows the effects of car seats on reducing fatalities of 3- to 5-year-old occupants.

3- to 5-Year-Old Occupants	
	Estimated Effect of Car Seats
Fatalities in Non-Rollover Crashes	39.1%
Fatalities in All Crashes	43.1%

The final table for the executive summary shows the estimated effectiveness for every CRS category assessed as part of this evaluation, separated by injury severity status (MAIS ≥ 2, MAIS ≥ 3, fatality), crash rollover status (non-rollover, all types of crashes), and crash databases (NASS-CDS, FARS). For some CRS categories, the table shows that the effectiveness labeled as *not significant*, indicating that the estimated coefficient of the countermeasure was not statistically significant at the 0.05 level. It is possible the uneven distribution of injury severity outcomes and the numbers of injuries and fatalities across the assessed age groups and CRS types contributed to the issue of statistical significance in this evaluation. The limited number of child occupant injuries by age group in the analytical data set affected the statistical significance of the results. It is possible that the effectiveness of child safety systems could be underestimated due to their improper use or installation.

Moderate to Critical Injuries (Injuries With MAIS ≥ 2) in Non-Rollover Crashes		
Evaluated Child Restraint System	Occupant's Age	Effectiveness
Rear-facing Car Seat	1 to 3	not significant
Car Seat	1 to 3	not significant
Car Seat	3 to 5	not significant
Booster Seat	4 to 8	not significant
Booster Seat	5 to 8	79.4%
Booster Seat	7 to 8	85.6%
Moderate to Critical Injuries (Injuries With MAIS ≥ 2) in All Crashes		
Evaluated Child Restraint System	Occupant's Age	Effectiveness
Rear-facing Car Seat	1 to 3	not significant
Car Seat	1 to 3	not significant
Car Seat	3 to 5	not significant
Booster Seat	4 to 8	not significant
Booster Seat	5 to 8	65.5%
Booster Seat	7 to 8	not significant
Serious to Critical Injuries (Injuries With MAIS ≥ 3) in Non-Rollover Crashes		
Evaluated Child Restraint System	Occupant's Age	Effectiveness
Rear-facing Car Seat	1 to 3	not significant
Car Seat	1 to 3	not significant
Car Seat	3 to 5	not significant
Booster Seat	4 to 8	not significant
Booster Seat	5 to 8	74.3%
Booster Seat	7 to 8	not significant
Serious to Critical Injuries (Injuries With MAIS ≥ 3) in All Crashes		
Evaluated Child Restraint System	Occupant's Age	Effectiveness
Rear-facing Car Seat	1 to 3	not significant
Car Seat	1 to 3	not significant
Car Seat	3 to 5	not significant
Booster Seat	4 to 8	not significant
Booster Seat	5 to 8	67.3%
Booster Seat	7 to 8	not significant
Child Fatalities in Non-Rollover Crashes		
Evaluated Child Restraint System	Occupant's Age	Effectiveness
Car Seat	1 to 3	52.3%
Car Seat	3 to 5	39.1%
Booster Seat	4 to 8	not significant
Booster Seat	7 to 8	not significant
Child Fatalities in All Crashes		
Evaluated Child Restraint System	Occupant's Age	Effectiveness
Car Seat	1 to 3	47.3%
Car Seat	3 to 5	43.1%
Booster Seat	4 to 8	not significant
Booster Seat	7 to 8	not significant

Literature Review

Before presenting the results of the most recent evaluation of child safety systems, it is appropriate to review previous NHTSA work on this topic.

Published in 1986, the NHTSA study *An Evaluation of Child Passenger Safety: The Effectiveness and Benefits of Child Safety Seats*,[2] found that correctly used child safety seats reduced fatality risk by 71 percent and serious injury risk by 67 percent. In 1984, the overall effectiveness of safety seats (correct users plus misusers) was 46 percent. Relative to no restraint, rear-facing child restraints were found 71 percent effective and forward-facing child restraints were found 54 percent effective.

In 1988 the NHTSA study Lives Saved by Child Restraints from 1982 through 1987[3] examined fatal crashes involving vehicle model year 1974 and later with known driver restraint use status and known child occupant (age 5 and under) restraint use status, showing the following fatality reductions:

- 69 percent for infants in child safety seats
- 47 percent for toddlers in child safety seats
- 36 percent for toddlers in adult belts

As other studies noted, this one cautioned that "because many restraints are incorrectly or incompletely used, potential effectiveness is probably higher than the estimates provided here."

In 2010 NHTSA again examined Child Safety Systems in Booster Seat Effectiveness Estimates Based on CDS and State Data,[4] showing a 14 percent reduction in overall injuries for children in booster seats (target age group 4 to 7). Due to sample size issues, many of the estimates were suspect. The analysis was conducted on both weighted and unweighted data, with the weighted estimate in the negative range.

Unlike previous studies which examined only children under seven years old, this study broadly surveys child safety seat systems used by child occupants from infancy up to age thirteen. This evaluation's goal is to estimate the effectiveness of child safety seat systems at reducing injuries and fatalities. Accordingly, the evaluation used data from both the Fatality Analysis Reporting System and the Crashworthiness Data System.

[2] Kahane, C. J. (1986, February). *An evaluation of child passenger safety: The effectiveness and benefits of child safety seats* (Report No. DOT HS 806 890). National Highway Traffic Safety Administration. Available at https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/806890.
[3] Partyka, S. C. (1988, December). *Lives saved by child restraints from 1982 through 1987* (Report No. 807 371). National Highway Traffic Safety Administration. Available at https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/807371.
[4] Sivinski, R. (2010, July). *Booster Seat Effectiveness Estimates Based on CDS and State Data* (Report No. DOT HS 811 338). National Highway Traffic Safety Administration. Available at https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/811338.

1 Introduction

Child occupant protection research[5] [6] has shown that premature graduation to restraint types inappropriate for a child's age, weight, or height can increase the likelihood of injuries. Moreover, the current state of this research demonstrates that an inappropriate restraint type might even double injury risk.[7] Given the importance of an appropriate child restraint type, NHTSA provides CRS recommendations to parents and care-givers.

The following list describes seat restraints commonly used by birth to 13-year-old occupants:

- Rear-Facing Car Seat: has a harness and will cradle and move with the child occupant to reduce stress to the child occupant's neck and spinal cord in a crash.
- Forward-Facing Car Seat: a harness and tether that limits the child occupant's forward movement during a crash.
- Booster Seat: positions the child occupant so that the seat belt appropriately fits the child occupant. The lap belt portion crosses the upper thighs not the stomach, and the shoulder belt portion lies snugly across the shoulder and chest without crossing the neck or face.
- Seat Belt: A seat belt prevents the child occupant from being ejected during a crash and minimizes the child occupant's body contact with the interior of the vehicle.

NHTSA recommends the following seat restraints for children from infants up to thirteen years old.[8] An appropriate seat restraint should be selected based on the child occupant's age and size. This analysis examined the effectiveness of those recommended restraint devices.

Table 1. NHTSA Recommended Seat Restraints From Birth to 13-Year-Old Occupants

Occupant's Age	Recommended Seat Restraint	General Guidelines
Birth to 12 Months	Rear-Facing Car Seat	Infant occupants under age one should always ride in a rear-facing car seat
1 to 3	Rear-Facing Car Seat, Forward-Facing Car Seat	1- to 3-year-old occupants should remain in a rear-facing car seat as long as possible until they reach the maximum height or weight limit allowed by the manufacturer of rear-facing car seats. Once the occupants outgrow a rear-facing car seat by the weight or height, they are ready to travel in a

[5] McMurry, T. L., Arbogast, K. B., Sherwood, C. P., Vaca, F., Bull, M., Crandall, J. R., & Kent, R. W (2017). Rear-facing versus forward-facing child restraints: An updated assessment. *Injury Prevention, 24*(1):55-59. doi:10.1136/injuryprev-2017-042512.
[6] Durbin, D. R., Hoffman, B. D., and Council on Injury, Violence, and Poison Prevention. (2018Child passenger safety. *Pediatrics. 142*(4): e20182461.
[7] Durbin, D., Chen, I., Smith, R., Elliott, M., & Winston, F. (2005). Effects of seating position and appropriate restraint use on the risk of injury to children in motor vehicle crashes. *Pediatrics, 115*(3), e305–e309.
[8] National Highway Traffic Safety Administration. (2019, July 12). *Car seat recommendations for children* [Flyer available as PDF]. www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/carseat-recommendations-for-children-by-age-size.pdf.

Occupant’s Age	Recommended Seat Restraint	General Guidelines
		forward-facing car seat with a harness and tether.
4 to 7	Forward-Facing Car Seat, Booster Seat	Keep 4-to 7-year-old occupants in a forward-facing car seat with a harness and tether as long as possible until they reach the maximum height or weight limit allowed by the manufacturer of forward-facing car seats. Once the occupants outgrow a forward-facing car seat with a harness by the weight or height, they are ready to travel in a booster seat.
8 to 13	Booster Seat, Seat Belt	Keep 8- to 13-year-old occupants in a booster seat as long as possible until the occupants fit in a seat belt properly. For a seat belt to fit properly the lap belt should lie snugly across the upper thighs not the stomach. The shoulder belt should lie snugly across the shoulder and chest without crossing the neck or face.

2 Evaluation Objectives

This evaluation examined the effects of CRSs on reducing occupant injury severity and fatalities. In this evaluation, CRSs include the car seats and booster seats, and the car seat categories include rear-facing and forward-facing car seats. Separate analyses were conducted for estimating CRS effectiveness in reducing occupant injury severity and in mitigating fatalities. The separate analyses were conducted because previous NHTSA research[9] indicated that the effectiveness of CRSs is different for different levels of injury severity considered.

This analysis examined occupants from 1 to 8 years old, since 28 States and the District of Columbia[10] require occupants under 8 to use CRSs when traveling.[11]. Occupants without a seat restraint, those of an unknown restraint status, or those for whom restraint type was unknown were not included in this analysis.

[9] Sivinski, 2010.

[10] Alaska, Arizona, California, Colorado, Delaware, District of Columbia, Georgia, Illinois, Kansas, Kentucky, Louisiana, Maryland, Massachusetts, Michigan, Nebraska, New Jersey, New York, North Carolina, North Dakota, Oklahoma, Oregon, Pennsylvania, Rhode Island, Tennessee, Utah, Vermont, Virginia, Washington, and Wisconsin.

[11] AAA Government Relations & Traffic Safety Advocacy. (2020). *Digest of motor laws* [Web page, annual listing]. Available at https://drivinglaws.aaa.com/tag/child-passenger-safety/.

3 Analysis of Child Restraint System Effectiveness on Injury Severity

This evaluation used the NASS-CDS data from 1998 to 2015 to estimate the effects of CRSs on reducing injury severity experienced by 1- to 8-year-old occupants in crashes. NASS-CDS reports an occupant's age in whole years. For example, the age of a 23-month-old occupant was coded as a 1-year-old in NASS-CDS. As another example, NASS-CDS reports an occupant's age as zero when an occupant's age was less than 12 months.

The MAIS in NASS-CDS ranges from 0 (no injuries) to 6 (critical injuries), and this analysis used MAIS to categorize injury severity experienced by 1- to 8-year-old occupants. Injury severity was analyzed according to two different categories: moderate to critical injuries (injuries with MAIS ≥ 2) and serious to critical injuries (injuries with MAIS ≥ 3). This was done because injuries at Abbreviated Injury Scale (AIS) level 2 were generally less life-threatening than injuries at the AIS level 3; the analysis seeks to understand if there is a differential effect across these injury severity thresholds. Examples of with AIS level 2 injuries are: upper/lower extremity joint injuries, abdominal/organ injuries and thorax/skeletal injuries. Injuries at AIS level 3 include: upper/lower extremity joint injuries, spinal joint injuries and thoracic/organ injuries.

The probability and standard error of experiencing moderate/serious to critical injuries (injuries with MAIS ≥ 2 and injuries MAIS ≥ 3) in rollover events are greater than the probability and standard error of experiencing moderate/serious to critical injuries in non-rollover crashes (see **Appendix A**). The distribution of occupant injury severity in rollover events is different from the distribution of occupant injury severity in non-rollover crashes. Rollover events might influence the analysis results of the CRS effectiveness. As a result, this evaluation separately examined the effects of CRSs in the analytical data sets of non-rollover crashes and all crashes. Crashed vehicles in the analytical data set of non-rollover crashes experienced no rollover events while crashed vehicles in the analytical data set of all crashes experienced non-rollover crashes and/or rollover events.

The effects of CRSs on moderate to critical injuries (injuries with MAIS ≥ 2) and serious to critical injuries (injuries with MAIS ≥ 3) were individually analyzed based on the analytical data sets of non-rollover crashes and all crashes in the following sections.

The analysis separated child occupants into the following groups: 1- to 3-year-old, 3- to 5-year-old, 4- to 8-year-old, and 7- to 8-year-old. The analysis examined the effects of CRSs on reducing moderate to critical injuries and serious to critical injuries by using the logistic regression analysis (see Section 3.3), and the effects of CRSs was examined by comparing with the effect of a specified reference group in each section. The following table shows the evaluated CRS and the reference group for each age group:

Table 2. Evaluation Topics of Child Restraint Systems on Injury Severity

Occupant's Age	Evaluated Child Restraint System	Reference Group
1 to 3	Rear-Facing Car Seat	Forward-Facing Car Seat
1 to 3	Car Seat	Booster Seat
3 to 5	Car Seat	Booster Seat
4 to 8	Booster Seat	Seat Belt
7 to 8	Booster Seat	Seat Belt

NASS-CDS records the type of CRS and whether it was in use, plus some information, but not every detail about whether it was used correctly. For example, frayed harnesses or improperly latched CRSs would not be recorded by NASS-CDS. This evaluation considered the recorded presence (as indicated in NASS-CDS) of a CRS, but this evaluation did not consider whether such CRSs were installed and used according to safety guidelines and the respective manufacturers' recommendations. Deviation from the proper use of CRSs might impact some of the effectiveness estimates shown in this evaluation.

3.1 National Automotive Sampling System-Crashworthiness Data System

NASS-CDS is a nationwide, three-stage, complex, probability-based survey sampling program of motor vehicle traffic crashes. In the NASS-CDS sample design, the United States was partitioned into 1,195 NASS Primary Sampling Units[12], and those PSUs were then stratified into 12 groups (strata) consisting of four geographic regions[13] and three urbanization types.[14]

NASS-CDS used the probability-proportional-to-selection sampling to select 24 PSUs with 2 PSUs per stratum from the nationwide NASS PSUs. NASS-CDS then selected police jurisdictions from the sampled PSUs. An average of seven PJs were selected from each PSU. The NASS-CDS tertiary sampling selection was the selection of police crash reports from the sampled PJs. Each data observation in the NASS-CDS has a sampling weight.

NASS-CDS collected the occupant injury information from hospitals, treatment facilities, and autopsies. Occupant injury severity was assessed by using AIS, ranging from 1 (minor injuries) to 6 (critical injuries). AIS has been continuously updated to keep pace with medical terminology,[15] and the following table shows the versions of the AIS that NHTSA has adopted over the years:

Table 3. NHTSA AIS Version by Year

AIS Version	NHTSA Data Years
AIS 2015	2017-Present
AIS 2005 Update 2008	2010-2016
AIS 1990/1998 Update	2000-2009
AIS 1990	1993-1999
AIS 1985	1985-1992
AIS 1980	1980-1984
AIS 1976	1976-1979

The analytical data set was used to examine the effects of CRSs on reducing occupant injury severity, and the analytical data set included three AIS versions: AIS 1990, AIS 1990/1998

[12] A PSU could be a county, a group of counties, a central city, or a portion of a large county excluding a central city.
[13] Northeast, South, Central, and West.
[14] Large Central City, Large Suburban Area, and All Others.
[15] Mynatt, M., Rudd, R., Alpert, N., Loftis, K., & Kulaga, A. (2017, June 5-8).). *Documenting injuries in NHTSA's CISS program*. (Paper Number 17-0173). 25th International Technical Conference on the Enhanced Safety of Vehicles, Detroit Michigan. Available at www-esv.nhtsa.dot.gov/Proceedings/25/25ESV-000173.pdf.

update, and AIS 2005 update 2008. This evaluation used the AIS levels as they were coded in the NASS-CDS data files.

3.2 Analytical Domain Variables

The sampling data observations in the analytical data set were collected by the three-stage complex survey sampling, and the sampling data observations were weighted at each stage of selection. Sub-setting the complex survey sample may delete PSUs and cause bias in variance estimates. This evaluation used the domain variables to specify an analytical data subset from the entire analytical data set without sub-setting the sample.

This evaluation used SAS 9.3[16] to perform the statistical analyses, and the DOMAIN statement was used in the analysis of survey data. The analytical data set was filtered by the vehicle, crash mode, driver and occupant conditions, and the following domain variables were used to specify the analytical data set from the NASS-CDS 1998-2015.

Light passenger vehicles

Passenger vehicles with the gross vehicle weight rating less than or equal to 10,000 pounds were considered as light passenger vehicles. The analysis included the light passenger vehicles. The following domain variable was used to specify the light passenger vehicles.

$$\text{LIGHT\_VEH} = \begin{cases} 1, \text{if a passenger vehicle with GVWR} \leq 10{,}000 \text{ pounds} \\ 0, \text{otherwise} \end{cases}$$

Towed vehicles

The analysis included the vehicles that were towed after a crash occurred. The following domain variable was used to specify the towed vehicles.

$$\text{TOWED\_VEH} = \begin{cases} 1, \text{if a crashed vehicle was towed} \\ 0, \text{otherwise} \end{cases}$$

Number of 1- to 8-year-old occupants

There must be at least one 1- to 8-year-old occupant in a passenger vehicle. The following domain variable was used to specify the passenger vehicles that carried at least one 1- to 8-year-old occupant.

$$\text{PASS\_GROUP} = \begin{cases} 1, \text{if at least one occupant between 1 and 8 years old in the vehicle} \\ 0, \text{otherwise} \end{cases}$$

Driver's age

The minimum age for restricted driver's license in 38 States[17] is 16 years old. The following domain variable was used to specify the drivers with the age greater than or equal to 16.

[16] SAS 9.3, released July 2011 by the SAS Institute.

[17] Alabama, Alaska, Arizona, Arkansas, California, Colorado, Florida, Georgia, Hawaii, Idaho, Illinois, Iowa, Kansas, Louisiana, Maine, Michigan, Minnesota, Mississippi, Missouri, Montana, Nebraska, Nevada, New Hampshire, New Mexico, North Carolina, North Dakota, Ohio, Oklahoma, Oregon, South Carolina, South Dakota,

$$\text{LEGAL\_AGE} = \begin{cases} 1, \text{if a driver's age} \geq 16 \text{ years} \\ 0, \text{otherwise} \end{cases}$$

<u>Driver's gender</u>

$$\text{DR\_GENDER} = \begin{cases} 1, \text{if a driver's gender is known} \\ 0, \text{otherwise} \end{cases}$$

<u>Belted driver</u>

The analysis examined driver seat belt use as a proxy for driver safety-related behavior. Seat belts include the shoulder belts, lap belts and lap-and-shoulder belts. The following domain variable was used to specify the belted drivers.

$$\text{BELT\_DRIVER} = \begin{cases} 1, \text{if a driver was belted} \\ 0, \text{otherwise} \end{cases}$$

<u>Occupant's seat position</u>

The analysis included occupants in the second or the third row of a vehicle. The following domain variable was used to specify occupants in the second or the third row of a vehicle.

$$\text{SEAT\_GROUP} = \begin{cases} 1, \text{if an occupant in the 2nd or 3rd row of a vehicle} \\ 0, \text{otherwise} \end{cases}$$

<u>Occupant with a known MAIS</u>

The analysis included the 1- to 8-year-old occupants with an MAIS from 0 to 6 in the analytical data set. The following domain variable was used to specify the occupants with an MAIS from 0 to 6.

$$\text{MAIS\_GROUP} = \begin{cases} 1, \text{if an occupant with a MAIS from 0 to 6} \\ 0, \text{otherwise} \end{cases}$$

The following table shows the weighted frequencies, unweighted frequencies and weighted percentages of car seat, booster seat and seat belt usages at each age from one to eight by applying the domain variables in this section:

Table 4. Seat Restraints Used by 1- to 8-Year-Old Occupants in Crashes

Occupant's Age	Car Seat	Booster Seat	Seat Belt	Total
1	177,250 (411) 93.86%	4,790.73 (12) 2.54%	6,811.91 (13) 3.61%	188,852 (436) 100%
2	200,449 (397) 85.18%	15,937.5 (44) 6.77%	18,926.6 (49) 8.04%	235,314 (490) 100%
3	98,044.5 (205) 50.97%	67,700.3 (118) 35.19%	26,613 (75) 13.84%	192,358 (398) 100%

Tennessee, Texas, Utah, Vermont, Washington, West Virginia, Wisconsin, Wyoming. Insurance Institute for Highway Safety. (n.a.) Graduated licensing laws by State. Available at www.iihs.org/topics/teenagers/graduated-licensing-laws-table.

Occupant's Age	Car Seat	Booster Seat	Seat Belt	Total
4	34,328 (103) 14.21%	103,627 (180) 42.90%	103,624 (160) 42.89%	241,579 (443) 100%
5	21,828.6 (46) 11.10%	71,736.1 (159) 36.48%	103,086 (238) 52.42%	196,651 (443) 100%
6	6,480.2 (12) 2.38%	46,185.8 (114) 16.99%	219,235 (291) 80.63%	271,901 (417) 100%
7	3,664.05 (4) 1.74%	39,310.5 (66) 18.65%	167,760 (329) 79.61%	210,734 (399) 100%
8	735.13 (2) 0.27%	48,726 (22) 17.65%	226,606 (337) 82.08%	276,067 (361) 100%

There are 411 car seat users 1-year-old in the analytical data set filtered by the domain variables in this section, and the weighted frequency of 1-year-old car seat users is 177,250. The weighted percentage of car seat usage in the 1-year-old occupants is 93.86 percent ((177,250/188,852) *100%) while the weighted percentage of booster seat usage in the 1-year-old occupants is 2.54 percent ((4,790.73/188,852) *100%).

The weighted percentage of car seat usage decreases when the occupant age increases while the weighted percentage of seat belt usage increases when the occupant age increases. The percentage of booster seat usage increases up to age four and then decreases starting age 5.

3.3 Analytical Method: Logistic Regression Analysis

The occupant injury severity was the dependent variable in the analysis. This section used moderate to critical injuries as an example to demonstrate the analysis method. The following variable denotes the dependent variable.

$$Y_i = \begin{cases} 1, \text{moderate to critical injuries} \\ 0, \text{otherwise} \end{cases}$$

The effect of CRSs on occupant injury severity was estimated by logistic regression analysis, since the dependent variable was binary. Denoting P_i as the probability of experiencing a severe injury by the i^{th} occupant, each Y_i is an independent Bernoulli random variable given selected PSU and PJ, with P_i as the expected value.

Assuming there are p independent variables in the logistic regression model, the following notations are used in the analysis.

$$\boldsymbol{X}^T = \left[1, X_1, X_2, \dots, X_p\right]^T$$

$$\boldsymbol{X}_i^T = \left[1, X_{i,1}, X_{i,2}, \dots, X_{i,p}\right]^T$$

$$\boldsymbol{B}^T = \left[B_0, B_1, B_2, \dots, B_p\right]^T$$

$\boldsymbol{X}^T$ is a vector with independent variables X_1 to X_p. $\boldsymbol{X}_i^T$ is the vector that provides the observed values for the independent variables based on the i^{th} observation. $\boldsymbol{B}^T$ is the vector with the parameters in the logistic regression model.

Based on the logistic function, the following equation presents P_i by using $\boldsymbol{X}_i^T$ and $\boldsymbol{B}$.

$$P_i = \frac{\exp(\boldsymbol{X}_i^T \boldsymbol{B})}{1 + \exp(\boldsymbol{X}_i^T \boldsymbol{B})}$$

Applying the logit transformation to P_i, the following equation presents the logistic regression model.

$$log\left(\frac{P_i}{1 - P_i}\right) = \boldsymbol{X}_i^T \boldsymbol{B}$$

The value $\left(\frac{P_i}{1-P_i}\right)$ is the odds of experiencing a severe injury by the i^{th} occupant, and the parameters, $B_0, B_1, B_2, \dots, B_p$ in the logistic regression model are estimated by the Maximum Likelihood Estimation (MLE) in this evaluation report.

Suppose X_q is a binary independent variable, and B_q is the parameter of X_q in the logistic regression model. With the other independent variables, X_1, X_2,.., X_{q-1}, $X_{q+1} \dots X_p$ being held constant, the following equation presents the logarithm of the ratio of the odds of experiencing severe injuries when X_q equals 1 to the odds of experiencing severe injuries when X_q equals 0.

$$log\left(\frac{\text{Odds}|X_q = 1}{\text{Odds}|X_q = 0}\right) = log(\text{Odds Ratio}) = B_q$$

The following equation presents the odds ratios by taking the exponential function on both sides of the above equation.

<u>Equation 1</u>

$$\left(\frac{\text{Odds}|X_q = 1}{\text{Odds}|X_q = 0}\right) = \text{Odds Ratio} = \exp(B_q)$$

The effect of X_q on reducing severe injuries is presented by the percentages of odds reduction, and the following equation shows the estimated effect of X_q.

<u>Equation 2</u>

$$\text{Efffect} = (1 - \text{Odds Ratio}) * 100\% = (1 - \exp(B_q)) * 100\%$$

Equations 1 and 2 will be used to present the effect of CRSs in the analysis.

3.4 Analytical Method: Selection Criterion for Logistic Regression Modeling

This evaluation used C-statistics as the model selection criterion when there was more than one candidate model. The value of a C-statistic is the area under the receiver operating characteristic curve of the logistic regression, and the ROC curve is created by plotting the value of Sensitivity on the y-axis (vertical axis) and the value of (1-Specificity) on the x-axis (horizontal axis) for different cut-off points.[18] Each point on the ROC curve presents a paired-value of Sensitivity and (1-Specificity) at a particular cut-off point. Following are the definitions of Sensitivity and Specificity.

Suppose Y is an observed value of a binary variable with the outcomes 0 or 1, and $\hat{Y}$ is a predicted value of Y by using the logistic regression model.

Sensitivity: the probability of both predicted value ($\hat{Y}$) and observed value (Y) being 1, and Sensitivity is presented by $P(\hat{Y} = 1|Y = 1)$ in Statistics.

Specificity: the probability of both predicted value ($\hat{Y}$) and observed value (Y) being 0, and Specificity is presented by $P(\hat{Y} = 0|Y = 0)$ in Statistics.

The value of the C-statistic of a logistic regression model ranges from 0 to 1, and a logistic regression model is not significant when the value of the C-statistics is less than 0.5. A logistic regression model fits the analytical data set better when the value of the C-statistics is higher.

3.5 Analytical Variables for the Injury Severity Analysis

The following variables were used in the logistic regression analysis.

Dependent Variable

The occupants with a MAIS from 0 to 6 were specified by using the domain variable (MAIS_GROUP) in Section 3.2. Occupant injury severity was the dependent variable in the analysis. The dependent variable was a binary variable defined by the following two different thresholds of occupant injury severity.

Moderate to Critical Injuries

Injuries with MAIS ≥ 2 were considered as moderate to critical injuries in Section 4. The following variable was used to present the status of moderate to critical injuries.

$$\text{MAIS2} = \begin{cases} 1, \text{if injuries with MAIS} \geq 2 \\ 0, \text{if injuries with MAIS} < 2 \end{cases}$$

Section 4 used MAIS2 as the dependent variable in the logistic regression analysis.

Serious to Critical Injuries

Injuries with MAIS ≥ 3 were considered as serious to critical injuries in Section 5. The following variable was used to present the status of serious to critical injuries in Section 5.

$$\text{MAIS3} = \begin{cases} 1, \text{if injuries with MAIS} \geq 3 \\ 0, \text{if injuries with MAIS} < 3 \end{cases}$$

Section 5 used MAIS3 as the dependent variable in the logistic regression analysis.

[18] A cut-off point is a probability decision threshold that determines the outcome of a predicted value.

Independent Variables

Driver's Gender

The drivers with a known gender were specified in the analysis by using the domain variable (DR_GENDER) in Section 3.2. The female drivers were used as the reference group of the male drivers, and the effect of male drivers was compared with the effect of female drivers in the logistic regression analysis. The following variable was used to present the driver's gender.

$$\text{MALE1} = \begin{cases} 1, \text{if a male driver} \\ 0, \text{if a female driver} \end{cases}$$

Driver's Age

The drivers with the age greater than or equal to 16 were specified by using the domain variable (LEGAL_AGE) in Section 3.2. The analytical data set presented the driver age in years. Driver age was a continuous variable in the analysis, and one unit increase of the driver age was 1 year. The following variable was used to present the driver age.

AGE1 = the driver age in years

Crash Mode

The effects of CRSs were separately examined in the analytical data sets of non-rollover crashes and all crashes. The following variables were used to present the crash mode in non-rollover crashes and all crashes.

Crash Mode in Non-Rollover Crashes

Crashed vehicles in non-rollover crashes experienced no rollovers, and the analytical data set of non-rollover crashes was specified by using the domain variable (COLLISION_GROUP, see Section 4). The non-rollover crashes in the analysis were categorized into frontal-impact, side-impact and rear-impact crashes by using the direction of the highest impact force striking the vehicle.[19] The analytical data set used the clock position to indicate the direction of the highest impact force striking the vehicle in a non-rollover crash. The following table shows the crash mode and its clock position of the highest impact force.

Table 5. Crash Mode and Direction of Highest Impact Force in Non-Rollover Crashes

Crash Mode	Clock Position of Highest Impact Force
Frontal-impact crash	11, 12 or 1 o'clock
Side-impact crash	2, 3, 4, 8, 9, or 10 o'clock
Rear-impact crash	5, 6 or 7 o'clock

If the highest impact force striking the vehicle in a non-rollover crash was at 11, 12 or 1 o'clock, the non-rollover crash was categorized into a frontal-impact crash. The crash modes in non-rollover crashes included the frontal-impact, rear-impact and side-impact crashes. The frontal-

[19] The highest impact force striking the vehicle can be applied to two different scenarios: objects impacted a vehicle and a vehicle impacted moving or fixed objects.

impact crashes were used as the reference group of the rear-impact and side-impact crashes in the analysis, and the effects of rear-impact and side-impact crashes were individually compared with the effect of frontal-impact crashes. The following variable was used to present the crash mode in non-rollover crashes.

$$\text{MODE\_COLL} = \begin{cases} \text{FRONTAL, if a frontal} - \text{impact crash} \\ \text{REAR, if a rear} - \text{impact crash} \\ \text{SIDE, if a side} - \text{impact crash} \end{cases}$$

Crash Mode in All Crashes

Crashed vehicles in all crashes experienced non-rollover crashes and/or rollovers, and the analytical data set of all crashes was specified by using the domain variable (CRASH_GROUP, see Section 4). The crashes in the analysis were categorized into frontal-impact crashes, side-impact crashes, rear-impact crashes, and rollovers.

If a crashed vehicle only experienced non-rollover crashes, the crash mode was categorized by using the direction of the highest impact force striking the vehicle in Table 4. If a crashed vehicle experienced a rollover event, the crash mode was categorized into rollovers. The following table shows the crash mode in all crashes.

Table 6. Crash Mode and Crash Conditions in All Crashes

Crash Mode	Crash Conditions
Frontal-impact crash	A vehicle experienced no rollovers and the clock position of highest impact force was at 11, 12 or 1 o'clock
Side-impact crash	A vehicle experienced no rollovers and the clock position of highest impact force was at 2, 3, 4, 8, 9, or 10 o'clock
Rear-impact crash	A vehicle experienced no rollovers and the clock position of highest impact force was at 5, 6 or 7 o'clock
Rollover	A vehicle experienced a rollover event

If a crashed vehicle only experienced non-rollover crashes with the highest impact force striking the vehicle at 11, 12 or 1 o'clock, the crash was categorized into a frontal-impact crash. The crash modes in all crashes included the frontal-impact crashes, rear-impact crashes, side-impact crashes, and rollovers. Rollovers were used as the reference group of the frontal-impact, side-impact and rear-impact crashes in the analysis, and the effects of frontal-impact, side-impact and rear-impact crashes were individually compared with the effect of rollovers. The following variable was used to present the crash mode in all crashes.

$$\text{MODE} = \begin{cases} \text{FRONTAL, if a frontal} - \text{impact crash without rollovers} \\ \text{REAR, if a rear} - \text{impact crash without rollovers} \\ \text{SIDE, if a side} - \text{impact crash without rollovers} \\ \text{Rollover, if a rollover event} \end{cases}$$

Child Occupant's Age

The passengers with the age from 1 to 8 were specified by using the domain variable (PASS_GROUP) in Section 3.2. The analytical data set presented the age of 1- to 8-year-old occupants in years. Occupant age was a continuous variable in the analysis, and one unit increase of occupant's age was 1 year. The following variable was used to present the occupant age.

AGE2 = the occupant age in years

Occupant's Seat Position

The occupants' seat positions were specified by using the domain variable (SEAT_GROUP) in Section 3.2. The occupants' seat positions included the center and outboard seats. The outboard seats were used as the reference group of the center seats in the analysis, and the effect of center seats was compared with the effect of outboard seats. The following variable was used to present an occupant's seat position:

$$\text{CENTER} = \begin{cases} 1, \text{if in a center seat} \\ 0, \text{if in an outboard seat} \end{cases}$$

Type of Car Seats

The car seat users were specified by using the domain variable (CARSEAT_GROUP, see Section 4.1.1). The car seat categories included the rear-facing and forward-facing car seats. The forward-facing car seats were used as the reference group of rear-facing car seats in the analysis, and the effect of rear-facing car seats was compared with the effect of forward-facing car seats. The following variable was used to present the type of car seat that was used by an occupant in a crash:

$$\text{REAR\_CARSEAT} = \begin{cases} 1, \text{if a rear} - \text{facing car seat user} \\ 0, \text{if a forward} - \text{facing car seat user} \end{cases}$$

Type of Child Restraint Systems

The CRS users were specified by using the domain variable (CRS_USER, see Section 4.2.1). The CRSs included the car seats and booster seats. The booster seats were used as the reference group of car seats in the analysis, and the effect of car seats was compared with the effect of booster seats. The following variable was used to present the type of CRS that was used by an occupant in a crash:

$$\text{CARSEAT} = \begin{cases} 1, \text{if a car seat user} \\ 0, \text{if a booster seat user} \end{cases}$$

Type of Seat Restraints

The booster seat and seat belt users were specified by using the domain variable (BOOSTER_SEATBELT, see Section 4.4.1). The seat restraints included the booster seats and seat belts. The seat belts were used as the reference group of booster seats in the analysis, and the effect of booster seats was compared with the effect of seat belts. The following variable was used to present the type of seat restraint that was used by an occupant in a crash:

$$\text{BOOSTERSEAT} = \begin{cases} 1, \text{if a booster seat user} \\ 0, \text{if a seat belt user} \end{cases}$$

4 Child Restraint System Effectiveness: Moderate to Critical Injuries (MAIS ≥ 2)

The NASS-CDS 1998-2015 was used to examine the effects of CRSs on reducing moderate to critical injuries experienced by the 1- to 8-year old occupants. Injuries with MAIS ≥ 2 were considered as moderate to critical injuries in Section 4, and the status of moderate to critical injuries (MAIS2) in Section 3.5 was used in the analysis.

The 1- to 8-year old occupants were separated into different age groups based on the evaluation topics in Table 2. The effects of CRSs on reducing moderate to critical injuries experienced by the occupants in different age groups were examined in the following sections.

This evaluation used the analytical data sets of non-rollover crashes and all crashes to examine the effects of CRSs on injury severity. The crashed vehicles in the analytical data set of non-rollover crashes experienced only non-rollover crashes. The following domain variable was used to specify non-rollover crashes:

$$\text{COLLISION\_GROUP} = \begin{cases} 1, \text{if a crashed vehicle only experienced non} - \text{rollover crashes} \\ 0, \text{others} \end{cases}$$

The crashed vehicles in the analytical data set of all crashes experienced non-rollover crashes and/or rollover events. The following domain variable was used to specify all crashes.

$$\text{CRASH\_GROUP} = \begin{cases} 1, \text{if a crashed vehicle experienced non} - \text{rollover crashes and/or rollovers} \\ 0, \text{others} \end{cases}$$

The effects of CRSs on reducing moderate to critical injuries were separately examined in the analytical data sets of non-rollover crashes and all crashes in the following sections.

4.1.1 Rear-Facing Car Seats: 1- to 3-Year-Old Occupants in Non-Rollover Crashes (MAIS ≥ 2)

This section examined the effect of rear-facing car seats on reducing moderate to critical injuries experienced by the 1- to 3-year-old occupants in non-rollover crashes. The forward-facing car seats were used as the reference group of the rear-facing car seats, and the effect of rear-facing car seats on reducing moderate to critical injuries was compared with the effect of forward-facing car seats in the analysis. An infant occupant’s age (less than 1 year) was recorded as zero in NASS-CDS, and the analytical data set in this section did not include occupants who were younger than 12 months.

The car seat categories included the rear-facing and forward-facing car seats. The following domain variables were used to specify 1- to 3-year-old car seat users:

$$\text{AGE\_1\_3} = \begin{cases} 1, \text{if an occupant is between 1 and 3 years old} \\ 0, \text{others} \end{cases}$$

$$\text{CARSEAT\_GROUP} = \begin{cases} 1, \text{if an occupant used a car seat} \\ 0, \text{others} \end{cases}$$

The analytical data set in this section was specified from the entire NASS-CDS 1998-2015 by using the above two domain variables, domain variables in Section 3.2 and the domain variable of non-rollover crashes in Section 4. The sampling data observations in the analytical data set satisfied the following vehicle, driver, and occupant conditions.

Vehicle

The collision-crashed passenger vehicle with the GVWR less than 10,000 pounds was towed and experienced no rollovers, and there was at least one 1- to 3-year-old car seat user in the collision-crashed passenger vehicle.

Driver

The driver was belted and was at least 16 years old. The belted drivers might be more likely to properly use the car seats than unbelted drivers.

Occupant

The 1- to 3-year-old car seat user with a known MAIS sat in the second or the third row of the passenger vehicle in the non-rollover crash.

The following table shows the weighted frequency, unweighted frequency and weighted percentage of injuries at each MAIS level experienced by the 1- to 3-year-old car seat users in the analytical data set:

Table 7. Distribution of MAIS Level in 1- to 3-Year-Old Car Seat Users in Non-Rollover Crashes

MAIS Level	Frequency	Weighted Percentage
0	300,689 (496)	78.08%
1	81,395 (241)	21.13%
2	1,189 (15)	0.31%
3	523.16 (8)	0.14%
4	1,222 (7)	0.32%
5	95.09 (3)	0.02%
6	8.38 (1)	0.00%
Total	385,122 (771)	100%

There are 241 car seat users 1- to 3 years old in the analytical data set who experienced MAIS level 1 injuries in non-rollover crashes. The weighted frequency of MAIS level 1 injuries experienced by the 1- to 3-year-old car seat users is 81,395, and the weighted percentage of MAIS level 1 injuries is 21.13 percent ((81,395/423,053.4)*100%). The weighted percentage of injuries does not monotonically decrease when the MAIS level increases. The impact of sampling weights and different NHTSA AIS versions over the years might influence the weighted percentage of injuries.

The weighted percentage of moderate to critical injuries experienced by the 1- to 3-year-old car seat users in non-rollover crashes is 0.79 percent (0.31%+0.14%+0.32%+0.02%+0.00%) while the weighted percentage of none to minor injuries[20] experienced by the 1- to 3-year-old car seat users in non-rollover crashes is 99.21 percent (78.08%+21.13%). The weighted percentage of moderate to critical injuries (0.79%) is substantially less than the weighted percentage of none to minor injuries (99.21%) in crashes.

The following table shows the weighted frequencies, unweighted frequencies and weighted percentages of rear-facing and forward-facing car seat usages in the analytical data set:

Table 8. Rear-Facing and Forward-Facing Car Seats Used by 1- to 3-Year-Old Occupants in Non-Rollover Crashes

	Frequency	**Weighted Percentage**
Rear-Facing Car Seat	12,314 (53)	3.20%
Forward-Facing Car Seat	372,808 (718)	96.80%
Total	385,122 (771)	100%

There are 53 1- to 3-year-old rear-facing car seat users 1- to 3 years old in the analytical data set, and the weighted frequency of the 1- to 3-year-old rear-facing car seat users is 12,314. The weighted percentage of rear-facing car seat usage is 3.20 percent ((12,314/385,122) *100%) while the weighted percentage of forward-facing car seat usage is 96.80 percent ((372,808/385,122) *100%). The 1- to 3-year-old car seat users who experienced non-rollover crashes used forward-facing car seats more frequently than rear-facing car seats.

The following contingency table shows the weighted frequencies, unweighted frequencies, weighted percentages, and standard errors of moderate to critical injuries experienced by the 1- to 3-year-old rear-facing and forward-facing car seat users in non-rollover crashes:

Table 9. Type of Car Seats and Status of Moderate to Critical Injuries Experienced by 1- to 3-Year-Old Occupants in Non-Rollover Crashes

	Moderate to Critical Injuries	**None to Minor Injuries**	**Total**
Rear-Facing Car Seat	132.43 (5) 1.08% (0.70%)	12,181 (48) 98.92% (0.70%)	12,314 (53) 100%
Forward-Facing Car Seat	2,906 (29) 0.78% (0.30%)	369,902 (689) 99.22% (0.30%)	372,808 (718) 100%

There are five 1- to 3-year-old rear-facing car seat users in the analytical data set who experienced moderate to critical injuries in crashes, and the weighted frequency of moderate to critical injuries experienced by the 1- to 3-year-old rear-facing car seat users is 132.43. The weighted percentage of moderate to critical injuries experienced by the rear-facing car seat users is 1.08 percent ((132.43/12,314)*100%) with the standard error of 0.70 percent while the weighted percentage of moderate to critical injuries experienced by the 1- to 3-year-old forward-facing car seat users is 0.78 percent ((2,906/372,808)*100%) with the standard error of 0.30 percent. The weighted percentage of moderate to critical injuries experienced by the rear-facing car seat users (1.08%) is greater than the weighted percentage of moderate to critical injuries experienced by the forward-facing car seat users (0.78%). The variation of experiencing

[20] None to minor injuries in this evaluation included no injuries (MAIS 0) and injuries at MAIS level 1.

moderate to critical injuries by the rear-facing car seat users is greater than the variation of experiencing moderate to critical injuries by the forward-facing car seat users, since the standard error in the rear-facing car seat users (0.70%) is greater than the standard error in the forward-facing car seat users (0.30%).

The effect of rear-facing car seats on reducing moderate to critical injuries experienced by the 1- to 3-year-old car seat users in non-rollover crashes was estimated by using the logistic regression analysis, and the effect of rear-facing car seats was compared with the effect of forward-facing car seats in the analysis. The status of moderate to critical injuries (MAIS2) in Section 3.5 was used as the dependent variable, and the driver's gender (MALE1), the driver age (AGE1), the non-rollover crash mode (MODE_COLL), the occupant age (AGE2), the occupant seat position (CENTER), and the type of car seats (REAR_CARSEAT) in Section 3.5 were used as the independent variables in the logistic regression analysis.

The domain variables in Section 3.2 and Section 4.1.1 and the domain variable of non-rollover crashes in Section 4 were used in the SAS survey analysis procedure to specify the analytical data set from the entire NASS-CDS. This section used the SAS SURVEYLOGISTIC procedure with RATEGT as the weight, PSU as the cluster and PSU STRATA as the strata to perform the logistic regression analysis. The following table shows the estimated parameters of independent variables in the full logistic regression model:

Table 10. Full Logistic Regression Model: 1- to 3-Year-Old Car Seat Users Experienced Moderate to Critical Injuries in Non-Rollover Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_1_3=1 CARSEAT_USER=1 COLLISION_GROUP=1

Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
MALE1=1	0.0625	0.5693	0.11	0.9140
AGE1	0.0315	0.0379	0.83	0.4176
MODE_COLL=REAR	-0.6529	0.6567	-0.99	0.3359
MODE_COLL=SIDE	0.3403	0.5884	0.58	0.5717
AGE2	-0.0689	0.1833	-0.38	0.7120
CENTER=1	-1.2090	0.6930	-1.74	0.1015
REAR_CARSEAT=1	0.2382	0.7745	0.31	0.7627

The 1- to 3-year-old rear-facing car seat users might not be less likely to experience moderate to critical injuries than the 1- to 3-year-old forward-facing car seat users, since the estimate of rear-facing car seat (REAR_CARSEAT=1) is positive (0.2382). The substantial difference between the weighted frequency of rear-facing car seat users (12,314, see Table 8) and the weighted frequency of forward-facing car seat users (372,808, see Table 8) might influence the analysis results. The 1- to 3-year-old car seat users in center seats might be significantly less likely to experience moderate to critical injuries than the 1- to 3-year-old car seat users in outboard seats, since the estimate of center seat (CENTER=1) is negative (-1.2090) with the p-value (0.1015) close to the significance level of 0.05.

This evaluation used the forward selection method[21] to remove independent variables that were not significant in the full logistic regression model. Nevertheless, this section kept the type of car seats (REAR_CARSEAT) in the final logistic regression model to show the effectiveness and significance of rear-facing car seats on reducing moderate to critical injuries in non-rollover crashes. The following table shows the analysis results of the final logistic regression model:

Table 11. Final Logistic Regression Model: 1- to 3-Year-Old Car Seat Users Experienced Moderate to Critical Injuries in Non-Rollover Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_1_3=1 CARSEAT_USER=1 COLLISION_GROUP=1

Global Model Test				
	F Test		P-value	
Likelihood Ratio	0.86		0.4277	
Score	3.37		0.0641	
Wald	2.70		0.1019	
Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
CENTER=1	-1.2955	0.5732	-2.26	0.0391*[22]
REAR_CARSEAT=1	0.2666	0.6361	0.42	0.6811
Odds Ratio Estimate				
Independent Variable	Estimate		95% Confidence Interval	
CENTER=1	0.274		(0.081, 0.929)	
REAR_CARSEAT=1	1.306		(0.336, 5.066)	
Model Fitting Assessment				
C Statistics	0.567			

The final logistic regression model is not significant, since the p-values of the likelihood ratio test (0.4277), the score test (0.0641) and the Wald test (0.1019) are greater than the significance level of 0.05. The C-statistic is 0.567, and the area under the ROC curve is 0.567 when the final logistic regression model uses the occupant seat position (CENTER) and the type of car seats (REAR_CARSEAT) as the independent variables. The final logistic regression model might not substantially fit the analytical data set.

The effect of center seat (CENTER=1) on reducing moderate to critical injuries is significant, since its p-value (0.0391) is less than the significance level of 0.05. The 1- to 3-year-old car seat users in center seats are significantly less likely to experience moderate to critical injuries than the 1- to 3-year-old car seat users in outboard seats, since the estimate of center seat (CENTER=1) is negative (-1.2955) with the p-value (0.0391) less than the significance level of 0.05.

The type of car seats (REAR_CARSEAT) is not significant, since its p-value (0.6811) is greater than the significance level of 0.05. The analysis results from NASS-CDS did not demonstrate

[21] Forward selection begins with an empty model and adds independent variables one by one. The added independent variable in each forward step is that with the greatest score by the goodness of fit measure.
[22] This evaluation used an asterisk to indicate a significant independent variable.

that the rear-facing car seats were effective in reducing moderate to critical injuries experienced by the 1- to 3-year-old car seat users in non-rollover crashes. The driver's gender, the driver age, the non-rollover crash mode, and the occupant age are not significant, since their p-values are greater than the significance level of 0.05.

The occupant's seat position is an important factor to consider, since it might influence the effect of car seats on reducing moderate to critical injuries. The ratio of the odds of experiencing moderate to critical injuries by the 1- to 3-year-old car seat users in center seats to the odds of experiencing moderate to critical injuries by the 1- to 3-year-old car seat users in outboard seats was estimated by applying Equation 1 and the final logistic regression model estimate of center seat (-1.2955).

$$\left(\frac{\text{Odds}|\text{Center Seat}}{\text{Odds}|\text{Outboard Seat}}\right) = \text{Odds Ratio} = \exp(-1.2955) = 0.274$$

The effect of center seats on reducing moderate to critical injuries experienced by the 1- to 3-year-old car seat users was estimated by using Equation 2.

$$\text{Effect of Center Seats} = \left(1 - \exp(-1.2955)\right) \cdot 100\% = 72.6\%$$

With other variables being held constant, the odds of experiencing moderate to critical injuries by the 1- to 3-year-old car seat users in center seats is 72.6 percent less than the odds of experiencing moderate to critical injuries by the 1- to 3-year-old car seat users in outboard seats. The estimated 95 percent confidence interval of the effect of center seats is between 7.1 percent ((1-0.929)*100%) and 91.9 percent ((1-0.081)*100%) based on the analytical data set from NASS-CDS.

4.1.2 Rear-Facing Car Seats: 1- to 3-Year-Old Occupants in All Crashes (MAIS ≥ 2)

This section examined the effect of rear-facing car seats on reducing moderate to critical injuries experienced by the 1- to 3-year-old occupants in all crashes. The forward-facing car seats were used as the reference group of the rear-facing car seats, and the effect of rear-facing car seats on reducing moderate to critical injuries was compared with the effect of forward-facing car seats in the analysis.

The analytical data set in this section was specified from the entire NASS-CDS by using the domain variables in Section 3.2 and Section 4.1.1 and the domain variable of all crashes in Section 4.

The following contingency table shows the weighted frequencies, unweighted frequencies, weighted percentages, and standard errors of moderate to critical injuries experienced by the 1- to 3-year-old rear-facing and forward-facing car seat users in all crashes:

Table 12. Type of Car Seats and Status of Moderate to Critical Injuries Experienced by 1- to 3-Year-Old Occupants in All Crashes

	Moderate to Critical Injuries	**None to Minor Injuries**	**Total**
Rear-Facing Car Seat	132.43 (5) 1.02% (0.65%)	12,900 (53) 98.98% (0.65%)	13,032 (58) 100%
Forward-Facing Car Seat	3,276 (36) 0.82% (0.28%)	398,187 (798) 99.18% (0.28%)	401,463 (834) 100%

There are five 1- to 3-year-old rear-facing car seat users in the analytical data set who experienced moderate to critical injuries in all crashes, and the weighted frequency of moderate to critical injuries experienced by the 1- to 3-year-old rear-facing car seat users is 132.43. The weighted percentage of moderate to critical injuries experienced by the rear-facing car seat users is 1.02 percent ((132.43/13,032)*100%) with the standard error of 0.65 percent while the weighted percentage of moderate to critical injuries experienced by the 1- to 3-year-old forward-facing car seat users is 0.82 percent ((3,276/401,463)*100%) with the standard error of 0.28 percent. The weighted percentage of moderate to critical injuries experienced by the rear-facing car seat users (1.02%) is greater than the weighted percentage of moderate to critical injuries experienced by the forward-facing car seat users (0.82%). The variation of experiencing moderate to critical injuries by the rear-facing car seat users is greater than the variation of experiencing moderate to critical injuries by the forward-facing car seat users, since the standard error in the rear-facing car seat users (0.65%) is greater than the standard error in the forward-facing car seat users (0.28%).

The effect of rear-facing car seats on reducing moderate to critical injuries experienced by the 1- to 3-year-old car seat users in all crashes was estimated by using the logistic regression analysis, and the effect of rear-facing car seats was compared with the effect of forward-facing car seats in the analysis. The status of moderate to critical injuries (MAIS2) in Section 3.5 was used as the dependent variable, and the driver's gender (MALE1), the driver age (AGE1), the crash mode (MODE), the occupant age (AGE2), the occupant seat position (CENTER), and the type of car seats (REAR_CARSEAT) in Section 3.5 were used as the independent variables in the logistic regression analysis.

The domain variables in Section 3.2 and Section 4.1.1 and the domain variable of all crashes in Section 4 were used in the SAS survey analysis procedure to specify the analytical data set from the entire NASS-CDS. This section used the SAS SURVEYLOGISTIC procedure with RATEGT as the weight, PSU as the cluster and PSU STRATA as the strata to perform the logistic regression analysis. The following table shows the estimated parameters of independent variables in the full logistic regression model:

Table 13. Full Logistic Regression Model: 1- to 3-Year-Old Car Seat Users Experienced Moderate to Critical Injuries in All Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_1_3=1 CARSEAT_USER=1 CRASH_GROUP=1

Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
MALE1=1	-0.00275	0.5612	-0.00	0.9962
AGE1	0.0348	0.0358	0.97	0.3470
MODE=FRONTAL	-0.4778	0.5634	-0.85	0.4098
MODE=REAR	-1.1730	0.6571	-1.79	0.0945
MODE =SIDE	-0.1695	0.7390	-0.23	0.8217
AGE2	0.1170	0.1873	0.62	0.5418
CENTER=1	-0.6418	0.5558	-1.15	0.2662
REAR_CARSEAT=1	0.2485	0.7162	0.35	0.7335

The 1- to 3-year-old rear-facing car seat users might not be less likely to experience moderate to critical injuries than the 1- to 3-year-old forward-facing car seat users, since the estimate of rear-facing car seat (REAR_CARSEAT=1) is positive (0.2485). The 1- to 3-year-old car seat users in center seats might be less likely to experience moderate to critical injuries than the 1- to 3-year-old car seat users in outboard seats, since the estimate of center seat (CENTER=1) is negative (-0.6418). The 1- to 3-year-old car seat users might be less likely to experience moderate to critical injuries in rear-impact non-rollover crashes than rollovers, since the estimate of rear-impact crash mode (MODE=REAR) is negative (-1.1730) with the p-value (0.0945) close to the significance level of 0.05.

This section kept the type of car seats (REAR_CARSEAT) in the final logistic regression model and used the forward selection method to remove other independent variables that were not significant in the full logistic regression model. The following table shows the analysis results of the final logistic regression model:

Table 14. Final Logistic Regression Model: 1- to 3-year Old Car Seat Users Experienced Moderate to Critical Injuries in All Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_1_3=1 CARSEAT_USER=1 CRASH_GROUP=1

Global Model Test				
	F Test		P-value	
Likelihood Ratio	0.21		0.8691	
Score	2.51		0.0970	
Wald	1.71		0.2119	
Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	p-value
MODE=FRONTAL	-0.4658	0.5769	-0.81	0.4320
MODE=REAR	-1.2631	0.5336	-2.37	0.0318*

MODE=SIDE	-0.2301	0.7563	-0.30	0.7651
REAR_CARSEAT=1	0.1764	0.6522	0.27	0.7905
Odds Ratio Estimate				
Independent Variable	Estimate		95% Confidence Interval	
MODE=FRONTAL	0.628		(0.184%, 2.146%)	
MODE=REAR	0.283		(0.091%, 0.882%)	
MODE=SIDE	0.794		(0.158%, 3.983%)	
REAR_CARSEAT=1	1.193		(0.297%, 4.790%)	
Model Fitting Assessment				
C Statistics	0.525			

The final logistic regression model is not significant, since the p-values of the likelihood ratio test (0.8691), the score test (0.0970) and the Wald test (0.2119) are greater than the significance level of 0.05. The C-statistic is 0.525, and the area under the ROC curve is 0.525 when the final logistic regression model uses the crash mode (MODE) and the type of car seats (REAR_CARSEAT) as the independent variables. The final logistic regression model might not substantially fit the analytical data set.

The type of car seats (REAR_CARSEAT) is not significant, since its p-value (0.7905) is greater than the significance level of 0.05. The analysis results from NASS-CDS did not demonstrate that the rear-facing car seats were effective in reducing moderate to critical injuries experienced by the 1- to 3-year-old car seat users in all crashes.

The driver's gender, the driver age, the occupant age, and the occupant seat position are not significant, since their p-values are greater than the significance level of 0.05.

The crash mode is significant, since the p-value of rear-impact crash (0.0318) is less than the significance level of 0.05. The 1- to 3-year-old car seat users are significantly less likely to experience moderate to critical injuries in rear-impact crashes than rollover events, since the estimate of rear-impact crashes (MODE=REAR) is negative (-1.2631) with the p-value (0.0318) less than the significance level of 0.05. The effect of center seats on reducing moderate to critical injuries is significant in the analytical data set of non-rollover crashes (see Section 4.1.1) while the effect of center seats is not significant in the analytical data set of all crashes (see Section 4.1.2). The independent variables in Section 3.5 could not explain all variations that are related to occupant injury severity in rollover events, and those variations influenced the analysis results.

4.2.1 Car Seats: 1- to 3-Year-Old Occupants in Non-Rollover Crashes (MAIS ≥ 2)

This section examined the effect of car seats on reducing moderate to critical injuries experienced by the 1- to 3-year-old occupants in non-rollover crashes. The booster seats were used as the reference group of the car seats, and the effect of car seats on reducing moderate to critical injuries was compared with the effect of booster seats in the analysis. An occupant's age less than 1 was recorded as 0 in NASS-CDS, and the analytical data set in this section did not include occupants who were younger than 12 months.

The CRSs included the car seats and booster seats. The following domain variables were used to specify 1-to 3-year-old CRS users:

$$\text{AGE\_1\_3} = \begin{cases} 1, \text{if an occupant is between 1 and 3 years old} \\ 0, \text{others} \end{cases}$$

$$\text{CRS\_USER} = \begin{cases} 1, \text{if an occupant used a car seat or a booster seat} \\ 0, \text{others} \end{cases}$$

The analytical data set in this section was specified from the entire NASS-CDS by using the above two domain variables, the domain variables in Section 3.2 and the domain variable of non-rollover crashes in Section 4. The sampling data observations in the analytical data set satisfied the following vehicle, driver and occupant conditions.

Vehicle

The collision-crashed passenger vehicle with the GVWR less than 10,000 pounds was towed and experienced no rollovers, and there was at least one 1- to 3-year-old CRS user in the collision-crashed passenger vehicle.

Driver

The driver was belted, and the driver was at least 16 years old. The belted drivers might be more likely to properly use the CRSs than unbelted drivers.

Occupant

The 1- to 3-year-old CRS user with a known MAIS sat in the second or the third row of the passenger vehicle in the non-rollover crash.

The following table shows the weighted frequency, unweighted frequency and weighted percentage of injuries at each MAIS level experienced by the 1- to 3-year-old CRS users in the analytical data set:

Table 15. Distribution of MAIS Level by 1- to 3-Year-Old Child Restraint System Users in Non-Rollover Crashes

MAIS Level	Frequency	Weighted Percentage
0	364,719 (608)	77.49%
1	101,723 (285)	21.61%
2	1,909 (19)	0.41%
3	1,006 (15)	0.21%
4	1,222 (7)	0.26%
5	105.14 (5)	0.02%
6	8.38 (1)	0.00%
Total	470,692 (940)	100%

There are 285 CRS users 1- to 3 years old in the analytical data set who experienced MAIS level 1 injuries in non-rollover crashes. The weighted frequency of MAIS level 1 injuries is 101,723, and the weighted percentage of MAIS level 1 injuries is 21.61 percent ((101,723/470,692)*100%). The weighted percentage of injuries does not monotonically decrease when the MAIS level increases. The impact of sampling weights and different NHTSA AIS versions over the years might influence the weighted percentage of injuries.

The weighted percentage of moderate to critical injuries experienced by the 1- to 3-year-old CRS users in non-rollover crashes is 0.90 percent (0.41%+0.21%+0.26%+0.02 %+0.00%) while the weighted percentage of none to minor injuries experienced by the 1- to 3-year-old CRS users in non-rollover crashes is 99.10 percent (77.49%+21.61%). The weighted percentage of moderate to critical injuries is substantially less than the weighted percentage of none to minor injuries in non-rollover crashes.

The following table shows the weighted frequencies, unweighted frequencies and weighted percentages of car seat and booster seat usages in the analytical data set:

Table 16. Car Seats and Booster Seats Used by 1- to 3-Year-Old Occupants in Non-Rollover Crashes

	Frequency	**Weighted Percentage**
Car Seat	397,015 (798)	84.35%
Booster Seat	73,677 (142)	15.65%
Total	470,692 (940)	100%

There are 798 car seat users 1- to 3 years old in the analytical data set, and the weighted frequency of the 1- to 3-year-old car seat users is 39,7015. The weighted percentage of car seat usage is 84.35 percent ((397,015/470,692)*100%) while the weighted percentage of booster seat usage is 15.65 percent ((73,677/470,692)*100%). The 1- to 3-year-old CRS users who experienced non-rollover crashes used car seats more frequently than booster seats.

The following contingency table shows the weighted frequencies, unweighted frequencies, weighted percentages, and standard errors of moderate to critical injuries experienced by the 1- to 3-year-old car seat and booster seat users in non-rollover crashes:

Table 17. Type of Child Restraint Systems and Status of Moderate to Critical Injuries Experienced by 1- to 3-Year-Old Occupants in Non-Rollover Crashes

	Moderate to Critical Injuries	**None to Minor Injuries**	**Total**
Car Seat	3,038 (34) 0.77% (0.29%)	393,977 (764) 99.23% (0.29%)	397,015 (798) 100%
Booster Seat	1,212 (13) 1.65% (0.81%)	72,465 (129) 98.35% (0.81%)	73,677 (142) 100%

There are thirty-four 1- to 3-year-old car seat users in the analytical data set who experienced moderate to critical injuries in non-rollover crashes, and the weighted frequency of moderate to critical injuries experienced by the 1- to 3-year-old car seat users is 3038. The weighted percentage of moderate to critical injuries experienced by the 1- to 3-year-old car seat users is 0.77 percent ((3,038/397,015)*100%) with the standard error of 0.29 percent while the weighted percentage of moderate to critical injuries experienced by the 1- to 3-year-old booster seat users is 1.65 percent ((1,212/73,677)*100%) with the standard error of 0.81 percent. The weighted percentage of moderate to critical injuries experienced by the car seat users (0.77%) is less than the weighted percentage of moderate to critical injuries experienced by the booster seat users (1.65%). The variation of experiencing moderate to critical injuries by the car seat users is less than the variation of experiencing moderate to critical injuries by the booster seat users, since the standard error in the car seat users (0.29%) is less than the standard error in the booster seat users (0.81%).

The effect of car seats on reducing moderate to critical injuries experienced by the 1- to 3-year-old CRS users in non-rollover crashes was estimated by using the logistic regression analysis, and the effect of car seats was compared with the effect of booster seats in the analysis. The status of moderate to critical injuries (MAIS2) in Section 3.5 was used as the dependent variable, and the driver's gender (MALE1), the driver age (AGE1), the non-rollover crash mode (MODE_COLL), the occupant age (AGE2), the occupant seat position (CENTER), and the type of CRS (CARSEAT) in Section 3.5 were used as the independent variables in the logistic regression analysis.

The domain variables in Section 3.2 and Section 4.2.1 and the domain variable of non-rollover crashes in Section 4 were used in the SAS survey analysis procedure to specify the analytical data set from the entire NASS-CDS. This section used the SAS SURVEYLOGISTIC procedure with RATEGT as the weight, PSU as the cluster and PSU STRATA as the strata to perform the logistic regression analysis. The following table shows the estimated parameters of independent variables in the full logistic regression model:

Table 18. Full Logistic Regression Model: 1- to 3-Year-Old Child Restraint System Users Experienced Moderate to Critical Injuries in Non-Rollover Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_1_3=1 CRS_USER=1 COLLISION_GROUP=1

Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
MALE1=1	-0.0537	0.4214	-0.13	0.9003
AGE1	0.0300	0.0345	0.87	0.3986
MODE_COLL=REAR	-1.0618	0.6660	-1.59	0.1318
MODE_COLL=SIDE	-0.1911	0.6239	-0.31	0.7636
AGE2	-0.2413	0.2242	-1.08	0.2987
CENTER=1	-1.4000	0.6111	-2.29	0.0369*
CARSEAT=1	-0.8493	0.6906	-1.23	0.2377

The 1- to 3-year-old car seat users might be less likely to experience moderate to critical injuries than the 1- to 3-year-old booster seat users, since the estimate of car seat (CARSEAT=1) is negative (-0.8493). The 1- to 3-year-old CRS users in center seats might be significantly less likely to experience moderate to critical injuries than the 1- to 3-year-old CRS users in outboard seats, since the estimate of center seat (CENTER=1) is negative (-1.4000) with the p-value (0.0369) less than the significance level of 0.05.

This section kept the type of CRS (CARSEAT) in the final logistic regression model and used the forward selection method to remove other independent variables that were not significant in the full logistic regression model. The following table shows the analysis results of the final logistic regression model:

Table 19. Final Logistic Regression Model: 1- to 3-Year-Old Child Restraint System Users Experienced Moderate to Critical Injuries in Non-Rollover Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_1_3=1 CRS_USER=1 COLLISION_GROUP=1

Global Model Test				
	F Test		P-value	
Likelihood Ratio	1.73		0.2028	
Score	4.90		0.0244	
Wald	3.53		0.0573	
Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
CENTER=1	-1.4566	0.5429	-2.68	0.0170*
CARSEAT=1	-0.6106	0.5955	-1.03	0.3214
Odds Ratio Estimate				
Independent Variable	Estimate		95% Confidence Interval	
CENTER=1	0.233		(0.073, 0.741)	
CARSEAT=1	0.543		(0.153, 1.932)	
Model Fitting Assessment				
C Statistics	0.607			

The final logistic regression model is not significant, since the p-values of the likelihood ratio test (0.2028) and the Wald test (0.0573) are greater than the significance level of 0.05. The C-statistic is 0.607, and the area under the ROC curve is 0.607 when the final logistic regression model uses the occupant seat position (CENTER) and the type of CRS (CARSEAT) as the independent variables. The final logistic regression model might not substantially fit the analytical data set.

The effect of center seats (CENTER=1) on reducing moderate to critical injuries is significant, since its p-value (0.0170) is less than the significance level of 0.05. The 1- to 3-year-old CRS users in center seats are significantly less likely to experience moderate to critical injuries than the 1- to 3-year-old CRS users in outboard seats, since the estimate of center seat (CENTER=1) is negative (-1.4566) with the p-value (0.0170) less than the significance level of 0.05.

The type of CRS (CARSEAT) is not significant, since its p-value (0.3214) is greater than the significance level of 0.05. The analysis results from NASS-CDS did not demonstrate that the car seats were effective in reducing moderate to critical injuries experienced by the 1- to 3-year-old CRS users in non-rollover crashes. The driver's gender, the driver age, the non-rollover crash mode, and the occupant age are not significant, since their p-values are greater than the significance level of 0.05.

The occupant's seat position is considered as an important variable, since it might influence the effect of car seats on reducing moderate to critical injuries. The ratio of the odds of experiencing moderate to critical injuries by the 1- to 3-year-old CRS users in center seats to the odds of experiencing moderate to critical injuries by the 1- to 3-year-old CRS users in outboard seats was estimated by applying Equation 1 and the final logistic regression model estimate of center seat (-1.4566).

$$\left(\frac{\text{Odds}|\text{Center Seat}}{\text{Odds}|\text{Outboard Seat}}\right) = \text{Odds Ratio} = \exp(-1.4566) = 0.233$$

The effect of center seats on reducing moderate to critical injuries experienced by the 1- to 3-year-old CRS users was estimated by using Equation 2.

$$\text{Effect of Center Seats} = \big(1 - \exp(-1.4566)\big) \cdot 100\% = 76.7\%$$

With other variables being held constant, the odds of experiencing moderate to critical injuries by the 1- to 3-year-old CRS users in center seats is 76.7 percent less than the odds of experiencing moderate to critical injuries by the 1- to 3-year-old CRS users in outboard seats. The estimated 95 percent confidence interval is between 25.9 percent ((1-0.741)*100%) and 92.7 percent ((1-0.073)*100%) based on the analytical data set from NASS-CDS.

4.2.2 Car Seats: 1- to 3-Year-Old Occupants in All Crashes (MAIS ≥ 2)

This section examined the effect of car seats on reducing moderate to critical injuries experienced by the 1- to 3-year-old occupants in all crashes. The booster seats were used as the reference group of the car seats, and the effect of car seats on reducing moderate to critical injuries was compared with the effect of booster seats in the analysis.

The analytical data set in this section was specified from the entire NASS-CDS by using the domain variables in Section 3.2 and Section 4.2.1 and the domain variable of all crashes in Section 4.

The following contingency table shows the weighted frequencies, unweighted frequencies, weighted percentages, and standard errors of moderate to critical injuries experienced by the 1- to 3-year-old CRS users in all crashes:

Table 20. Type of Child Restraint Systems and Status of Moderate to Critical Injuries Experienced by 1- to 3-Year-Old Occupants in All Crashes

	Moderate to Critical Injuries	**None to Minor Injuries**	**Total**
Car Seat	3,409 (41) 1.57% (0.77%)	76,002 (878) 98.43% (0.77%)	426,389 (919) 100%
Booster Seat	1,212 (13) 0.80% (0.28%)	76,002 (149) 99.20% (0.28%)	77,215 (162) 100%

There are 13 car seat users 1- to 3 years old in the analytical data set who experienced moderate to critical injuries in all crashes, and the weighted frequency of moderate to critical injuries experienced by the 1- to 3-year-old car seat users is 1,212. The weighted percentage of moderate to critical injuries experienced by the car seat users is 0.80 percent ((1,212/77,215)*100%) with the standard error of 0.28 percent while the weighted percentage of moderate to critical injuries experienced by the 1- to 3-year-old booster seat users is 1.57 percent ((3,409/426,389)*100%)

with the standard error of 0.77 percent. The weighted percentage of moderate to critical injuries experienced by the car seat users (0.80%) is less than the weighted percentage of moderate to critical injuries experienced by the booster seat users (1.57%). The variation of experiencing moderate to critical injuries by the car seat users is less than the variation of experiencing moderate to critical injuries by the booster seat users, since the standard error in the car seat users (0.28%) is less than the standard error in the booster seat users (0.77%).

The effect of car seats on reducing moderate to critical injuries experienced by the 1- to 3-year-old CRS users in all crashes was estimated by using the logistic regression analysis, and the effect of car seats was compared with the effect of booster seats in the analysis. The status of moderate to critical injuries (MAIS2) in Section 3.5 was used as the dependent variable, and the driver's gender (MALE1), the driver age (AGE1), the crash mode (MODE), the occupant age (AGE2), the occupant seat position (CENTER), and the type of CRS (CARSEAT) in Section 3.5 were used as the independent variables in the logistic regression analysis.

The domain variables in Section 3.2 and Section 4.2.1 and the domain variable of all crashes in Section 4 were used in the SAS survey analysis procedure to specify the analytical data set from the entire NASS-CDS. This section used the SAS SURVEYLOGISTIC procedure with RATEGT as the weight, PSU as the cluster and PSU STRATA as the strata to perform the logistic regression analysis. The following table shows the estimated parameters of independent variables in the full logistic regression model:

Table 21. Full Logistic Regression Model: 1- to 3-Year-Old Child Restraint System Users Experienced Moderate to Critical Injuries in All Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_1_3=1 CRS_USER=1 CRASH_GROUP=1

Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
MALE1=1	-0.1124	0.3953	-0.28	0.7800
AGE1	0.0325	0.0331	0.98	0.3428
MODE=FRONTAL	-0.0646	0.7011	-0.09	0.9278
MODE=REAR	-1.1296	0.7000	-1.61	0.1274
MODE =SIDE	-0.2412	0.6349	-0.38	0.7093
AGE2	-0.0718	0.2839	-0.25	0.8037
CENTER=1	-0.8445	0.5554	-1.52	0.1492
CARSEAT=1	-0.6734	0.7258	-0.93	0.3682

The 1- to 3-year-old car seat users might be less likely to experience moderate to critical injuries than the 1- to 3-year-old booster seat users, since the estimate of car seat (CARSEAT=1) is negative (-0.6734). The 1- to 3-year-old CRS users in center seats might be less likely to experience moderate to critical injuries than the 1- to 3-year-old CRS users in outboard seats, since the estimate of center seat (CENTER=1) is negative (-0.8445). The 1- to 3-year-old CRS users might be less likely to experience moderate to critical injuries in rear-impact crashes than rollovers, since the estimate of rear-impact crash (MODE=REAR) is negative (-1.1296) with the p-value (0.1274) close to the significance level of 0.05.

This section kept the type of CRS (CARSEAT) in the final logistic regression model and used the forward selection method to remove other independent variables that were not significant in the full logistic regression model. The following table shows the analysis results of the final logistic regression model:

Table 22. Final Logistic Regression Model: 1- to 3-Year-Old Child Restraint System Users Experienced Moderate to Critical Injuries in All Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_1_3=1 CRS_USER=1 CRASH_GROUP=1

Global Model Test				
	F Test		P-value	
Likelihood Ratio	0.43		0.7227	
Score	4.13		0.0248	
Wald	3.70		0.0349	
Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
MODE=FRONTAL	-0.1272	0.6381	-0.20	0.8447
MODE=REAR	-1.2233	0.5582	-2.19	0.0446*
MODE=SIDE	-0.3128	0.6640	-0.47	0.6443
CARSEAT=1	-0.6863	0.6101	-1.12	0.2783
Odds Ratio Estimate				
Independent Variable	Estimate		95% Confidence Interval	
MODE=FRONTAL	0.881		(0.226%, 3.431%)	
MODE=REAR	0.294		(0.090%, 0.967%)	
MODE=SIDE	0.731		(0.178%, 3.011%)	
CARSEAT=1	0.503		(0.137%, 1.848%)	
Model Fitting Assessment				
C Statistics	0.543			

The final logistic regression model is not significant, since the p-value of the likelihood ratio test (0.7227) is greater than the significance level of 0.05. The C-statistic is 0.543, and the area under the ROC curve is 0.543 when the final logistic regression model uses the crash mode (MODE) and the type of CRS (CARSEAT) as the independent variables. The final logistic regression model might not substantially fit the analytical data set.

The type of CRS (CARSEAT) is not significant, since its p-value (0.2783) is greater than the significance level of 0.05. The analysis results from NASS-CDS did not demonstrate that the car seats were effective in reducing moderate to critical injuries experienced by the 1- to 3-year-old CRS users in all crashes. The driver's gender, the driver age, the occupant age, and the occupant seat position are not significant, since their p-values are greater than the significance level of 0.05.

The crash mode is significant, since the p-value of rear-impact crash (0.0446) is less than the significance level of 0.05. The 1- to 3-year-old CRS users are significantly less likely to experience moderate to critical injuries in rear-impact crashes than rollover events, since the estimate of rear-impact crashes (MODE=REAR) is negative (-1.2233) with the p-value (0.0446) less than the significance level of 0.05.

The effect of center seats on reducing moderate to critical injuries is significant in the analytical data set of non-rollover crashes (see Section 4.2.1), but the effect of center seats is not significant in the analytical data set of all crashes (see Section 4.2.2). The independent variables in Section 3.5 could not explain all variations that are related to occupant injury severity in rollover events, and those variations influenced the analysis results.

4.3.1 Car Seats: 3- to 5-Year-Old Occupants in Non-Rollover Crashes (MAIS ≥ 2)

This section examined the effect of car seats on reducing moderate to critical injuries experienced by the 3- to 5-year-old occupants in non-rollover crashes. The booster seats were used as the reference group of the car seats, and the effect of car seats on reducing moderate to critical injuries was compared with the effect of booster seats in the analysis.

Child restraint systems included the car seats and booster seats. The following domain variables were used to specify 3- to 5-year-old CRS users:

$$\text{AGE\_3\_5} = \begin{cases} 1, \text{if an occupant is between 3 and 5 years old} \\ 0, \text{others} \end{cases}$$

$$\text{CRS\_USER} = \begin{cases} 1, \text{if an occupant used a car seat or a booster seat} \\ 0, \text{others} \end{cases}$$

The analytical data set in this section was specified from the entire NASS-CDS set by using the above two domain variables, the domain variables in Section 3.2, and the domain variable of non-rollover crashes in Section 4. The sampling data observations in the analytical data set satisfied the following vehicle, driver, and occupant conditions.

<u>Vehicle</u>

The collision-crashed passenger vehicle with the GVWR less than 10,000 pounds was towed and experienced no rollovers, and there was at least one 3- to 5-year-old CRS user in the collision-crashed passenger vehicle.

<u>Driver</u>

The driver was belted and was at least 16 years- ld. The belted drivers might be more likely to properly use the CRSs than unbelted drivers.

<u>Occupant</u>

The 3- to 5-year-old CRS user with a known MAIS sat in the second or the third row of the passenger vehicle in the non-rollover crash.

The following table shows the weighted frequency, unweighted frequency, and weighted percentage of injuries at each MAIS level experienced by the 3- to 5-year-old CRS users in the analytical data set:

Table 23. Distribution of MAIS Level in 3- to 5-Year-Old Child Restraint System Users in Non-Rollover Crashes

MAIS Level	Frequency	Weighted Percentage
0	249825 (402)	72.86%
1	89345 (216)	26.06%
2	707.92 (14)	0.21%
3	2596 (12)	0.76%
4	380.56 (5)	0.10%
5	48.68 (4)	0.01%
6	0 (0)	0%
Total	342904 (653)	100%

There are 216 3- to 5-year-old CRS users 3- to 5 years old in the analytical data set who experienced MAIS level 1 injuries in non-rollover crashes. The weighted frequency of MAIS level 1 injuries experienced by the 3- to 5-year-old CRS users is 89,345, and the weighted percentage of MAIS level 1 injuries is 26.06 percent ((89,345/342,904)*100%). The weighted percentage of injuries does not monotonically decrease when the MAIS level increases. The impact of sampling weights and different NHTSA AIS versions over the years might influence the weighted percentage of injuries.

The weighted percentage of moderate to critical injuries experienced by the 3- to 5-year-old CRS users in non-rollover crashes is 1.08 percent (0.21%+0.76%+0.10%+ 0.01%+0%) while the weighted percentage of none to minor injuries experienced by the 3- to 5-year-old CRS users in non-rollover crashes is 98.92 percent (72.86%+26.06%). The weighted percentage of moderate to critical injuries is substantially less than the weighted percentage of none to minor injuries in non-rollover crashes.

The following table shows the weighted frequencies, unweighted frequencies and weighted percentages of car seat and booster seat usages in the analytical data set:

Table 24. Car Seats and Booster Seats Used by 3- to 5-Year-Old Occupants in Non-Rollover Crashes

	Frequency	Weighted Percentage
Car Seat	132,554 (285)	38.66%
Booster Seat	210,350 (368)	61.34%
Total	342,904 (653)	100%

There are 285 unweighted 3- to 5-year-old car seat users in the analytical data set, and the weighted frequency of the 3- to 5-year-old car seat users is 132554. The weighted percentage of car seat usage is 38.66 percent ((132,554/342,904)*100%) while the weighted percentage of booster seat usage is 61.34 percent ((210,350/342,904)*100%). The 3- to 5-year-old occupants who experienced non-rollover crashes used booster seats more frequently than car seats.

The following contingency table shows the weighted frequencies, unweighted frequencies, weighted percentages, and standard errors of moderate to critical injuries experienced by the 3- to 5-year-old car seat users and booster seat users in non-rollover crashes:

Table 25. Type of Child Restraint Systems and Status of Moderate to Critical Injuries Experienced by 3- to 5-Year-Old Occupants in Non-Rollover Crashes

	Moderate to Critical Injuries	**None to Minor Injuries**	**Total**
Car Seat	925.46 (16) 0.70% (0.27%)	131,628 (269) 99.30% (0.27%)	132,554 (285) 100%
Booster Seat	2,808 (19) 1.33% (0.84%)	207,542 (349) 98.67% (0.84%)	210,350 (368) 100%

There are 16 car seat users 3- to 5 years old in the analytical data set who experienced moderate to critical injuries in non-rollover crashes, and the weighted frequency of moderate to critical injuries experienced by the 3- to 5-year-old car seat users is 925.46. The weighted percentage of moderate to critical injuries experienced by the car seat users is 0.70 percent ((925.46 /132,554)*100%) with the standard error of 0.27 percent while the weighted percentage of moderate to critical injuries experienced by the booster seat users is 1.33 percent ((2,808/210,350)*100%) with the standard error of 0.84 percent. The weighted percentage of moderate to critical injuries experienced by the car seat users (0.70%) is less than the weighted percentage of moderate to critical injuries experienced by the booster seat users (1.33%). The variation of experiencing moderate to critical injuries by the car seat users is less than the variation of experiencing moderate to critical injuries by the booster seat users, since the standard error in the car seat users (0.27%) is less than the standard error in the booster seat users (0.84%).

The effect of car seats on reducing moderate to critical injuries experienced by the 3- to 5-year-old CRS users was estimated by using logistic regression analysis, and the effect of car seats was compared with the effect of booster seats in the analysis. The status of moderate to critical injuries (MAIS2) in Section 3.5 was used as the dependent variable, and the driver's gender (MALE1), the driver age (AGE1), the non-rollover crash mode (MODE_COLL), the occupant age (AGE2), the occupant seat position (CENTER), and the type of CRS (CARSEAT) in Section 3.5 were used as the independent variables in the logistic regression analysis.

The domain variables in Section 3.2 and Section 4.3.1 and the domain variable of non-rollover crashes in Section 4 were used in the SAS survey analysis procedure to specify the analytical data set from the entire NASS-CDS. This section used the SAS SURVEYLOGISTIC procedure with RATEGT as the weight, PSU as the cluster and PSU STRATA as the strata to perform the logistic regression analysis. The following table shows a part of analysis results of the full logistic regression model:

Table 26. Full Logistic Regression Model: 3- to 5-Year-Old Child Restraint System Users Experienced Moderate to Critical Injuries in Non-Rollover Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_3_5=1 CRS_USER=1 COLLISION_GROUP=1

Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
MALE1=1	-0.5791	0.5739	-1.01	0.3290
AGE1	0.00358	0.0609	0.06	0.9539

Parameter Estimate				
MODE_COLL=REAR	-0.6961	0.7890	-0.88	0.3915
MODE_COLL=SIDE	-0.4555	0.9391	-0.49	0.6347
AGE2	-0.0383	0.2555	-0.15	0.8828
CENTER=1	-0.0149	0.6797	-0.02	0.9829
CARSEAT=1	-0.7065	0.8131	-0.87	0.3986

The 3- to 5-year-old car seat users might be less likely to experience moderate to critical injuries than the 3- to 5-year-old booster seat users, since the estimate of car seat (CARSEAT=1) is negative (-0.7065). The 3- to 5-year-old CRS users in center seats might be less likely to experience moderate to critical injuries than the 3- to 5-year-old CRS users in outboard seats, since the estimate of center seat (CENTER=1) is negative (-0.0149).

This section kept the type of CRS (CARSEAT) in the final logistic regression model and used the forward selection method to remove other independent variables that were not significant in the full logistic regression model. Nevertheless, forward selection failed to produce a logistic regression model that included significant independent variables. Multi-collinearity issues among the independent variables in the analytical data set might cause the insignificant analysis results, since multi-collinearity issues could have inflated variance estimates in the analysis.

Candidate logistic regression models were selected to examine effects of independent variables on occupant injury severity. C-statistics were used as the model selection criterion. A logistic regression model fits the analytical data set better when the value of the C-statistic is higher. Appendix B listed the values of C-statistics of the logistic regression models that used a single or a combination of the independent variables in Section 3.5. The logistic regression models with the first- and the second-greatest values of C-statistics in **Appendix B** were selected as the candidate logistic regression models, and the following table shows the values of the C-statistics and the independent variables included in the candidate logistic regression models:

*Table 27. Candidate Logistic Regression Models in **Appendix B***

Independent Variables	C-statistics
AGE2 CARSEAT	0.523
AGE2 CENTER CARSEAT	0.522
AGE1 AGE2 CENTER CARSEAT	0.522

The C-statistic of the logistic regression model that used the occupant age (AGE2) and the type of CRS (CARSEAT) as the independent variables is 0.532. The candidate logistic regression models in Table 27 have similar prediction performances, since their values of C-statistics are close. The logistic regression model that used the occupant age (AGE2) and the type of CRS (CARSEAT) as the independent variables was selected as the final logistic regression model, since a logistic regression model with small number of independent variables is more easily to be interpreted than a logistic regression model with a large number of independent variables. The following table shows the estimated parameters of independent variables in the full logistic regression model:

Table 28. Final Logistic Regression Model: 3- to 5-Year-Old Child Restraint System Users Experienced Moderate to Critical Injuries in Non-Rollover Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_3_5=1 CRS_USER=1 COLLISION_GROUP=1

Global Model Test				
	F Test		P-value	
Likelihood Ratio	0.31		0.6626	
Score	0.74		0.4945	
Wald	0.46		0.6390	
Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
AGE2	-0.0575	0.2678	-0.21	0.8328
CARSEAT=1	-0.6852	0.8093	-0.85	0.4105
Odds Ratio Estimate				
Independent Variable	Estimate		95% Confidence Interval	
AGE2	0.944		(0.533, 1.671)	
CARSEAT=1	0.504		(0.090, 2.828)	
Model Fitting Assessment				
C Statistics	0.523			

The final logistic regression model is not significant, since the p-values of the likelihood ratio test (0.6626), the score test (0.4945) and the Wald test (0.6390) are greater than the significance level of 0.05. The C-statistic is 0.523, and the area under the ROC curve is 0.523 when the final logistic regression model uses the occupant age (AGE2) and the type of CRS (CARSEAT) as the independent variables. The final logistic regression model might not substantially fit the analytical data set.

The type of CRS (CARSEAT) is not significant, since its p-value (0.4105) is greater than 0.05. The analysis results from NASS-CDS did not demonstrate that the car seats were effective in reducing moderate to critical injuries experienced by the 3- to 5-year-old CRS users in non-rollover crashes. Occupant age (AGE2) is not significant, since its p-value (0.8328) is greater than the significance level of 0.05.

Each candidate model in Table 27 used the occupant age (AGE2) and the type of CRS (CARSEAT) as the independent variables. This section grouped the CRS users by their ages to examine the association between the type of CRSs and occupant injury severity. The following contingency tables show the weighted frequencies, unweighted frequencies and weighted percentages of moderate to critical injuries experienced by the car seat and booster seat users at each occupant's age from age three to five:

Table 29. Type of Child Restraint Systems and Status of Moderate to Critical Injuries Experienced by 3-Year-Old Occupants in Non-Rollover Crashes

	Moderate to Critical Injuries	**None to Minor Injuries**	**Total**
Car Seat	288.52 (7) 0.33%	86,319 (151) 99.67%	86,608 (158) 100%
Booster Seat	489.95 (9) 0.89%	54,378 (88) 99.11%	54,868 (97) 100%

The weighted percentage of moderate to critical injuries experienced by the 3-year-old car seat users is 0.33 percent ((288.52/86,608)*100%) while the weighted percentage of moderate to critical injuries experienced by the 3-year-old booster seat users is 0.89 percent ((489.95/54,868)*100%). The weighted percentage of moderate to critical injuries experienced by the 3-year-old car seat users (0.33%) is less than the weighted percentage of moderate to critical injuries experienced by the 3-year-old booster seat users (0.89%).

Table 30. Type of Child Restraint Systems and Status of Moderate to Critical Injuries Experienced by 4-Year-Old Occupants in Non-Rollover Crashes

	Moderate to Critical Injuries	**None to Minor Injuries**	**Total**
Car Seat	403.39 (5) 1.64%	24,241 (80) 98.36%	24,645 (85) 100%
Booster Seat	2,239 (6) 2.42%	90,236 (135) 97.58%	92,475 (141) 100%

The weighted percentage of moderate to critical injuries experienced by the 4-year-old car seat users is 1.64 percent ((403.39/24,645)*100%) while the weighted percentage of moderate to critical injuries experienced by the 4-year-old booster seat users is 2.42 percent ((2,239/92,475)*100%). The weighted percentage of moderate to critical injuries experienced by the 4-year-old car seat users (1.64%) is less than the weighted percentage of moderate to critical injuries experienced by the 4-year-old booster seat users (2.24%).

Table 31. Type of Child Restraint Systems and Status of Moderate to Critical Injuries Experienced by 5-Year-Old Occupants in Non-Rollover Crashes

	Moderate to Critical Injuries	**None to Minor Injuries**	**Total**
Car Seat	233.55 (4) 1.10%	21,067 (38) 98.90%	21,301 (42) 100%
Booster Seat	78.96 (4) 0.13%	62,928 (126) 99.87%	63,007 (130) 100%

The weighted percentage of moderate to critical injuries experienced by the 5-year-old car seat users is 1.10 percent ((233.55/21,301) *100%) while the weighted percentage of moderate to critical injuries experienced by the 5-year-old booster seat users is 0.13 percent ((78.96/63,007) *100%). The weighted percentage of moderate to critical injuries experienced by the 5-year-old car seat users (1.10%) is greater than the weighted percentage of moderate to critical injuries experienced by the 5-year-old booster seat users (0.13%).

The weighted percentage of moderate to critical injuries experienced by the car seat users was less than the weighted percentage of moderate to critical injuries experienced by the booster seat users in Table 29 and Table 30 while the weighted percentage of moderate to critical injuries experienced by the car seat users was greater than the weighted percentage of moderate to critical injuries experienced by the booster seat users in Table 31. There is an association among the type of CRSs, occupant's age and occupant injury severity. This association might cause multi-collinearity issues and influence the significance of the final logistic regression model.

4.3.2 Car Seats: 3- to 5-Year-Old Occupants in All Crashes (MAIS ≥ 2)

This section examined the effect of car seats on reducing moderate to critical injuries experienced by the 3- to 5-year-old occupants in all crashes. The booster seats were used as the reference group of the car seats, and the effect of car seats on reducing moderate to critical injuries was compared with the effect of booster seats in the analysis.

The analytical data set in this section was specified from the entire NASS-CDS by using the domain variables in Section 3.2 and Section 4.3.1 and the domain variable of all crashes in Section 4.

The following contingency table shows the weighted frequencies, unweighted frequencies, weighted percentages, and standard errors of moderate to critical injuries experienced by the 3- to 5-year-old CRS users in all crashes:

Table 32. Type of Child Restraint Systems and Status of Moderate to Critical Injuries Experienced by 3- to 5-Year-Old Occupants in All Crashes

	Moderate to Critical Injuries	**None to Minor Injuries**	**Total**
Car Seat	1,140 (18) 0.79% (0.33%)	143,392 (311) 99.21% (0.33%)	144,532 (329) 100%
Booster Seat	3,288 (26) 1.53% (0.81%)	211,933 (379) 98.47% (0.81%)	215,220 (405) 100%

There are 18 car seat users 3- to 5 years old in the analytical data set who experienced moderate to critical injuries in all crashes, and the weighted frequency of moderate to critical injuries experienced by the 3- to 5-year-old car seat users is 1,140. The weighted percentage of moderate to critical injuries experienced by the car seat users is 0.79 percent ((1,140/144,532)*100%) with the standard error of 0.33 percent while the weighted percentage of moderate to critical injuries experienced by the 3- to 5-year-old booster seat users is 1.53 percent ((3,288/215,220)*100%) with the standard error of 0.81 percent. The weighted percentage of moderate to critical injuries experienced by the car seat users (0.79%) is less than the weighted percentage of moderate to critical injuries experienced by the booster seat users (1.53%). The variation of experiencing moderate to critical injuries by the car seat users is less than the variation of experiencing moderate to critical injuries by the booster seat users, since the standard error in the car seat users (0.33%) is less than the standard error in the booster seat users (0.81%).

The effect of car seats on reducing moderate to critical injuries experienced by the 3- to 5-year-old CRS users in all crashes was estimated by using the logistic regression analysis, and the effect of car seats was compared with the effect of booster seats in the analysis. The status of moderate to critical injuries (MAIS2) in Section 3.5 was used as the dependent variable, and the driver's gender (MALE1), the driver age (AGE1), the crash mode (MODE), the occupant age (AGE2), the occupant seat position (CENTER), and the type of CRS (CARSEAT) in Section 3.5 were used as the independent variables in the logistic regression analysis.

The domain variables in Section 3.2 and Section 4.3.1 and the domain variable of all crashes in Section 4 were used in the SAS survey analysis procedure to specify the analytical data set from the entire NASS-CDS. This section used the SAS SURVEYLOGISTIC procedure with RATEGT as the weight, PSU as the cluster and PSU STRATA as the strata to perform the logistic regression analysis. The following table shows the estimated parameters of independent variables in the full logistic regression model:

Table 33. Full Logistic Regression Model: 3- to 5-Year-Old Child Restraint System Users Experienced Moderate to Critical Injuries in All Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_3_5=1 CRS_USER=1 CRASH_GROUP=1

Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
MALE1=1	-0.7108	0.4084	-1.74	0.1023
AGE1	0.00358	0.0530	0.07	0.9470
MODE=FRONTAL	-1.4731	0.6730	-2.19	0.0448*
MODE=REAR	-2.2105	0.8166	-2.71	0.0162*
MODE =SIDE	-1.9453	0.4688	-4.15	0.0009*
AGE2	0.0548	0.2274	0.24	0.8128
CENTER=1	0.1193	0.5410	0.22	0.8285
CARSEAT=1	-0.8773	0.6375	-1.38	0.1889

The 3- to 5-year-old car seat users might be less likely to experience moderate to critical injuries than the 3- to 5-year-old booster seat users, since the estimate of car seat (CARSEAT=1) is negative (-0.8773). The 3- to 5-year-old CRS users in center seats not might be less likely to experience moderate to critical injuries than the 3- to 5-year-old CRS users in outboard seats, since the estimate of center seat (CENTER=1) is positive (0.1193). The 3- to 5-year-old CRS users might be significantly less likely to experience moderate to critical injuries in non-rollover crashes than rollovers, since the estimates of frontal-impact crash (MODE=FRONTAL), rear-impact crash (MODE=REAR) and side-impact crash (MODE=SIDE) are negative (-1.4731 in frontal-impact crash, -2.2105 in rear-impact crash and -1.9453 in side-impact crash) with the p-values (0.0448 in frontal-impact crash, 0.0162 in rear-impact crash and 0.0009 in side-impact crash) less than the significance level of 0.05.

This section kept the type of CRS (CARSEAT) in the final logistic regression model and used the forward selection method to remove other independent variables that were not significant in the full logistic regression model. The following table shows the analysis results of the final logistic regression model:

Table 34. Final Logistic Regression Model: 3- to 5-Year-Old Child Restraint System Users Experienced Moderate to Critical Injuries in All Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_3_5=1 CRS_USER=1 CRASH_GROUP=1

Global Model Test				
	F Test		P-value	
Likelihood Ratio	0.97		0.4099	
Score	12.48		0.0003	
Wald	12.84		0.0003	
Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
MODE=FRONTAL	-1.5176	0.5986	-2.54	0.0229*
MODE=REAR	-2.1226	0.7275	-2.92	0.0106*
MODE=SIDE	-1.8663	0.3969	-4.70	0.0003*
CARSEAT=1	-0.8614	0.5716	-1.51	0.1526
Odds Ratio Estimate				
Independent Variable	Estimate		95% Confidence Interval	
MODE=FRONTAL	0.219		(0.061, 0.785)	
MODE=REAR	0.120		(0.025, 0.564)	
MODE=SIDE	0.155		(0.066, 0.360)	
CARSEAT=1	0.423		(0.125, 1.429)	
Model Fitting Assessment				
C Statistics	0.524			

The final logistic regression model is not significant, since the p-value of the likelihood ratio test (0.4099) is greater than the significance level of 0.05. The C-statistic is 0.524, and the area under the ROC curve is 0.524 when the final logistic regression model uses the crash mode (MODE) and the type of CRS (CARSEAT) as the independent variables. The final logistic regression model might not substantially fit the analytical data set.

The type of CRS (CARSEAT) is not significant, since its p-value (0.1526) is greater than the significance level of 0.05. The analysis results from NASS-CDS did not demonstrate that the car seats were effective in reducing moderate to critical injuries experienced by the 3- to 5-year-old CRS users in all crashes. The driver’s gender, the driver age, the occupant age, and the occupant seat position are not significant, since their p-values are greater than the significance level of 0.05.

The crash mode is significant, since the p-values of frontal-impact crash (MODE=FRONTAL), rear-impact crash (MODE=REAR) and side-impact crash (MODE=SIDE) are less than the significance level of 0.05 (0.0229 in frontal-impact crash, 0.0106 in rear-impact crash and 0.0003 in side-impact crash). The 3- to 5-year-old CRS users are significantly less likely to experience moderate to critical injuries in non-rollover crashes than rollover events, since the estimates of frontal-impact crash (MODE=FRONTAL), rear-impact crash (MODE=REAR) and side-impact crash (MODE=SIDE) are negative (-1.5176 in frontal-impact crash, -2.1226 in rear-impact crash and -1.8663 in side-impact crash) with the p-values (0.0229 in frontal-impact crash, 0.0106 in rear-impact crash and 0.0003 in side-impact crash) less than the significance level of 0.05.

The analysis results of the analytical data set of non-rollover crashes are different from the analysis results of the analytical data sets of all non-rollover crashes (see Section 4.3.1 and Section 4.3.2). The independent variables in Section 3.5 could not explain all variations that were related to occupant injury severity in rollover events, and those variations influenced the analysis results.

4.4.1 Booster Seats: 4- to 8-Year-Old Occupants in Non-Rollover Crashes (MAIS ≥ 2)

This section examines the effect of booster seats on reducing moderate to critical injuries experienced by 4- to 8-year-old occupants in non-rollover crashes. The seat belts were used as the reference group for the booster seats, and the effect of booster seats on reducing moderate to critical injuries was compared with the effect of seat belts in the analysis.

The following domain variables were used to specify 4- to 8-year-old booster seat and seat belt users:

$$\text{AGE\_4\_8} = \begin{cases} 1, \text{if an occupant is between 4 and 8 years old} \\ 0, \text{others} \end{cases}$$

$$\text{BOOSTER\_SEATBELT} = \begin{cases} 1, \text{if an occupant used a booster seat or a selt belt} \\ 0, \text{others} \end{cases}$$

The analytical data set in this section was specified from the entire NASS-CDS by using the above two domain variables, the domain variables in Section 3.2, and the domain variable of non-rollover crashes in Section 4. The sampling data observations in the analytical data set satisfied the following vehicle, driver and occupant conditions.

<u>Vehicle</u>

The collision-crashed passenger vehicle with GVWR less than 10,000 pounds was towed and experienced no rollovers, and there was at least one 4- to 8-year-old booster seat or seat belt user in the collision-crashed passenger vehicle.

<u>Driver</u>

The driver was belted and was at least 16 years old. The belted drivers might be more likely to properly use the booster seats than unbelted drivers.

<u>Occupant</u>

The 4- to 8-year-old booster seat or seat belt user with a known MAIS sat in the second or the third row of the passenger vehicle in the non-rollover crash.

The following table shows the weighted frequency, unweighted frequency and weighted percentage of injury at each level of MAIS experienced by the 4- to 8-year-old booster and seat belt users in the analytical data set:

Table 35. Distribution of MAIS Level in 4- to 8-Year-Old Booster Seat and Seat Belt Users in Non-Rollover Crashes

MAIS Level	Frequency	Weighted Percentage
0	643,680 (895)	75.84%
1	196,160 (541)	23.11%
2	5,387 (51)	0.63%
3	2,945 (27)	0.35%
4	100.66 (5)	0.01%
5	351.36 (9)	0.04%
6	123.28 (3)	0.02%
Total	848,748 (1531)	100%

There are 541 booster seat and seat belt users 4- to 8 years old in the analytical data set who experienced MAIS level 1 injuries in non-rollover crashes. The weighted frequency of MAIS level 1 injuries experienced by the 4- to 8-year-old booster seat and seat belt users is 196,160, and the weighted percentage of MAIS level 1 injuries is 23.11 percent ((196,160/848,748)*100%). The weighted percentage of injuries does not monotonically decrease when the MAIS level increases. The impact of sampling weights and different NHTSA AIS versions over the years might influence the weighted percentage of injuries.

The weighted percentage of moderate to critical injuries experienced by the 4- to 8-year-old booster seat and seat belt users in non-rollover crashes is 1.05 percent (0.63%+0.35%+ 0.01%+0.04%+0.02%) while the weighted percentage of none to minor injuries experienced by the 4- to 8-year-old booster seat and seat belt users in non-rollover crashes is 98.95 percent (75.84%+23.11%). The weighted percentage of moderate to critical injuries is substantially less than the weighted percentage of none to minor injuries in non-rollover crashes.

The following table shows the weighted frequencies, unweighted frequencies and weighted percentages of booster seat and seat belt usages in the analytical data set:

Table 36. Booster Seats and Seat Belts Used by 4- to 8-Year-Old Occupants in Non-Rollover Crashes

	Frequency	Weighted Percentage
Booster Seat	240,971 (435)	28.39%
Seat Belt	607,777 (1096)	71.61%
Total	848,748 (1531)	100%

There are 435 booster seat users 4- to 8 years old in the analytical data set, and the weighted frequency of the 4- to 8-year-old booster seat users is 240,971. The weighted percentage of booster seat usage is 28.39 percent ((240,971/848,748)*100%) while the weighted percentage of seat belt usage is 71.61 percent ((607,777/848,748)*100%). The 4- to 8- year-old occupants who experienced non-rollover crashes used seat belts more frequently than booster seats.

The following contingency table shows the weighted frequencies, unweighted frequencies, weighted percentages, and standard errors of moderate to critical injuries experienced by the 4- to 8-year-old booster seat users and seat belt users in non-rollover crashes:

Table 37. Type of Seat Restraints and Status of Moderate to Critical Injuries Experienced by 4- to 8-Year-Old Occupants in Non-Rollover Crashes

	Moderate to Critical Injuries	None to Minor Injuries	Total
Booster Seat	2,665 (18) 1.11% (0.71%)	238,306 (417) 98.89% (0.71%)	24,0971 (435) 100%
Seat Belt	6,243 (77) 1.03% (0.20%)	601,534 (1019) 98.97% (0.20%)	607,777 (1096) 100%

There are 18 booster seat users 4- to 8 years old in the analytical data set who experienced moderate to critical injuries in non-rollover crashes, and the weighted frequency of moderate to critical injuries experienced by the 4- to 8- year-old booster seat users is 2,665. The weighted percentage of moderate to critical injuries experienced by the booster seat users is 1.11 percent ((2,665/240,971)*100%) with the standard error of 0.71 percent while the weighted percentage of moderate to critical injuries experienced by the seat belt users is 1.03 percent ((6,243/607,777)*100%) with the standard error of 0.20 percent. The weighted percentage of moderate to critical injuries experienced by the booster seat users (1.11%) is greater than the weighted percentage of moderate to critical injuries experienced by the seat belt users (1.03%). The variation of experiencing moderate to critical injuries by the booster seat users is greater than the variation of experiencing moderate to critical injuries by the seat belt users, since the standard error in the booster seat users (0.71%) is greater than the standard error in the seat belt users (0.20%).

The weighted percentage of moderate to critical injuries experienced by the 4- to 8-year-old booster seat users in Table 37 might be impacted by sampling weights, and this section examined the weighted percentage of moderate to critical injuries experienced by the booster seat users at each age from four to eight. The following contingency table shows the weighted frequency, unweighted frequency, weighted percentage, and standard errors of moderate to critical injuries experienced by the booster seat users at each age from four to eight:

Table 38. Occupant's Age and Status of Moderate to Critical Injuries Experienced by 4- to 8-Year-Old Booster Seat Users in Non-Rollover Crashes

Age of Booster Seat User	Moderate to Critical Injuries	None to Minor Injuries	Total
4	2,506 (14) 1.45% (1.09%)	169,868 (251) 98.55% (1.09%)	172,374 (265) 100%
5	713.76 (15) 0.47% (0.24%)	151,975 (305) 99.53% (0.24%)	152,689 (320) 100%
6	799.89 (19) 0.41% (0.15%)	193,439 (321) 99.59% (0.15%)	194,239 (340) 100%
7	1,972 (21) 1.15% (0.55%)	169,274 (309) 98.85% (0.55%)	171,246 (330) 100%
8	2,916 (26) 1.84% (0.36%)	155,285 (250) 98.16% (0.36%)	158,200 (276) 100%

There are 14 booster seat users 4 years old in the analytical data set who experienced moderate to critical injuries, and the weighted frequency of moderate to critical injuries experienced by the 4-year-old booster seat users is 2,506. The weighted percentage of moderate to critical injuries experienced by the 4-year-old booster seat users is 1.45 percent ((2,506/172,374)*100%) with the standard error of 1.09 percent while the weighted percentage of moderate to critical injuries experienced by the 5-year-old booster seat users is 0.47 percent ((713.76/152,689)*100%) with the standard error of 0.24 percent. The variation of experiencing moderate to critical injuries by the 4-year-old booster seat users is greater than the variations of experiencing moderate to critical injuries by the booster seat users at the other ages in Table 38, since the standard error in 4-year-old booster seat users (1.09%) is greater than the standard errors in booster seat users at the other ages in Table 38 (0.24% at age 5, 0.15% at age 6, 0.55% at age 7, and 0.36% at age 8). The variation of experiencing moderate to critical injuries by the 4-year-old booster seat users might be impacted by the sampling weights.

The coefficient of variation of sampling weights was used to assess the impact of sampling weights. The CV of sampling weights was calculated by using the following equation:

$$\text{CV of Sampling Weights} = \frac{\text{Standard Deviation of Sampling Weights}}{\text{Mean of Sampling Weights}}$$

The impact of sampling weights increases when the CV of sampling weights increases. The sampling weights have a greater influence on the variation of the analytical data set when the impact of sampling weights increases. The following shows the CV of sampling weights of the booster seat users at each age from age 4 to 8:

Table 39. Booster Seat User's Age and Coefficient of Variation of Sampling in Non-Rollover Crashes

Age of Booster Seat User	Mean of Sampling Weights	Standard Deviation of Sampling Weights	CV of Sampling Weights
4	651.23	1,673.55	256.98%
5	477.32	829.12	173.70%
6	414.53	571.26	137.81%
7	715.43	1,168.21	163.29%
8	551.28	505.03	91.61%

The CV of sampling weights of the 4-year-old booster seat users is 256.98 percent while the CV of sampling weights of the 5-year-old booster seat users is 173.70 percent. The sampling weights have a greater impact on the 4-year-old booster seat users than the booster seat users at the other ages in Table 39, since the CV of sampling weights of 4-year-old booster seat users (256.98%) is greater than the CVs of sampling weights of the booster seat users at the other ages in Table 39 (173.70% at age 5, 137.81% at age 6, 163.29% at age 7, and 91.61% at age 8). The sampling weights of the 4-year-old booster seat users inflated the estimated variance and impacted the significance of the analysis results.

The effect of booster seats on reducing moderate to critical injuries experienced by the 4- to 8-year-old booster seat and seat belt users in non-rollover crashes was estimated by using the logistic regression analysis, and the effect of booster seats was compared with the effect of seat belts in the analysis. The status of moderate to critical injuries (MAIS2) in Section 3.5 was used as the dependent variable, and the driver's gender (MALE1), the driver age (AGE1), the non-rollover crash mode (MODE_COLL), the occupant age (AGE2), the occupant seat position (CENTER), and the type of seat restraints (BOOSTERSEAT) in Section 3.5 were used as the independent variables in the logistic regression analysis.

The domain variables in Section 3.2 and Section 4.4.1 and the domain variable of non-rollover crashes in Section 4 were used in the SAS survey analysis procedure to specify the analytical data set from the entire NASS-CDS. This section used the SAS SURVEYLOGISTIC procedure with RATEGT as the weight, PSU as the cluster and PSU STRATA as the strata to perform the logistic regression analysis. The following table shows a part of analysis results of the full logistic regression model:

Table 40. Full Logistic Regression Model: 4- to 8-Year-Old Booster Seat and Seat Belt Users Experienced Moderate to Critical Injuries in Non-Rollover Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_4_8=1 BOOSTER_SEATBELT=1 COLLISION_GROUP=1

Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
MALE1=1	-0.5754	0.5872	-0.98	0.3426
AGE1	-0.00892	0.0201	-0.44	0.6638
MODE_COLL=REAR	-1.1335	0.6097	-1.86	0.0827
MODE_COLL=SIDE	-1.4153	0.6019	-2.35	0.0328*
AGE2	0.1776	0.2227	0.80	0.4376
CENTER=1	-0.5943	0.5052	-1.18	0.2578
BOOSTERSEAT=1	0.1377	0.5269	0.26	0.7974

The 4- to 8-year-old booster seat users might not be less likely to experience moderate to critical injuries than the 4- to 8-year-old seat belt users, since the estimate of booster seat (BOOSTERSEAT=1) is positive (0.1377). The 4- to 8-year-old booster seat and seat belt users in center seats might be less likely to experience moderate to critical injuries than the 4- to 8- year-old booster seat and seat belt users in outboard seats, since the estimate of center seat (CENTER=1) is negative (-0.5943). The 4- to 8-year-old booster seat and seat belt users in side-impact non-rollover crashes might be significantly less likely to experience moderate to critical injuries than the 4- to 8-year-old booster seat and seat belt users in frontal-impact non-rollover crashes, since the estimate of side-impact non-rollover crash (MODE=SIDE) is negative (-1.4153) with the p-value (0.0328) less than the significance level of 0.05.

This section kept the type of seat restraints (BOOSTERSEAT) in the final logistic regression model and used the forward selection method to remove other independent variables that were not significant in the full logistic regression model. The following table shows the analysis results of the final logistic regression model:

Table 41. Final Logistic Regression Model: 4- to 8-Year-Old Booster Seat and Seat Belt Users Experienced Moderate to Critical Injuries in Non-Rollover Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_4_8=1 BOOSTER_SEATBELT=1 COLLISION_GROUP=1

Global Model Test				
	F Test		P-value	
Likelihood Ratio	1.21		0.3164	
Score	2.38		0.1171	
Wald	2.25		0.1314	
Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
MODE_COLL=REAR	-1.1353	0.5877	-1.93	0.0725
MODE_COLL=SIDE	-1.2571	0.5260	-2.39	0.0304*
BOOSTERSEAT=1	-0.0563	0.7096	-0.08	0.9378
Odds Ratio Estimate				
Independent Variable	Estimate		95% Confidence Interval	
MODE_COLL=REAR	0.321		(0.092, 1.124)	
MODE_COLL=SIDE	0.284		(0.093, 0.873)	
BOOSTERSEAT=1	0.945		(0.208, 4.289)	
Model Fitting Assessment				
C Statistics	0.504			

The final logistic regression model is not significant, since the p-values of the likelihood ratio test (0.3164), the score test (0.1171) and the Wald test (0.1314) are greater than the significance level of 0.05. The C-statistic is 0.504, and the area under the ROC curve is 0.504 when the final logistic regression model uses the non-rollover crash mode (MODE_COLL) and the type of seat restraints (BOOSTERSEAT) as the independent variables. The final logistic regression model might not substantially fit the analytical data set.

The 4- to 8-year-old booster seat and seat belt users in side-impact non-rollover crashes are significantly less likely to experience moderate to critical injuries than the 4- to 8-year-old booster seat and seat belt users in frontal-impact non-rollover crashes, since the estimate of side-impact non-rollover crash (MODE_COLL=SIDE) is negative (-1.2571) with the p-value (0.0304) less than the significance level of 0.05.

The type of seat restraints (BOOSTERSEAT) is not significant, since its p-value (0.9378) is greater than the significance level of 0.05. The analysis results from NASS-CDS did not demonstrate that the booster seats were effective in reducing moderate to critical injuries experienced by the 4- to 8-year-old CRS users in non-rollover crashes. The driver's gender, the driver age, the occupant age, and the occupant seat position are not significant, since their p-values are greater than the significance level of 0.05.

Table 38 and Table 39 showed that the sampling weights of the 4-year-old booster seat users impacted the standard error of experiencing moderate to critical injuries by the 4- to 8-year-old booster seat users in non-rollover crashes. The sampling weights of the 4-year-old booster seat users also influenced the significance of the analysis results. Trimming the sampling weights[23] might resolve the significance issues but might cause biased estimates. Section 4.5.1 used the 5- to 8-year-old booster seat and seat belt users to estimate the effect of booster seats on reducing moderate to critical injuries in non-rollover crashes.

4.4.2 Booster Seats: 4- to 8-Year-Old Occupants in All Crashes (MAIS ≥ 2)

This section examined the effect of booster seats on reducing moderate to critical injuries experienced by the 4- to 8-year-old occupants in all crashes. The seat belts were used as the reference group of the booster seats, and the effect of booster seats on reducing moderate to critical injuries was compared with the effect of seat belts in the analysis.

The analytical data set in this section was specified from the entire NASS-CDS by using the domain variables in Section 3.2 and Section 4.4.1 and the domain variable of all crashes in Section 4.

The following contingency table shows the weighted frequencies, unweighted frequencies, weighted percentages, and standard errors of moderate to critical injuries experienced by the 4- to 8-year-old booster seat and seat belt users in all crashes:

Table 42. Type of Seat Restraints and Status of Moderate to Critical Injuries Experienced by 4- to 8-Year-Old Occupants in All Crashes

	Moderate to Critical Injuries	None to Minor Injuries	Total
Booster Seat	3,652 (26) 1.29% (0.61%)	280,285 (455) 98.71% (0.61%)	283,937 (481) 100%
Seat Belt	7,889 (93) 1.15% (0.27%)	677,000 (1,140) 98.85% (0.27%)	684,890 (1,233) 100%

There are 26 booster seat users 4- to 8 years old in the analytical data set who experienced moderate to critical injuries in all crashes, and the weighted frequency of moderate to critical injuries experienced by the 4- to 8-year-old booster seat users is 3,652. The weighted percentage of moderate to critical injuries experienced by the booster seat users is 1.29 percent ((3,652/283,937)*100%) with the standard error of 0.61 percent while the weighted percentage of moderate to critical injuries experienced by the 4- to 8-year-old seat belt users is 1.15 percent ((7,889/684,890)*100%) with the standard error of 0.27 percent. The weighted percentage of moderate to critical injuries experienced by the booster seat users (1.29%) is greater than the weighted percentage of moderate to critical injuries experienced by the seat belt users (1.15%). The variation of experiencing moderate to critical injuries by the booster seat users is greater than the variation of experiencing moderate to critical injuries by the seat belt users, since the standard error in the booster seat users (0.61%) is greater than the standard error in the seat belt users (0.27%). Table 39 showed that the variation of experiencing moderate to critical injuries by the booster seat users was impacted by the sampling weights of the 4-year-old booster seat users.

[23] Trimming the sampling weights is a process of re-assigning extreme sampling weights to other data observations in the analytical data set.

The effect of booster seats on reducing moderate to critical injuries experienced by the 4- to 8-year-old booster seat and seat belt users in all crashes was estimated by using the logistic regression analysis, and the effect of booster seats was compared with the effect of seat belts in the analysis. The status of moderate to critical injuries (MAIS2) in Section 3.5 was used as the dependent variable, and the driver's gender (MALE1), the driver age (AGE1), the crash mode (MODE), the occupant age (AGE2), the occupant seat position (CENTER), and the type of seat restraints (BOOSTERSEAT) in Section 3.5 were used as the independent variables in the logistic regression analysis.

The domain variables in Section 3.2 and Section 4.4.1 and the domain variable of all crashes in Section 4 were used in the SAS survey analysis procedure to specify the analytical data set from the entire NASS-CDS. This section used the SAS SURVEYLOGISTIC procedure with RATEGT as the weight, PSU as the cluster and PSU STRATA as the strata to perform the logistic regression analysis. The following table shows the estimated parameters of independent variables in the full logistic regression model:

Table 43. Full Logistic Regression Model: 4- to 8-Year-Old Booster Seat and Seat Belt Users Experienced Moderate to Critical Injuries in All Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_4_8=1 BOOSTER_SEATBELT=1 CRASH_GROUP=1

Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
MALE1=1	-0.6008	0.5480	-1.10	0.2902
AGE1	-0.00557	0.0173	-0.32	0.7514
MODE=FRONTAL	-0.6683	0.6715	-1.00	0.3354
MODE=REAR	-1.7771	0.7128	-2.49	0.0248*
MODE =SIDE	-2.0549	0.5852	-3.51	0.0031*
AGE2	-0.00452	0.1475	-0.03	0.9759
CENTER=1	-1.1186	0.5373	-2.08	0.0549
BOOSTERSEAT=1	0.1677	0.5036	0.33	0.7437

The 4- to 8-year-old booster seat users might not be less likely to experience moderate to critical injuries than the 4- to 8-year-old seat belt users, since the estimate of booster seat (BOOSTERSEAT=1) is positive (0.1677). The 4- to 8-year-old booster seat and seat belt users in center seats might be significantly less likely to experience moderate to critical injuries than the 4- to 8-year-old booster seat and seat belt users in outboard seats, since the estimate of center seat (CENTER=1) is negative (-1.1186) with the p-value (0.0549) close to the significance level of 0.05. The 4- to 8-year-old booster seat and seat belt users might be significantly less likely to experience moderate to critical injuries in rear-impact crashes than rollovers, since the estimate of rear-impact crashes (MODE=REAR) is negative (-1.7771) with the p-value (0.0248) less than the significance level of 0.05. The 4- to 8-year-old booster seat and seat belt users might be significantly less likely to experience moderate to critical injuries in side-impact crashes than rollovers, since the estimate of side-impact crashes (MODE=SIDE) is negative (-2.0549) with the p-value (0.0031) less than the significance level of 0.05.

This section kept the type of seat restraints (BOOSTERSEAT) in the final logistic regression model and used the forward selection method to remove other independent variables that were not significant in the full logistic regression model. The following table shows the analysis results of the final logistic regression model:

Table 44. Final Logistic Regression Model: 4- to 8-Year-Old Booster Seat and Seat Belt Users Experienced Moderate to Critical Injuries in All Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_4_8=1 BOOSTER_SEATBELT=1 CRASH_GROUP=1

Global Model Test				
	F Test		P-value	
Likelihood Ratio	1.83		0.1510	
Score	5.78		0.0074	
Wald	12.63		0.0003	
Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
MODE=FRONTAL	-0.6662	0.6382	-1.04	0.3131
MODE =REAR	-1.7520	0.6034	-2.90	0.0109*
MODE =SIDE	-1.9395	0.4764	-4.07	0.0010*
CENTER=1	-1.2785	0.5576	-2.29	0.0367*
BOOSTERSEAT=1	0.1068	0.5584	0.19	0.8508
Odds Ratio Estimate				
Independent Variable	Estimate		95% Confidence Interval	
MODE=FRONTAL	0.514		(0.132, 2.002)	
MODE =REAR	0.173		(0.048, 0.628)	
MODE =SIDE	0.144		(0.052, 0.397)	
CENTER=1	0.278		(0.085, 0.914)	
BOOSTERSEAT=1	1.113		(0.338, 3.658)	
Model Fitting Assessment				
C Statistics	0.505			

The final logistic regression model is not significant, since the p-value of the likelihood ratio test (0.1510) is greater than the significance level of 0.05. The C-statistic is 0.505, and the area under the ROC curve is 0.505 when the final logistic regression model uses the crash mode (MODE), the occupant seat position (CENTER) and the type of seat restraints (BOOSTERSEAT) as the independent variables. The final logistic regression model might not substantially fit the analytical data set.

The effect of center seats (CENTER=1) on reducing moderate to critical injuries is significant, since its p-value (0.0367) is less than the significance level of 0.05. The 4- to 8-year-old booster seat and seat belt users in center seats are significantly less likely to experience moderate to critical injuries than the 4- to 8-year-old booster seat and seat belt users in outboard seats, since the estimate of center seat (CENTER=1) is negative (-1.2785) with the p-value (0.0367) less than the significance level of 0.05.

The type of seat restraints (BOOSTERSEAT) is not significant, since its p-value (0.8508) is greater than the significance level of 0.05. The analysis results from NASS-CDS did not demonstrate that the booster seats were effective in reducing moderate to critical injuries experienced by the 4- to 8-year-old booster seat and seat belt users in all crashes. The driver's gender, the driver age and the occupant age are not significant, since their p-values are greater than the significance level of 0.05.

The occupant's seat position is considered as an important variable, since it might influence the effect of booster seats on reducing moderate to critical injuries. The ratio of the odds of experiencing moderate to critical injuries by the 4- to 8-year-old booster seat and seat belt users in center seats to the odds of experiencing moderate to critical injuries by the 4- to 8-year-old booster seat and seat belt users in outboard seats was estimated by applying Equation 1 and the final logistic regression model estimate of center seat (-1.2785).

$$\left(\frac{\text{Odds}|\text{Center Seat}}{\text{Odds}|\text{Outboard Seat}}\right) = \text{Odds Ratio} = \exp(-1.2785) = 0.278$$

The effect of center seats on reducing moderate to critical injuries experienced by the 4- to 8-year-old booster seat and seat belt users was estimated by using Equation 2.

$$\text{Effect of Center Seats} = \left(1 - \exp(-1.2785)\right) \cdot 100\% = 72.2\%$$

With other variables being held constant, the odds of experiencing moderate to critical injuries by the 4- to 8-year-old booster seat and seat belt users in center seats is 72.2 percent less than the odds of experiencing moderate to critical injuries by the 4- to 8-year-old booster seat and seat belt users in outboard seats. The estimated 95 percent confidence interval is between 8.6 percent ((1-0.914)*100%) and 91.5 percent ((1-0.085)*100%) based on the analytical data set from NASS-CDS.

The crash mode is significant, since the p-values of rear-impact crash (MODE=REAR) and side-impact crash (MODE=SIDE) are less than the significance level of 0.05 (0.0109 in rear-impact crash and 0.0010 in side-impact crash). The 4- to 8-year-old booster seat and seat belt users are significantly less likely to experience moderate to critical injuries in rear-impact crashes than rollover events, since the estimate of rear-impact crash (MODE=REAR) is negative (-1.7520) with the p-value (0.0109) less than the significance level of 0.05. The 4- to 8-year-old booster seat and seat belt users are significantly less likely to experience moderate to critical injuries in side-impact crashes than rollover events, since the estimate of side-impact crash (MODE=SIDE) is negative (-1.9395) with the p-value (0.0010) less than the significance level of 0.05.

Table 39 and Table 42 showed that the sampling weights of the 4-year-old booster seat users impacted the standard error of experiencing moderate to critical injuries experienced by the 4- to 8-year-old booster seat users in all crashes. The sampling weights of the 4-year-old booster seat users also influenced the significance of the analysis results. Section 4.5.2 used the 5- to 8-year-old booster seat and seat belt users to estimate the effect of booster seats on reducing moderate to critical injuries in all crashes.

The effect of center seats on reducing moderate to critical injuries is significant in the analytical data set of all crashes (see Section 4.4.2) while the effect of center seats is not significant in the analytical data set of non-rollover crashes (see Section 4.4.1). The distribution of occupant injury severity in rollovers is different from the distribution of occupant injury severity in non-rollover crashes.

4.5.1 Booster Seats: 5- to 8-Year-Old Occupants in Non-Rollover Crashes (MAIS ≥ 2)

This section examined the effect of booster seats on reducing moderate to critical injuries experienced by the 5- to 8-year-old occupants in non-rollover crashes. The seat belts were used as the reference group of the booster seats, and the effect of booster seats on reducing moderate to critical injuries was compared with the effect of seat belts in the analysis.

The following domain variables were used to specify 5- to 8-year-old booster seat and seat belt users:

$$\text{AGE\_5\_8} = \begin{cases} 1, \text{if an occupant is between 5 and 8 years old} \\ 0, \text{others} \end{cases}$$

$$\text{BOOSTER\_SEATBELT} = \begin{cases} 1, \text{if an occupant used a booster seat or a selt belt} \\ 0, \text{others} \end{cases}$$

The analytical data set in this section was specified from the entire NASS-CDS by using the above two domain variables, the domain variables in Section 3.2, and the domain variable of non-rollover crashes in Section 4. The sampling data observations in the analytical data set satisfied the following vehicle, driver and occupant conditions.

<u>Vehicle</u>

The collision-crashed passenger vehicle with the GVWR less than 10,000 pounds was towed and experienced no rollovers, and there was at least one 5- to 8-year-old booster seat or a seat belt user in the collision-crashed passenger vehicle.

<u>Driver</u>

The driver was belted and was at least 16 years old. The belted drivers might be more likely to properly use the booster seats than unbelted drivers.

<u>Occupant</u>

The 5- to 8-year-old booster seat or seat belt user with a known MAIS sat in the second or the third row of the passenger vehicle in the non-rollover crash.

The following shows the weighted frequency, unweighted frequency and weighted percentage of injuries at each MAIS level experienced by the 5- to 8-year-old booster seat and seat belt users in the analytical data set:

Table 45. Distribution of MAIS Level in 5- to 8-Year-Old Booster Seat and Seat Belt Users in Non-Rollover Crashes

MAIS Level	Frequency	Weighted Percentage
0	514803 (724)	76.11%
1	155169 (461)	22.94%

MAIS Level	Frequency	Weighted Percentage
2	5038 (44)	0.75%
3	893.22 (23)	0.13%
4	100.66 (5)	0.02%
5	246.35 (6)	0.04%
6	123.28 (3)	0.01%
Total	676374 (1266)	100%

There are 461 booster seat and seat belt users 5- to 8 years old in the analytical data set who experienced MAIS level 1 injuries in non-rollover crashes. The weighted frequency of MAIS level 1 injuries experienced by the 5- to 8-year-old booster seat and seat belt users is 155,169, and the weighted percentage of MAIS level 1 injuries is 22.94 percent ((155,169/676,374)*100%). The weighted percentage of injuries does not monotonically decrease when the MAIS level increases. The impact of sampling weights and different NHTSA AIS versions over the years might influence the weighted percentage of injuries.

The weighted percentage of moderate to critical injuries experienced by the 5- to 8-year-old booster seat and seat belt users in non-rollover crashes is 0.95 percent (0.75%+0.13%+ 0.02%+0.04%+0.01%) while the weighted percentage of none to minor injuries experienced by the 5- to 8-year-old booster seat and seat belt users in non-rollover crashes is 99.05 percent (76.11%+22.94%). The weighted percentage of moderate to critical injuries is substantially less than the weighted percentage of none to minor injuries in non-rollover crashes.

The following shows the weighted frequencies, unweighted frequencies and weighted percentages of booster seat and seat belt usages in the analytical data set:

Table 46. Booster Seats and Seat Belts Used by 5- to 8-Year-Old Occupants in Non-Rollover Crashes

	Frequency	Weighted Percentage
Booster Seat	148496 (294)	21.95%
Seat Belt	527878 (972)	78.05%
Total	676374 (1266)	100%

There are 294 booster seat users 5- to 8 years old in the analytical data set, and the weighted frequency of the 5- to 8-year-old booster seat users is 148,496. The weighted percentage of booster seat usage is 21.95 percent ((148,496/676,374)*100%) while the weighted percentage of seat belt usage is 78.05 percent ((527,878/676,374)*100%). The 5- to 8-year-old occupants who experienced non-rollover crashes used seat belts more frequently than booster seats.

The following table shows the weighted frequencies, unweighted frequencies, weighted percentages, and standard errors of injury severities experienced by the 5- to 8-year-old booster seat and seat belt users in non-rollover crashes:

Table 47. Type of Seat Restraints and Status of Moderate to Critical Injuries Experienced by 5- to 8-Year-Old Occupants in Non-Rollover Crashes

	Moderate to Critical Injuries	**None to Minor Injuries**	**Total**
Booster Seat	425.49 (12) 0.29% (0.06%)	148,070 (282) 99.71% (0.06%)	148,496 (294) 100%
Seat Belt	5,976 (69) 1.13% (0.24%)	521,902 (903) 98.87% (0.24%)	527,878 (972) 100%

There are 12 booster seat users 5- to 8 years old in the analytical data set who experienced moderate to critical injuries in non-rollover crashes, and the weighted frequency of moderate to critical injuries experienced by the 5- to 8-year-old booster seat users is 425.49. The weighted percentage of moderate to critical injuries experienced by the booster seat users is 0.29 percent ((425.49/148,496)*100%) with the standard error of 0.06 percent while the weighted percentage of moderate to critical injuries experienced by the seat belt users is 1.13 percent ((5,976/527,878)*100%) with the standard error of 0.24 percent. The weighted percentage of moderate to critical injuries experienced by the booster seat users (0.29%) is less than the weighted percentage of moderate to critical injuries experienced by the seat belt users (1.12%). The variation of experiencing moderate to critical injuries by the booster seat users is less than the variation of experiencing moderate to critical injuries by the seat belt users, since the standard error in the booster seat users (0.06%) is less than the standard error in the seat belt users (0.24%).

The effect of booster seats on reducing moderate to critical injuries experienced by the 5- to 8-year-old booster seat and seat belt users in non-rollover crashes was estimated by using the logistic regression analysis, and the effect of booster seats was compared with the effect of seat belts in the analysis. The status of moderate to critical injuries (MAIS2) in Section 3.5 was used as the dependent variable, and the driver's gender (MALE1), the driver age (AGE1), the non-rollover crash mode (MODE_COLL), the occupant age (AGE2), the occupant seat position (CENTER), and the type of seat restraints (BOOSTERSEAT) in Section 3.5 were used as the independent variables in the logistic regression analysis.

The domain variables in Section 3.2 and Section 4.5.1 and the domain variable of non-rollover crashes in Section 4 were used in the SAS survey analysis procedure to specify the analytical data set from the entire NASS-CDS. This section used the SAS SURVEYLOGISTIC procedure with RATEGT as the weight, PSU as the cluster and PSU STRATA as the strata to perform the logistic regression analysis. The following table shows the estimated parameters of independent variables in the full logistic regression model:

Table 48. Full Logistic Regression Model: 5- to 8-Year-Old Booster Seat and Seat Belt Users Experienced Moderate to Critical Injuries in Non-Rollover Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_5_8=1 BOOSTER_SEATBELT=1 COLLISION_GROUP=1

Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
MALE1=1	-0.4162	0.5027	-0.83	0.4207
AGE1	-0.00133	0.0238	-0.06	0.9561
MODE_COLL=REAR	-0.9675	0.5953	-1.63	0.1249
MODE_COLL=SIDE	-1.4657	0.6785	-2.16	0.0474*
AGE2	0.5075	0.1191	4.26	0.0007*
CENTER=1	-0.5472	0.4789	-1.14	0.2711
BOOSTERSEAT=1	-1.1181	0.3584	-3.12	0.0070*

The 5- to 8-year-old booster seat users might be significantly less likely to experience moderate to critical injuries than the 5- to 8-year-old seat belt users, since the estimate of booster seat (BOOSTER=1) is negative (-1.1181) with the p-value (0.0070) less than 0.05. The 5- to 8-year-old booster seat and seat belt users in center seats might be less likely to experience moderate to critical injuries than the 5- to 8-year-old booster seat and seat belt users in outboard seats, since the estimate of center seat (CENTER=1) is negative (-0.5472).

The 5- to 8-year-old booster seat and seat belt users in side-impact non-rollover crashes might be significantly less likely to experience moderate to critical injuries than the 5- to 8-year-old booster seat and seat belt users in frontal-impact non-rollover crashes, since the estimate of side-impact non-rollover crash (MODE_COLL=SIDE) is negative (-1.4975) with the p-value (0.0474) less than the significance level of 0.05. Older booster seat and seat belt users might be significantly more likely to experience moderate to critical injuries than younger booster seat and seat belt users, since the estimate of occupant's age (AGE2) is positive (0.5075) with the p-value (0.0007) less than the significance level of 0.05.

This section kept the type of seat restraints (BOOSTERSEAT) in the final logistic regression model and used the forward selection method to remove other independent variables that were not significant in the full logistic regression model. The following table shows the analysis results of the final logistic regression model:

Table 49. Final Logistic Regression Model: 5- to 8-Year-Old Booster Seat and Seat Belt Users Experienced Moderate to Critical Injuries in Non-Rollover Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_5_8=1 BOOSTER_SEATBELT=1 COLLISION_GROUP=1

Global Model Test		
	F Test	P-value
Likelihood Ratio	4.13	0.0602
Score	25.31	0.0001
Wald	18.15	0.0007
Parameter Estimate		

Independent Variable	Estimate	Standard Error	t Test	P-value
BOOSTERSEAT=1	-1.3825	0.3245	-4.26	0.0007
Odds Ratio Estimate				
Independent Variable	Estimate		95% Confidence Interval	
BOOSTERSEAT=1	0.251		(0.126, 0.501)	
Model Fitting Assessment				
C Statistics	0.545			

The final logistic regression model is not significant, since the p-value of the likelihood ratio test (0.0602) is less than the significance level of 0.05. The C-statistic is 0.545, and the area under the ROC curve is 0.545 when the final logistic regression model uses the type of seat restraints (BOOSTERSEAT) as the independent variable. The final logistic regression model might not substantially fit the analytical data set.

The effect of booster seats (BOOSTERSEAT=1) on reducing moderate to critical injuries is significant, since its p-value (0.0007) is less than the significance level of 0.05. The 5- to 8-year-old booster seat users are significantly less likely to experience moderate to critical injuries than the 5- to 8-year-old seat belt users, since the estimate of booster seat (BOOSTERSEAT=1) is negative (-1.3825) with the p-value (0.0007) less than the significance level of 0.05. The driver's gender, the driver age, the non-rollover crash mode, the occupant age, and the occupant seat position are not significant, since their p-values are greater than the significance level of 0.05.

The ratio of the odds of experiencing moderate to critical injuries by the booster seat users to the odds of experiencing moderate to critical injuries by the seat belt users was estimated by applying Equation 1 and the final logistic regression model estimate of booster seat (-1.3825).

$$\left(\frac{\text{Odds}|\text{Booster Seat}}{\text{Odds}|\text{Seat Belt}}\right) = \text{Odds Ratio} = \exp(-1.3825) = 0.251$$

The effect of booster seats on reducing moderate to critical injuries experienced by the 5- to 8-year-old booster seat and seat belt users was estimated by using Equation 2.

$$\text{Effect of Booster Seats} = \left(1 - \exp(-1.3825)\right) \cdot 100\% = 74.9\%$$

With other variables being held constant, the odds of experiencing moderate to critical injuries by the 5- to 8-year-old booster seat users is 74.9 percent less than the odds of experiencing moderate to critical injuries by the 5- to 8-year-old seat belt users. The estimated 95 percent confidence interval is between 49.9 percent ((1-0.501)*100%) and 87.4 percent ((1-0.126)*100%) based on the analytical data set from NASS-CDS.

4.5.2 Booster Seats: 5- to 8-Year-Old Occupants in All Crashes (MAIS ≥ 2)

This section examined the effect of booster seats on reducing moderate to critical injuries experienced by the 5- to 8-year-old occupants in all crashes. The seat belts were used as the reference group of the booster seats, and the effect of booster seats on reducing moderate to critical injuries was compared with the effect of seat belts in the analysis.

The analytical data set in this section was specified from the entire NASS-CDS by using the domain variables in Section 3.2 and Section 4.5.1 and the domain variable of all crashes in Section 4.

The following contingency table shows the weighted frequencies, unweighted frequencies, weighted percentages, and standard errors of moderate to critical injuries experienced by the 5- to 8-year-old booster seat and seat belt users in all crashes:

Table 50. Type of Seat Restraints and Status of Moderate to Critical Injuries Experienced by 5- to 8-Year-Old Occupants in All Crashes

	Moderate to Critical Injuries	**None to Minor Injuries**	**Total**
Booster Seat	1,170 (16) 0.62% (0.25%)	188,538 (309) 99.38% (0.25%)	189,708 (325) 100%
Seat Belt	7,187 (82) 1.21% (0.25%)	588,589 (1006) 98.79% (0.25%)	595,776 (1088) 100%

There are sixteen 5- to 8-year-old booster seat users in the analytical data set who experienced moderate to critical injuries in all crashes, and the weighted frequency of moderate to critical injuries experienced by the 5- to 8-year-old booster seat users is 1,170. The weighted percentage of moderate to critical injuries experienced by the booster seat users is 0.62 percent ((1,170/189,708)*100%) with the standard error of 0.25 percent while the weighted percentage of moderate to critical injuries experienced by the 5- to 8-year-old seat belt users is 1.21 percent ((7,187/595,776)*100%) with the standard error of 0.25 percent. The weighted percentage of moderate to critical injuries experienced by the booster seat users (0.62%) is less than the weighted percentage of moderate to critical injuries experienced by the seat belt users (1.21%). The variation of experiencing moderate to critical injuries by the booster seat users is equivalent to the variation of experiencing moderate to critical injuries by the seat belt users, since the standard error in the booster seat users (0.25%) is equal to the standard error in the seat belt users (0.25%).

The effect of booster seats on reducing moderate to critical injuries experienced by the 5- to 8-year-old booster seat and seat belt users in all crashes was estimated by using the logistic regression analysis, and the effect of booster seats was compared with the effect of seat belts in the analysis. The status of moderate to critical injuries (MAIS2) in Section 3.5 was used as the dependent variable, and the driver's gender (MALE1), the driver age (AGE1), the crash mode (MODE), the occupant age (AGE2), the occupant seat position (CENTER), and the type of seat restraints (BOOSTERSEAT) in Section 3.5 were used as the independent variables in the logistic regression analysis.

The domain variables in Section 3.2 and Section 4.5.1 and the domain variable of all crashes in Section 4 were used in the SAS survey analysis procedure to specify the analytical data set from the entire NASS-CDS. This section used the SAS SURVEYLOGISTIC procedure with RATEGT as the weight, PSU as the cluster and PSU STRATA as the strata to perform the logistic regression analysis. The following table shows the estimated parameters of independent variables in the full logistic regression model:

Table 51. Full Logistic Regression Model: 5- to 8-Year-Old Booster Seat and Seat Belt Users Experienced Moderate to Critical Injuries in All Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_5_8=1 BOOSTER_SEATBELT=1 CRASH_GROUP=1

Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
MALE1=1	-0.3774	0.4466	-0.84	0.4114
AGE1	-0.00269	0.0203	-0.13	0.8962
MODE=FRONTAL	-0.2822	0.7352	-0.38	0.7065
MODE=REAR	-1.2228	0.8359	-1.46	0.1641
MODE =SIDE	-1.6949	0.4837	-3.50	0.0032*
AGE2	0.2518	0.1545	1.63	0.1240
CENTER=1	-0.9824	0.5822	-1.69	0.1122
BOOSTERSEAT=1	-0.4314	0.4911	-0.88	0.3935

The 5- to 8-year-old booster seat users might be less likely to experience moderate to critical injuries than the 5- to 8-year-old seat belt users, since the estimate of booster seat (BOOSTERSEAT=1) is negative (-0.4314). The 5- to 8-year-old booster seat and seat belt users in center seats might be less likely to experience moderate to critical injuries than the 5- to 8-year-old booster seat and seat belt users in outboard seats, since the estimate of center seat (CENTER=1) is negative (-0.9824). The 5- to 8-year-old booster seat and seat belt users might be significantly less likely to experience moderate to critical injuries in side-impact crashes than rollovers, since the estimate of side-impact crashes (MODE=SIDE) is negative (-1.6949) with the p-value (0.0032) less than the significance level of 0.05.

This section kept the type of seat restraints (BOOSTERSEAT) in the final logistic regression model and used the forward selection method to remove other independent variables that were not significant in the full logistic regression model. The following table shows the analysis results of the final logistic regression model:

Table 52. Final Logistic Regression Model: 5- to 8-Year-Old Booster Seat and Seat Belt Users Experienced Moderate to Critical Injuries in All Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_5_8=1 BOOSTER_SEATBELT=1 CRASH_GROUP=1

Global Model Test				
	F Test		P-value	
Likelihood Ratio	1.31		0.2853	
Score	12.44		0.0003	
Wald	12.06		0.0004	
Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
MODE=FRONTAL	-0.5149	0.6769	-0.76	0.4587
MODE=REAR	-1.4632	0.6826	-2.14	0.0488*
MODE=SIDE	-1.8290	0.4691	-3.90	0.0014*

CENTER=1	-1.0639	0.4673	-2.28	0.0379*
BOOSTERSEAT=1	-0.6266	0.4796	-1.31	0.2111
Odds Ratio Estimate				
Independent Variable	Estimate		95% Confidence Interval	
MODE=FRONTAL	0.598		(0.141, 2.529)	
MODE=REAR	0.231		(0.054, 0.992)	
MODE=SIDE	0.161		(0.059, 0.436)	
CENTER=1	0.345		(0.127, 0.934)	
BOOSTERSEAT=1	0.534		(0.192, 1.485)	
Model Fitting Assessment				
C Statistics	0.508			

The final logistic regression model is not significant, since the p-value of the likelihood ratio test (0.2853) is greater than the significance level of 0.05. The C-statistic is 0.508, and the area under the ROC curve is 0.508 when the final logistic regression model uses the crash mode (MODE), the occupant seat position (CENTER) and the type of seat restraints (BOOSTERSEAT) as the independent variables. The final logistic regression model might not substantially fit the analytical data set.

The effect of center seats (CENTER=1) on reducing moderate to critical injuries is significant, since its p-value (0.0379) is less than the significance level of 0.05. The 5- to 8-year-old booster seat and seat belt users in center seats are significantly less likely to experience moderate to critical injuries than the 5- to 8-year-old booster seat and seat belt users in outboard seats, since the estimate of center seat (CENTER=1) is negative (-1.0639) with the p-value (0.0379) less than the significance level of 0.05.

The type of seat restraints (BOOSTERSEAT) is not significant, since its p-value (0.2111) is greater than the significance level of 0.05. The analysis results from NASS-CDS did not demonstrate that the booster seats were effective in reducing moderate to critical injuries experienced by the 5- to 8-year-old booster seat and seat belt users in all crashes. The driver's gender, the driver age and the occupant age are not significant, since their p-values are greater than the significance level of 0.05.

The occupant's seat position is considered as an important variable, since it might influence the effect of booster seats on reducing moderate to critical injuries. The ratio of the odds of experiencing moderate to critical injuries by the 5- to 8-year-old booster seat and seat belt users in center seats to the odds of experiencing moderate to critical injuries by the 5- to 8-year-old booster seat and seat belt users in outboard seats was estimated by applying Equation 1 and the final logistic regression model estimate of center seat (-1.0639).

$$\left(\frac{\text{Odds}|\text{Center Seat}}{\text{Odds}|\text{Outboard Seat}}\right) = \text{Odds Ratio} = \exp(-1.0639) = 0.345$$

The effect of center seats on reducing moderate to critical injuries experienced by the 5- to 8-year-old booster seat and seat belt users was estimated by using Equation 2.

$$\text{Effect of Center Seats} = \left(1 - \exp(-1.0639)\right) \cdot 100\% = 65.5\%$$

With other variables being held constant, the odds of experiencing moderate to critical injuries by the 5- to 8-year-old booster seat and seat belt users in center seats is 65.5 percent less than the odds of experiencing moderate to critical injuries by the 5- to 8-year-old booster seat and seat belt users in outboard seats. The estimated 95 percent confidence interval is between 6.6 percent ((1-0.934)*100%) and 87.3 percent ((1-0.127)*100%) based on the analytical data set from NASS-CDS.

The crash mode is significant, since the p-values of rear-impact crash (MODE=REAR) and side-impact crash (MODE=SIDE) are less than the significance level of 0.05 (0.0488 in rear-impact crash and 0.0014 in side-impact crash). The 5- to 8-year-old booster seat and seat belt users are significantly less likely to experience moderate to critical injuries in rear-impact crashes than rollover events, since the estimate of rear-impact crash (MODE=REAR) is negative (-1.4632) with the p-value (0.0488) less than the significance level of 0.05. The 5- to 8-year-old booster seat and seat belt users are significantly less likely to experience moderate to critical injuries in side-impact crashes than rollover events, since the estimate of side-impact crash (MODE=SIDE) is negative (-1.8290) with the p-value (0.0014) less than the significance level of 0.05.

The effect of booster seats on reducing moderate to critical injuries experienced by 5- to 8-year-old booster seat and seat belt users is significant in non-rollover crashes (see Section 4.5.1) but not in all crashes. Variations that are related to occupant injury severity in rollover events might influence the analysis results.

The effect of booster seats on reducing moderate to critical injuries is significant in the analytical data set of non-rollover crashes (see Section 4.5.1). Nevertheless, the effect of center seats on reducing moderate to critical injuries is significant in the analytical data set of all crashes (see Section 4.5.2). The distribution of occupant injury severity in rollovers is different from the distribution of occupant injury severity in non-rollover crashes.

4.6.1 Booster Seats: 7- to 8-Year-Old Occupants in Non-Rollover Crashes (MAIS ≥ 2)

This section examined the effect of booster seats on reducing moderate to critical injuries experienced by the 7- to 8-year-old occupants in non-rollover crashes. The seat belts were used as the reference group of the booster seats, and the effect of booster seats on reducing moderate to critical injuries was compared with the effect of seat belts in the analysis.

The following domain variables were used to specify 7- to 8-year-old booster seat and seat belt users:

$$\text{AGE\_7\_8} = \begin{cases} 1, \text{if an occupant is between 7 and 8 years old} \\ 0, \text{others} \end{cases}$$

$$\text{BOOSTER\_SEATBELT} = \begin{cases} 1, \text{if an occupant used a booster seat or a selt belt} \\ 0, \text{others} \end{cases}$$

The analytical data set in this section was specified from the entire NASS-CDS by using the above two domain variables, the domain variables in Section 3.2, and the domain variable of non-rollover crashes in Section 4. The sampling data observations in the analytical data set satisfied the following vehicle, driver and occupant conditions.

Vehicle

The collision-crashed passenger vehicle with the GVWR less than 10,000 pounds was towed and experienced no rollovers, and there was at least one 5- to 8-year-old booster seat or a seat belt user in the collision-crashed passenger vehicle

The collision-crashed passenger vehicle with the GVWR less than 10,000 pounds was towed and experienced no rollovers, and there was at least one 7- to 8-year-old booster seat or seat belt user in the collision-crashed passenger vehicle.

Driver

The driver was belted and was at least 16 years old. The belted drivers might be more likely to properly use the booster seats than unbelted drivers.

Occupant

The 7- to 8-year-old booster seat or seat belt user with a known MAIS sat in the second or the third row of the passenger vehicle in the non-rollover crash.

The following shows the weighted frequency, unweighted frequency and weighted percentage of injuries at each MAIS level experienced by the 7- to 8-year-old booster seat and seat belt users in the analytical data set:

Table 53. Distribution of MAIS Level in 7- to 8-Year-Old Booster Seat and Seat Belt Users in Non-Rollover Crashes

MAIS Level	Frequency	Weighted Percentage
0	241266 (342)	73.23%
1	83292 (217)	25.28%
2	3967 (26)	1.20%
3	629.05810 (14)	0.19%
4	18.16383 (1)	0.02%
5	176.20960 (4)	0.05%
6	97.70666 (2)	0.03%
Total	329446 (606)	100%

There are 217 booster seat and seat belt users 7- to 8 years old in the analytical data set who experienced MAIS level 1injuries in non-rollover crashes. The weighted frequency of MAIS level 1 injuries experienced by the 7- to 8-year-old booster seat and seat belt users is 83,292, and the weighted percentage of MAIS level 1 injuries is 25.28 percent ((83,292/329,446)*100%). The weighted percentage of injuries does not monotonically decrease when the MAIS level increases. The impact of sampling weights and different NHTSA AIS versions over the years might influence the weighted percentage of injuries.

The weighted percentage of moderate to critical injuries experienced by the 7- to 8-year-old booster seat and seat belt users in non-rollover crashes is 1.49 percent ((1.20%+0.19%+0.02%+0.05%+0.03%)*100%) while the weighted percentage of none to minor injuries experienced by the 7- to 8-year-old booster seat and seat belt users in non-rollover crashes is 98.51 percent ((73.23%+25.28%)*100%). The weighted percentage of moderate to critical injuries is substantially less than the weighted percentage of none to minor injuries in non-rollover crashes.

The following shows the weighted frequencies, unweighted frequencies and weighted percentages of booster seat and seat belt usages in the analytical data set:

Table 54. Booster Seats and Seat Belts Used by 7- to 8-Year-Old Occupants in Non-Rollover Crashes

	Frequency	**Weighted Percentage**
Booster Seat	45695 (68)	13.87%
Seat Belt	283751 (538)	86.13%
Total	329446 (606)	100%

There are sixty-eight 7- to 8-year-old booster seat users in the analytical data set, and the weighted frequency of the 7- to 8-year-old booster seat users is 45695. The weighted percentage of booster seat usage is 13.87 percent ((45,695/329,446)*100%) while the weighted percentage of seat belt usage is 86.13 percent ((28,3751/329,446)*100%). The 7- to 8-year-old occupants who experienced non-rollover crashes used seat belts more frequently than booster seats.

The following contingency table shows the weighted frequencies, unweighted frequencies, weighted percentages, and standard errors of injury severity experienced by the 7- to 8-year-old booster seat and seat belt users in non-rollover crashes:

Table 55. Type of Seat Restraints and Status of Moderate to Critical Injuries Experienced by 7- to 8-Year-Old Booster Seat and Seat Belt Users in Non-Rollover Crashes

	Moderate to Critical Injuries	**None to Minor Injuries**	**Total**
Booster Seat	112.14 (2) 0.25% (0.18%)	45,583 (66) 99.75% (0.18%)	45,695 (68) 100%
Seat Belt	4,776 (45) 1.68% (0.42%)	278,976 (493) 98.32% (0.42%)	283,751 (538) 100%

There are two 7- to 8-year-old booster seat users in the analytical data set who experienced moderate to critical injuries in non-rollover crashes, and the weighted frequency of moderate to critical injuries experienced by the 7- to 8-year-old booster seat users is 112.14. The weighted percentage of moderate to critical injuries experienced by the booster seat users is 0.25 percent ((112.14 /45,695) *100%) with the standard error of 0.18 percent while the weighted percentage of moderate to critical injuries experienced by the seat belt users is 1.68 percent ((4,776/283,751)*100%) with the standard error of 0.42 percent. The weighted percentage of moderate to critical injuries experienced by the booster seat users (0.25%) is less than the weighted percentage of moderate to critical injuries experienced by the seat belt users (1.68%). The variation of experiencing moderate to critical injuries by the booster seat users is less than the variation of experiencing moderate to critical injuries by the seat belt users, since the standard error in the booster seat users (0.18%) is less than the standard error in the seat belt users (0.42%).

The effect of booster seats on reducing moderate to critical injuries experienced by the 7- to 8-year-old booster seat and seat belt users in non-rollover crashes was estimated by using the logistic regression analysis, and the effect of booster seats was compared with the effect of seat belts in the analysis. The status of moderate to critical injuries (MAIS2) in Section 3.5 was used as the dependent variable, and the driver's gender (MALE1), the driver age (AGE1), the non-rollover crash mode (MODE_COLL), the occupant age (AGE2), the occupant seat position (CENTER), and the type of seat restraints (BOOSTERSEAT) in Section 3.5 were used as the independent variables in the logistic regression analysis.

The domain variables in Section 3.2 and Section 4.6.1 and the domain variable of non-rollover crashes in Section 4 were used in the SAS survey analysis procedure to specify the analytical data set from the entire NASS-CDS. This section used the SAS SURVEYLOGISTIC procedure with RATEGT as the weight, PSU as the cluster and PSU STRATA as the strata to perform the logistic regression analysis. The following table shows the estimated parameters of independent variables in the full logistic regression model:

Table 56. Full Logistic Regression Model: 7- to 8-Year-Old Booster Seat and Seat Belt Users Experienced Moderate to Critical Injuries in Non-Rollover Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_7_8=1 BOOSTER_ SEATBELT=1 COLLISION_GROUP=1

Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
MALE1=1	-0.7782	0.7051	-1.10	0.2871
AGE1	0.00408	0.0212	0.19	0.8503
MODE_COLL=REAR	-0.9534	0.6914	-1.38	0.1881
MODE_COLL=SIDE	-1.9200	0.5588	-3.44	0.0037*
AGE2	0.2491	0.5117	0.49	0.6334
CENTER=1	-1.0560	0.6709	-1.57	0.1363
BOOSTERSEAT=1	-2.1301	0.9599	-2.22	0.0423*

The 7- to 8-year-old booster seat users might be significantly less likely to experience moderate to critical injuries than the 7- to 8-year-old seat belt users, since the estimate of booster seat (BOOSTERSEAT=1) is negative (-2.1301) with the p-value (0.0423) less than the significance level of 0.05. The 7- to 8-year-old booster seat and seat belt users in center seats might be less likely to experience moderate to critical injuries in non-rollover crashes than the 7- to 8-year-old booster seat and seat belt users in outboard seats, since the estimate of center seat (CENTER=1) is negative (-1.0560). The 7- to 8-year-old booster seat and seat belt users in side-impact non-rollover crashes might be significantly less likely to experience moderate to critical injuries than the 7- to 8-year-old booster seat and seat belt users in frontal-impact non-rollover crashes, since the estimate of side-impact non-rollover crash (MODE=SIDE) is negative (-1.9200) with the p-value (0.0037) less than the significance level of 0.05.

This section kept the type of seat restraints (BOOSTERSEAT) in the final logistic regression model and used forward selection method to remove other independent variables that were not significant in the full logistic regression model. The following table shows the analysis results of the final logistic regression model:

Table 57. Final Logistic Regression Model: 7- to 8-Year-Old Booster Seat and Seat Belt Users Experienced Moderate to Critical Injuries in Non-Rollover Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_7_8=1 BOOSTER_SEATBELT=1 COLLISION_GROUP=1

Global Model Test				
	F Test		P-value	
Likelihood Ratio	1.58		0.2284	
Score	10.43		0.0056	
Wald	6.00		0.0271	
Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
BOOSTERSEAT=1	-1.9386	0.7914	-2.45	0.0271*
Odds Ratio Estimate				
Independent Variable	Estimate		95% Confidence Interval	
BOOSTERSEAT=1	0.144		(0.027, 0.778)	
Model Fitting Assessment				
C Statistics	0.538			

The final logistic regression model is not significant, since the p-value of the likelihood ratio test (0.2284) is greater than the significance level of 0.05. The C-statistic is 0.538, and the area under the ROC curve is 0.538 when the final logistic regression model uses the type of seat restraint (BOOSTERSEAT) as the independent variable. The final logistic regression model might not substantially fit the analytical data set.

The effect of booster seats (BOOSTERSEAT=1) on reducing moderate to critical injuries is significant, since its p-value (0.0271) is less than the significance level of 0.05. The 7- to 8-year-old booster seat users are significantly less likely to experience moderate to critical injuries than the 7- to 8-year-old seat belt users, since the estimate of booster seat (BOOSTERSEAT=1) is negative (-1.9386) with the p-value (0.0271) less than the significance level of 0.05. The driver's gender, the driver age, the non-rollover crash mode, the occupant age, and the occupant seat position are not significant, since their p-values are greater than the significance level of 0.05.

The ratio of the odds of experiencing moderate to critical injuries by the booster seat users to the odds of experiencing moderate to critical injuries by the seat belt users was estimated by applying Equation 1 and the final logistic regression model estimate of booster seat (-1.9386).

$$\left(\frac{\text{Odds}|\text{Booster Seat}}{\text{Odds}|\text{Seat Belt}}\right) = \text{Odds Ratio} = \exp(-1.9386) = 0.144$$

The effect of booster seats on reducing moderate to critical injuries experienced by the 7- to 8-year-old booster seat and seat belt users was estimated by using Equation 2.

$$\text{Effect of Booster Seats} = \big(1 - \exp(-1.9386)\big) \cdot 100\% = 85.6\%$$

With other variables being held constant, the odds of experiencing moderate to critical injuries by the 7- to 8-year-old booster seat users is 85.6 percent less than the odds of experiencing moderate to critical injuries by the 7- to 8-year-old seat belt users. The estimated 95 percent confidence interval is between 22.2 percent ((1-0.778)*100%) and 97.3 percent ((1-0.027)*100%) based on the analytical data set from NASS-CDS.

4.6.2 Booster Seats: 7- to 8-Year-Old Occupants in All Crashes (MAIS ≥ 2)

This section examined the effect of booster seats on reducing moderate to critical injuries experienced by the 7- to 8-year-old occupants in all crashes. The seat belts were used as the reference group of the booster seats, and the effect of booster seats on reducing moderate to critical injuries was compared with the effect of seat belts in the analysis.

The analytical data set in this section was specified from the entire NASS-CDS by using the domain variables in Section 3.2 and Section 4.6.1 and the domain variable of all crashes in Section 4.

The following contingency table shows the weighted frequencies, unweighted frequencies, weighted percentages, and standard errors of moderate to critical injuries experienced by the 7- to 8-year-old booster seat and seat belt users in all crashes:

Table 58. Type of Seat Restraints and Status of Moderate to Critical Injuries Experienced by 7- to 8-Year-Old Occupants in All Crashes

	Moderate to Critical Injuries	**None to Minor Injuries**	**Total**
Booster Seat	619.44 (3) 0.72% (0.63%)	84826 (77) 99.28% (0.63%)	85445 (80) 100%
Seat Belt	5588 (50) 1.66% (0.45%)	331944 (550) 98.34% (0.45%)	337532 (600) 100%

There are three booster seat users 7- to 8 years old in the analytical data set who experienced moderate to critical injuries in all crashes, and the weighted frequency of moderate to critical injuries experienced by the 7- to 8-year-old booster seat users is 619.44. The weighted percentage of moderate to critical injuries experienced by the booster seat users is 0.72 percent ((619.44 /85,445)*100%) with the standard error of 0.63 percent while the weighted percentage of moderate to critical injuries experienced by the 7- to 8-year-old seat belt users is 1.66 percent ((5,588/337,532)*100%) with the standard error of 0.45 percent. The weighted percentage of moderate to critical injuries experienced by the booster seat users (0.72%) is less than the weighted percentage of moderate to critical injuries experienced by the seat belt users (1.66%). The variation of experiencing moderate to critical injuries by the booster seat users is greater than the variation of experiencing moderate to critical injuries by the seat belt users, since the standard error in the booster seat users (0.63%) is greater than the standard error in the seat belt users (0.45%).

The effect of booster seats on reducing moderate to critical injuries experienced by the 7- to 8-year-old booster seat and seat belt users in all crashes was estimated by using the logistic regression analysis, and the effect of booster seats was compared with the effect of seat belts in the analysis. The status of moderate to critical injuries (MAIS2) in Section 3.5 was used as the dependent variable, and the driver's gender (MALE1), the driver age (AGE1), the crash mode (MODE), the occupant age (AGE2), the occupant seat position (CENTER), and the type of seat restraints (BOOSTERSEAT) in Section 3.5 were used as the independent variables in the logistic regression analysis.

The domain variables in Section 3.2 and Section 4.6.1 and the domain variable of all crashes in Section 4 were used in the SAS survey analysis procedure to specify the analytical data set from the entire NASS-CDS. This section used the SAS SURVEYLOGISTIC procedure with RATEGT as the weight, PSU as the cluster and PSU STRATA as the strata to perform the logistic regression analysis. The following table shows the estimated parameters of independent variables in the full logistic regression model:

Table 59. Full Logistic Regression Model: 7- to 8-Year-Old Booster Seat and Seat Belt Users Experienced Moderate to Critical Injuries in All Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_7_8=1 BOOSTER_SEATBELT=1 CRASH_GROUP=1

Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
MALE1=1	-0.6821	0.5889	-1.16	0.2648
AGE1	-0.00082	0.0217	-0.04	0.9703
MODE=FRONTAL	0.2414	0.8293	0.29	0.7749
MODE=REAR	-0.6477	1.0961	-0.59	0.5634
MODE=SIDE	-1.6378	0.6366	-2.57	0.0212*
AGE2	-0.0668	0.4514	-0.15	0.8844
CENTER=1	-1.3070	0.6716	-1.95	0.0706
BOOSTERSEAT=1	-0.5935	0.8743	-0.68	0.5076

The 7- to 8-year-old booster seat users might be less likely to experience moderate to critical injuries than the 7- to 8-year-old seat belt users, since the estimate of booster seat (BOOSTERSEAT=1) is negative (-0.5935). The 7- to 8-year-old booster seat and seat belt users in center seats might be significantly less likely to experience moderate to critical injuries than the 7- to 8-year-old booster seat and seat belt users in outboard seats, since the estimate of center seat (CENTER=1) is negative (-1.3070) with the p-value (0.0706) close to the significance level of 0.05. The 7- to 8-year-old booster seat and seat belt users might be significantly less likely to experience moderate to critical injuries in side-impact crashes than rollovers, since the estimate of side-impact crashes (MODE=SIDE) is negative (-1.6378) with the p-value (0.0212) less than the significance level of 0.05.

This section kept the type of seat restraints (BOOSTERSEAT) in the final logistic regression model and used the forward selection method to remove other independent variables that were not significant in the full logistic regression model. The following table shows the analysis results of the final logistic regression model:

Table 60. Final Logistic Regression Model: 7- to 8-Year-Old Booster Seat and Seat Belt Users Experienced Moderate to Critical Injuries in All Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_7_8=1 BOOSTER_SEATBELT=1 CRASH_GROUP=1

Global Model Test				
	F Test		P-value	
Likelihood Ratio	1.03		0.3782	
Score	106.31		<.0001	
Wald	13.79		0.0002	
Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
MODE=FRONTAL	0.1123	0.8872	0.13	0.9010
MODE=REAR	-0.6660	1.0458	-0.64	0.5338
MODE=SIDE	-1.5895	0.5799	-2.74	0.0152*
CENTER=1	-1.4919	0.6142	-2.43	0.0282*
BOOSTERSEAT=1	-0.6263	0.8847	-0.71	0.4898
Odds Ratio Estimate				
Independent Variable	Estimate		95% Confidence Interval	
MODE=FRONTAL	1.119		(0.169, 7.413)	
MODE=REAR	0.514		(0.055, 4.773)	
MODE=SIDE	0.204		(0.059, 0.702)	
CENTER=1	0.225		(0.061, 0.833)	
BOOSTERSEAT=1	0.535		(0.081, 3.523)	
Model Fitting Assessment				
C Statistics	0.508			

The final logistic regression model is not significant, since the p-value of the likelihood ratio test (0.3782) is greater than the significance level of 0.05. The C-statistic is 0.508, and the area under the ROC curve is 0.508 when the final logistic regression model uses the crash mode (MODE), the occupant seat position (CENTER) and the type of seat restraints (BOOSTERSEAT) as the independent variables. The final logistic regression model might not substantially fit the analytical data set.

The effect of center seats (CENTER=1) on reducing moderate to critical injuries is significant, since its p-value (0.0282) is less than the significance level of 0.05. The 7- to 8-year-old booster seat and seat belt users in center seats are significantly less likely to experience moderate to critical injuries than the 7- to 8-year-old booster seat and seat belt users in outboard seats, since the estimate of center seat (CENTER=1) is negative (-1.4919) with the p-value (0.0282) less than the significance level of 0.05.

The type of seat restraints (BOOSTERSEAT) is not significant, since its p-value (0.4898) is greater than the significance level of 0.05. The analysis results from NASS-CDS did not demonstrate that the booster seats were effective in reducing moderate to critical injuries experienced by the 7- to 8-year-old booster seat and seat belt users in all crashes. The driver's gender, the driver age and the occupant age are not significant, since their p-values are greater than the significance level of 0.05.

The occupant's seat position is considered as an important variable, since it might influence the effect of booster seats on reducing moderate to critical injuries. The ratio of the odds of experiencing moderate to critical injuries by the 7- to 8-year-old booster seat and seat belt users in center seats to the odds of experiencing moderate to critical injuries by the 7- to 8-year-old booster seat and seat belt users in outboard seats was estimated by applying Equation 1 and the final logistic regression model estimate of center seat (-1.4919).

$$\left(\frac{\text{Odds}|\text{Center Seat}}{\text{Odds}|\text{Outboard Seat}}\right) = \text{Odds Ratio} = \exp(-1.4919) = 0.225$$

The effect of center seats on reducing moderate to critical injuries experienced by the 7- to 8-year-old booster seat and seat belt users was estimated by using Equation 2.

$$\text{Effect of Center Seats} = \left(1 - \exp(-1.4919)\right) \cdot 100\% = 77.5\%$$

With other variables being held constant, the odds of experiencing moderate to critical injuries by the 7- to 8-year-old booster seat and seat belt users in center seats is 77.5 percent less than the odds of experiencing moderate to critical injuries by the 7- to 8-year-old booster seat and seat belt users in outboard seats. The estimated 95 percent confidence interval is between 16.7 percent ((1-0.833)*100%) and 93.9 percent ((1-0.061)*100%) based on the analytical data set from NASS-CDS.

The crash mode is significant, since the p-value of side-impact crash (0.0152) is less than the significance level of 0.05. The 7- to 8-year-old booster seat and seat belt users are significantly less likely to experience moderate to critical injuries in side-impact crashes than rollover events, since the estimate of side-impact crash (MODE=SIDE) is negative (-1.5895) with the p-value (0.0152) less than the significance level of 0.05.

The effect of booster seats on reducing moderate to critical injuries experienced by 7- to 8-year-old booster seat and seat belt users is significant in non-rollover crashes (see Section 4.6.1) but not in all crashes. Variations that are related to occupant injury severity in rollover events might influence the analysis results.

The effect of booster seats on reducing moderate to critical injuries is significant in the analytical data set of non-rollover crashes (see Section 4.6.1). Nevertheless, the effect of center seats on reducing moderate to critical injuries is significant in the analytical data set of all crashes (see Section 4.6.2). The distribution of occupant injury severity in rollovers is different from the distribution of occupant injury severity in non-rollover crashes.

4.7 Summary: Child Restraint System Effectiveness With Respect to Moderate to Critical Injuries (MAIS ≥ 2)

The NASS-CDS 1998-2015 was used to examine the effects of CRSs on reducing moderate to critical injuries experienced by the 1- to 8-year-old occupants. Injuries with MAIS ≥ 2 were considered as moderate to critical injuries. The effects of CRSs on reducing moderate to critical injuries were separately examined in the analytical data sets of non-rollover crashes and all crashes. Crashed vehicles in the analytical data set of non-rollover crashes experienced no rollovers while crashed vehicles in the analytical data set of all crashes experienced non-rollover crashes and/or rollovers.

The CRSs included the car seats and booster seats, and the car seat categories included the rear-facing and forward-facing car seats. The 1- to 8-year-old occupants were separated into different age groups. The effects of CRSs on reducing moderate to critical injuries experienced by the occupants in different age groups were separately examined in Section 4.1.1 to 4.6.2.

The effects of different types of CRSs on reducing moderate to critical injuries were estimated by using the logistic regression analysis. The SAS SURVEYLOGISTIC procedure was used to perform the logistic regression analysis. The logistic regression analysis also examined the effects of other independent variables that might be associated with occupant injury severity. The driver's gender, the driver age, the crash mode, the occupant age, and the occupant seat position were used as the independent variables in the logistic regression analysis.

This section summarized the effects of CRSs and occupant's seat position, since the occupant seat position might influence the effects of CRSs. The following summary shows the analysis results of occupants in different age groups.

Rear-Facing Car Seats: 1- to 3-Year-Old Occupants in Non-Rollover Crashes

The forward-facing car seats were used as the reference group of the rear-facing car seats. The effect of rear-facing car seats on reducing moderate to critical injuries experienced by the 1- to 3-year-old car seat users in non-rollover crashes was not significantly greater than the effect of forward-facing car seats based on the analysis results from NASS-CDS.

The occupant's seat position is significant. The following table shows the estimated effect of center seats on reducing moderate to critical injuries in non-rollover crashes:

Table 61. Center Seats on Reducing Moderate to Critical Injuries Experienced by 1- to 3-Year-Old Car Seat Users in Non-Rollover Crashes

Evaluated Group	Reference Group	Estimated Effect	95 % Confidence Interval
Center Seat	Outboard Seat	72.6%	(7.1%, 91.9%)

With other variables being held constant, the odds of experiencing moderate to critical injuries by the 1- to 3-year-old car seat users in center seats is 72.6 percent less than the odds of experiencing moderate to critical injuries by the 1- to 3-year-old car seat users in outboard seats. The estimated 95 percent confidence interval is between 7.1 percent and 91.9 percent based on the analytical data set from NASS-CDS.

Car Seats: 1- to 3-Year-Old Occupants in Non-Rollover Crashes

The booster seats were used as the reference group of the car seats. The effect of car seats on reducing moderate to critical injuries experienced by the 1- to 3-year-old CRS users in non-rollover crashes was not significantly greater than the effect of booster seats based on the analysis results from NASS-CDS.

The occupant’s seat position is significant. The following table shows the estimated effect of center seats on reducing moderate to critical injuries in non-rollover crashes:

Table 62. Center Seats on Reducing Moderate to Critical Injuries Experienced by 1- to 3-Year-Old Child Restraint System Users in Non-Rollover Crashes

Evaluated Group	**Reference Group**	**Estimated Effect**	**95 % Confidence Interval**
Center Seat	Outboard Seat	76.7%	(25.9%, 92.7%)

With other variables being held constant, the odds of experiencing moderate to critical injuries by the 1- to 3-year-old CRS users in center seats is 76.7 percent less than the odds of experiencing moderate to critical injuries by the 1- to 3-year-old CRS users in outboard seats. The estimated 95 percent confidence interval is between 25.9 percent and 92.7 percent based on the analytical data set from NASS-CDS.

Booster Seats: 4- to 8-Year-Old Occupants in All Crashes

The seat belts were used as the reference group of the booster seats. The effect of booster seats on reducing moderate to critical injuries experienced by the 4- to 8-year-old booster seat and seat belt users in all crashes was not significantly greater than the effect of seat belts based on the analysis results from NASS-CDS.

The occupant’s seat position is significant. The following table shows the estimated effect of center seats on reducing moderate to critical injuries in all crashes:

Table 63. Center Seats on Reducing Moderate to Critical Injuries Experienced by 4- to 8-Year-Old Booster Seat and Seat Belt Users in Non-Rollover Crashes

Evaluated Group	**Reference Group**	**Estimated Effect**	**95 % Confidence Interval**
Center Seat	Outboard Seat	72.2%	(8.6%, 91.5%)

With other variables being held constant, the odds of experiencing moderate to critical injuries by the 4- to 8-year-old booster seat and seat belt users in center seats is 72.2 percent less than the odds of experiencing moderate to critical injuries by the 4- to 8-year-old booster seat and seat belt users in outboard seats. The estimated 95 percent confidence interval is between 8.6 percent and 91.5 percent based on the analytical data set from NASS-CDS.

Booster Seats: 5- to 8-Year-Old Occupants in Non-Rollover Crashes

The seat belts were used as the reference group of the booster seats. The effect of booster seats on reducing moderate to critical injuries experienced by the 5- to 8-year-old booster seat and seat belt users in non-rollover crashes was significantly greater than the effect of seat belts based on the analysis results from NASS-CDS.

Table 64. Booster Seats on Reducing Moderate to Critical Injuries Experienced by 5- to 8-Year-Old Booster Seat and Seat Belt Users in Non-Rollover Crashes

Evaluated Group	Reference Group	Estimated Effect	95 % Confidence Interval
Booster Seat	Seat Belt	74.9%	(49.9%, 87.4%)

With other variables being held constant, the odds of experiencing moderate to critical injuries by the 5- to 8-year-old booster seat users is 74.9 percent less than the odds of experiencing moderate to critical injuries by the 5- to 8-year-old seat belt users. The estimated 95 percent confidence interval is between 49.9 percent and 87.4 percent based on the analytical data set from NASS-CDS.

<u>Booster Seats: 5- to 8-Year-Old Occupants in All Crashes</u>

The seat belts were used as the reference group of the booster seats. The effect of booster seats on reducing moderate to critical injuries experienced by the 5- to 8-year-old booster seat and seat belt users in all crashes was not significantly greater than the effect of seat belts based on the analysis results from NASS-CDS.

The occupant's seat position is significant. The following table shows the estimated effect of center seats on reducing moderate to critical injuries in all crashe:

Table 65. Center Seats on Reducing Moderate to Critical Injuries Experienced by 5- to 8-Year-Old Booster Seat and Seat Belt Users in All Crashes

Evaluated Group	Reference Group	Estimated Effect	95 % Confidence Interval
Center Seat	Outboard Seat	65.5%	(6.6%, 87.3%)

With other variables being held constant, the odds of experiencing moderate to critical injuries by the 5- to 8-year-old booster seat and seat belt users in center seats is 65.5 percent less than the odds of experiencing moderate to critical injuries by the 5- to 8-year-old booster seat and seat belt users in outboard seats. The estimated 95 percent confidence interval is between 6.6 percent and 87.3 percent based on the analytical data set from NASS-CDS.

<u>Booster Seats: 7- to 8-Year-Old Occupants in Non-rollover crashes</u>

The seat belts were used as the reference group of the booster seats. The effect of booster seats on reducing moderate to critical injuries experienced by the 7- to 8-year-old booster seat and seat belt users in non-rollover crashes was significantly greater than the effect of seat belts based on the analysis results from NASS-CDS.

Table 66. Booster Seats on Reducing Moderate to Critical Injuries Experienced by 7- to 8-Year-Old Booster Seat and Seat Belt Users in Non-Rollover Crashes

Evaluated Group	Reference Group	Estimated Effect	95 % Confidence Interval
Booster Seat	Seat Belt	85.6%	(22.2%, 97.3%)

With other variables being held constant, the odds of experiencing moderate to critical injuries by the 7- to 8-year-old booster seat users in non-rollover crashes is 85.6 percent less than the odds of experiencing moderate to critical injuries by the 7- to 8-year-old seat belt users. The estimated 95 percent confidence interval is between 22.2 percent and 97.3 percent based on the analytical data set from NASS-CDS.

Booster Seats: 7- to 8-Year-Old Occupants in All Crashes

The seat belts were used as the reference group of the booster seats. The effect of booster seats on reducing moderate to critical injuries experienced by the 7- to 8-year-old booster seat and seat belt users in all crashes was not significantly greater than the effect of seat based on the analysis results from NASS-CDS.

The occupant's seat position is significant. The following table shows the estimated effect of center seats on reducing moderate to critical injuries in all crashes:

Table 67. Center Seats on Reducing Moderate to Critical Injuries Experienced by 7- to 8-Year-Old Booster Seat and Seat Belt Users in All Crashes

Evaluated Group	Reference Group	Estimated Effect	95 % Confidence Interval
Center Seat	Outboard Seat	77.5%	(16.7%, 93.9%)

With other variables being held constant, the odds of experiencing moderate to critical injuries by the 7- to 8-year-old booster seat and seat belt users in center seats is 77.5 percent less than the odds of experiencing moderate to critical injuries by the 7- to 8-year-old booster seat and seat belt users in outboard seats. The estimated 95 percent confidence interval is between 16.7 percent and 93.9 percent based on the analytical data set from NASS-CDS.

5 Child Restraint System Effectiveness: Serious to Critical Injuries (MAIS ≥ 3)

The NASS-CDS 1998-2015 was used to examine the effects of CRSs on reducing serious to critical injuries experienced by the 1- to 8-year old occupants. Injuries with MAIS ≥ 3 were considered as serious to critical injuries in Section 5, and the status of serious to critical injuries (MAIS3) in Section 3.5 was used in the analysis.

The 1- to 8-year old occupants were separated into different age groups based on the evaluation topics in Table 2. The effects of CRSs on reducing serious to critical injuries experienced by the occupants in different age groups were separately examined in the analytical data sets of non-rollover crashes and all crashes in the following sections.

5.1.1 Rear-Facing Car Seats: 1- to 3-Year-Old Occupants in Non-Rollover Crashes (MAIS ≥ 3)

This section examines the effect of rear-facing car seats on reducing serious to critical injuries experienced by the 1- to 3-year-old occupants in non-rollover crashes. The forward-facing car seats were used as the reference group of the rear-facing car seats, and the effect of rear-facing car seats on reducing serious to critical injuries was compared with the effect of forward-facing car seats in the analysis. An infant occupant's age (less than 1 year) was recorded as zero in NASS-CDS, and the analytical data set in this section did not include occupants who were younger than 12 months.

The car seat categories included the rear-facing and forward-facing car seats, and the 1- to 3-year-old car seat users in non-rollover crashes were specified from the entire NASS-CDS by using the domain variables in Section 3.2 and Section 4.1.1 and the domain variable of non-rollover crashes in Section 4. The analytical data set in this section was the same as the analytical data set in Section 4.1.1 except the MAIS threshold of occupant injury severity. Injuries with MAIS ≥ 3 were considered as serious to critical injuries in this section while injuries with MAIS ≥ 2 were considered as moderate to critical injuries in Section 4.1.1. The analysis results that were not related to moderate to critical injuries in Section 4.1.1 can be applied to this section.

This section examined the same distribution of MAIS-coded injuries as did Section 4.1.1. The weighted percentage of serious to critical injuries experienced by the 1- to 3-year-old car seat users in non-rollover crashes is 0.48 percent (0.14%+0.32%+0.02%+0.00%, see Table 7 in Section 4.1.1) while the weighted percentage of none to moderate injuries experienced by the 1- to 3-year-old car seat users in non-rollover crashes is 99.52 percent (78.08%+21.13%+0.31%, see Table 7 in Section 4.1.1). The weighted percentage of serious to critical injuries (0.48%) is substantially less than the weighted percentage of none to moderate injuries (99.52%) in non-rollover crashes.

The weighted percentages of rear-facing and forward-facing car seat usages in Section 4.1.1 were applied to this section. The weighted percentage of rear-facing car seat usage in non-rollover crashes was 3.20 percent (see Table 8 in Section 4.1.1) while the weighted percentage of forward-facing car seat usage in non-rollover crashes was 96.80 percent (see Table 8 in Section 4.1.1). The 1- to 3-year-old car seat users who experienced non-rollover crashes used forward-facing car seats more frequently than rear-facing car seats.

The following contingency table shows the weighted frequencies, unweighted frequencies, weighted percentages, and standard errors of serious to critical injuries experienced by the 1- to 3-year-old rear-facing and forward-facing car seat users in non-rollover crashes:

Table 68. Type of Car Seats and Status of Serious to Critical Injuries Experienced by 1- to 3-Year-Old Occupants in Non-Rollover Crashes

	Serious to Critical Injuries	**None to Moderate Injuries**	**Total**
Rear-Facing Car Seat	96.42 (3) 0.78% (0.54%)	12,218 (50) 99.22% (0.54%)	12,314 (53) 100%
Forward-Facing Car Seat	1,752 (16) 0.47% (0.18%)	371,056 (702) 99.53% (0.18%)	372,808 (718) 100%

There are three rear-facing car seat users 1- to 3 years old in the analytical data set who experienced serious to critical injuries in non-rollover crashes, and the weighted frequency of serious to critical injuries experienced by the 1- to 3-year-old rear-facing car seat users is 96.42. The weighted percentage of serious to critical injuries experienced by the rear-facing car seat users is 0.78 percent ((96.42/12,314)*100%) with the standard error of 0.54 percent while the weighted percentage of serious to critical injuries experienced by the forward-facing car seat users is 0.47 percent ((1,752/372,808)*100%) with the standard error of 0.18 percent. The weighted percentage of serious to critical injuries experienced by the rear-facing car seat users (0.78%) is greater than the weighted percentage of serious to critical injuries experienced by the forward-facing car seat users (0.47%). The variation of experiencing serious to critical injuries by the rear-facing car seat users is greater than the variation of experiencing serious to critical injuries by the forward-facing car seat users, since the standard error in the rear-facing car seat users (0.54%) is greater than the standard error in the forward-facing car seat users (0.18%).

The effect of rear-facing car seats on reducing serious to critical injuries experienced by the 1- to 3-year-old car seat users in non-rollover crashes was estimated by using the logistic regression analysis, and the effect of rear-facing car seats was compared with the effect of forward-facing car seats in the analysis. The status of serious to critical injuries (MAIS3) in Section 3.5 was used as the dependent variable, and the driver's gender (MALE1), the driver age (AGE1), the non-rollover crash mode (MODE_COLL), the occupant age (AGE2), the occupant seat position (CENTER), and the type of car seats (REAR_CARSEAT) in Section 3.5 were used as the independent variables in the logistic regression analysis.

The domain variables in Section 3.2 and Section 4.1.1 and the domain variable of non-rollover crashes in Section 4 were used in the SAS survey analysis procedure to specify the analytical data set from the entire NASS-CDS. This section used the SAS SURVEYLOGISTIC procedure with ratio inflation factor (RATEGT) as the weight, PSU as the cluster and PSU STRATA as the strata to perform the logistic regression analysis. The following table shows the estimated parameters of independent variables in the full logistic regression model:

Table 69. Full Logistic Regression Model: 1- to 3-Year-Old Car Seat Users Experienced Serious to Critical Injuries in Non-Rollover Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_1_3=1 CARSEAT_USER=1 COLLISION_GROUP=1

Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
MALE1=1	-1.3575	0.3975	-3.42	0.0038*
AGE1	0.0689	0.0376	1.83	0.0869
MODE_COLL=REAR	-0.1417	0.7741	-0.18	0.8572
MODE_COLL=SIDE	0.6093	0.7389	0.82	0.4225
AGE2	0.1324	0.3512	0.38	0.7115
CENTER=1	-0.7374	1.0203	-0.72	0.4810
REAR_CARSEAT=1	0.2243	1.1821	0.19	0.8521

The 1- to 3-year-old rear-facing car seat users might not be less likely to experience serious to critical injuries than the 1- to 3-year-old forward-facing car seat users, since the estimate of rear-facing car seat (REAR_CARSEAT=1) is positive (0.2243). The 1- to 3-year-old car seat users in center seats might be less likely to experience serious to critical injuries than the 1- to 3-year-old car seat users in outboard seats, since the estimate of center seat (CENTER=1) is negative (-0.7374). The car seat users who traveled with a male driver might be significantly less likely to experience serious to critical injuries than the car seat users who traveled with a female driver, since the estimate of male driver (MALE1=1) is negative (-1.3575) with the p-value (0.0038) less than the significance level of 0.05.

This section kept the type of car seats (REAR_CARSEAT) in the final logistic regression model and used the forward selection method to remove other independent variables that were not significant in the full logistic regression model. The following table shows the analysis results of the final logistic regression model:

Table 70. Final Logistic Regression Model: 1- to 3-Year-Old Car Seat Users Experienced Serious to Critical Injuries in Non-Rollover Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_1_3=1 CARSEAT_USER=1 COLLISION_GROUP=1

Global Model Test				
	F Test		P-value	
Likelihood Ratio	0.48		0.5420	
Score	9.09		0.0029	
Wald	3.84		0.0467	
Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
MALE1=1	-1.1389	0.4136	-2.75	0.0148*
REAR_CARSEAT=1	0.4304	0.8085	0.53	0.6022
Odds Ratio Estimate				
Independent Variable	Estimate		95% Confidence Interval	
MALE1=1	0.320		(0.133, 0.773)	
REAR_CARSEAT=1	1.538		(0.275, 8.616)	
Model Fitting Assessment				
C Statistics	0.534			

The final logistic regression model is not significant, since the p-value of the likelihood ratio test (0.5420) is greater than the significance level of 0.05. The C-statistic is 0.534, and the area under the ROC curve is 0.534 when the final logistic regression model uses the type of car seats (REAR_CARSEAT) and the driver's gender (MALE1) as the independent variables. The final logistic regression model might not substantially fit the analytical data set.

The 1- to 3-year-old car seat users who traveled with a male driver are significantly less likely to experience serious to critical injuries than the 1- to 3-year-old car seat users who traveled with a female driver, since the estimate of male driver (MALE1=1) is negative (-1.1389) with the p-value (0.0148) less than the significance level of 0.05. The driver's gender in the final logistic regression model might present effects of other variables that were associated with the driver's gender and occupant injury severity. For example, the car seat installation influenced the effect of car seats on reducing serious to critical injuries, and male drivers might be more likely to properly install car seats than female drivers.

The type of car seats (REAR_CARSEAT) is not significant, since its p-value (0.6022) is greater than the significance level of 0.05. The analysis results from NASS-CDS did not demonstrate that the rear-facing car seats were effective in reducing serious to critical injuries experienced by the 1- to 3-year-old car seat users in non-rollover crashes. Driver age, the non-rollover crash mode, the occupant age, and the occupant seat position are not significant, since their p-values are greater than the significance level of 0.05.

5.1.2 Rear-Facing Car Seats: 1- to 3-Year-Old Occupants in All Crashes (MAIS ≥ 3)

This section examined the effect of rear-facing car seats on reducing serious to critical injuries experienced by the 1- to 3-year-old occupants in all crashes. The forward-facing car seats were used as the reference group of the rear-facing car seats, and the effect of rear-facing car seats on reducing serious to critical injuries was compared with the effect of forward-facing car seats in the analysis.

The analytical data set in this section was specified from the entire NASS-CDS by using the domain variables in Section 3.2 and Section 4.1.1 and the domain variable of all crashes in Section 4.

The following contingency table shows the weighted frequencies, unweighted frequencies, weighted percentages, and standard errors of serious to critical injuries experienced by the 1- to 3-year-old rear-facing and forward-facing car seat users in all crashes:

Table 71. Type of Car Seats and Status of Serious to Critical Injuries Experienced by 1- to 3-Year-Old Occupants in All Crashes

	Serious to Critical Injuries	**None to Moderate Injuries**	**Total**
Rear-Facing Car Seat	96.42 (3) 0.74% (0.50%)	12936 (55) 99.26% (0.50%)	13032 (58) 100%
Forward-Facing Car Seat	2123 (23) 0.53% (0.17%)	399340 (811) 99.47% (0.17%)	401463 (834) 100%

There are three 1- to 3-year-old rear-facing car seat users in the analytical data set who experienced serious to critical injuries in all crashes, and the weighted frequency of serious to critical injuries experienced by the 1- to 3-year-old rear-facing car seat users is 96.42. The weighted percentage of serious to critical injuries experienced by the rear-facing car seat users is 0.74 percent ((96.42/13,032)*100%) with the standard error of 0.50 percent while the weighted percentage of serious to critical injuries experienced by the 1- to 3-year-old forward-facing car seat users is 0.53 percent ((2,123/401,463)*100%) with the standard error of 0.17 percent. The weighted percentage of serious to critical injuries experienced by the rear-facing car seat users (0.74%) is greater than the weighted percentage of serious to critical injuries experienced by the forward-facing car seat users (0.53%). The variation of experiencing serious to critical injuries by the rear-facing car seat users is greater than the variation of experiencing serious to critical injuries by the forward-facing car seat users, since the standard error in the rear-facing car seat users (0.50%) is greater than the standard error in the forward-facing car seat users (0.17%).

The effect of rear-facing car seats on reducing serious to critical injuries experienced by the 1- to 3-year-old car seat users in all crashes was estimated by using the logistic regression analysis, and the effect of rear-facing car seats was compared with the effect of forward-facing car seats in the analysis. The status of serious to critical injuries (MAIS3) in Section 3.5 was used as the dependent variable, and the driver's gender (MALE1), the driver age (AGE1), the crash mode (MODE), the occupant age (AGE2), the occupant seat position (CENTER), and the type of car seats (REAR_CARSEAT) in Section 3.5 were used as the independent variables in the logistic regression analysis.

The domain variables in Section 3.2 and Section 4.1.1 and the domain variable of all crashes in Section 4 were used in the SAS survey analysis procedure to specify the analytical data set from the entire NASS-CDS. This section used the SAS SURVEYLOGISTIC procedure with RATEGT as the weight, PSU as the cluster and PSU STRATA as the strata to perform the logistic regression analysis. The following table shows the estimated parameters of independent variables in the full logistic regression model:

Table 72. Full Logistic Regression Model: 1- to 3-Year-Old Car Seat Users Experienced Serious to Critical Injuries in All Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_1_3=1 CARSEAT_USER=1 CRASH _GROUP=1

Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
MALE1=1	-1.2715	0.4314	-2.95	0.0100*
AGE1	0.0717	0.0331	2.17	0.0467*
MODE=FRONTAL	-1.2927	0.6999	-1.85	0.0846
MODE=REAR	-1.4542	0.6406	-2.27	0.0384*
MODE =SIDE	-0.6973	0.8825	-0.79	0.4418
AGE2	0.3376	0.3186	1.06	0.3061
CENTER=1	-0.1262	0.8103	-0.16	0.8783
REAR_CARSEAT=1	0.3105	1.1137	0.28	0.7842

The 1- to 3-year-old rear-facing car seat users might not be less likely to experience serious to critical injuries than the 1- to 3-year-old forward-facing car seat users, since the estimate of rear-facing car seat (REAR_CARSEAT=1) is positive (0.3105). The 1- to 3-year-old car seat users in center seats might be less likely to experience serious to critical injuries than the 1- to 3-year-old car seat users in outboard seats, since the estimate of center seat (CENTER=1) is negative (-0.1262).

The 1- to 3-year-old car seat users who traveled with a male driver might be significantly less likely to experience serious to critical injuries than the 1- to 3-year-old car seat users who traveled with a female driver, since the estimate of male driver (MALE1=1) is negative (-1.2715) with the p-value (0.0100) less than the significance level of 0.05. The likelihood of experiencing serious to critical injuries by the 1- to 3-year-old car seat users might significantly increase when the driver age increases, since the estimate of driver age (AGE1) is positive (0.0717) with the p-value (0.0467) less than the significance level of 0.05. The 1- to 3-year-old car seat users might be significantly less likely to experience serious to critical injuries in rear-impact non-rollover crashes than rollovers, since the estimate of rear-impact crash mode (MODE=REAR) is negative (-1.4542) with the p-value (0.0384) less than the significance level of 0.05.

This section kept the type of car seats (REAR_CARSEAT) in the final logistic regression model and used the forward selection method to remove other independent variables that were not significant in the full logistic regression model. The following table shows the analysis results of the final logistic regression model:

Table 73. Final Logistic Regression Model: 1- to 3-Year-Old Car Seat Users Experienced Serious to Critical Injuries in All Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_1_3=1 CARSEAT_USER=1 CRASH _GROUP=1

Global Model Test				
	F Test		P-value	
Likelihood Ratio	1.01		0.4021	
Score	11.73		0.0005	
Wald	3.94		0.0277	
Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
MALE1=1	-1.2729	0.4122	-3.09	0.0075*
AGE1	0.0707	0.0306	2.31	0.0352*
MODE=FRONTAL	-1.1866	0.6138	-1.93	0.0723
MODE=REAR	-1.4262	0.6004	-2.38	0.0313*
MODE=SIDE	-0.6414	0.8100	-0.79	0.4408
REAR_CARSEAT=1	0.0882	1.0875	0.08	0.9364
Odds Ratio Estimate				
Independent Variable	Estimate		95% Confidence Interval	
MALE1=1	0.280		(0.116, 0.674)	
AGE1	1.073		(1.006, 1.146)	
MODE=FRONTAL	0.305		(0.083, 1.130)	
MODE=REAR	0.240		(0.067, 0.864)	
MODE=SIDE	0.527		(0.094, 2.960)	
REAR_CARSEAT=1	1.092		(0.108, 11.091)	
Model Fitting Assessment				
C Statistics	0.589			

The final logistic regression model is not significant, since the p-value of the likelihood ratio test (0.4021) is greater than the significance level of 0.05. The C-statistic is 0.589, and the area under the ROC curve is 0.589 when the final logistic regression model uses the driver’s gender (MALE1), the driver age (AGE1), the crash mode (MODE), and the type of car seats (REAR_CARSEAT) as the independent variables. The final logistic regression model might not substantially fit the analytical data set.

The type of car seats (REAR_CARSEAT) is not significant, since its p-value (0.9364) is greater than the significance level of 0.05. The analysis results from NASS-CDS did not demonstrate that the rear-facing car seats were effective in reducing serious to critical injuries experienced by the 1- to 3-year-old car seat users in all crashes. Occupant age and the occupant seat position are not significant, since their p-values are greater than the significance level of 0.05.

The driver’s gender (MALE1) is significant, since its p-value (0.0075) is less than the significance level of 0.05. The 1- to 3-year-old car seat users who traveled with a male driver is significantly less likely to experience serious to critical injuries in all crashes than the 1- to 3-year-old car seat users who traveled with a female driver, since the estimate of male driver

(MALE1=1) is negative (-1.2729) with the p-value (0.0075) less than the significance level of 0.05. Driver age (AGE1) is significant, since its p-value (0.0352) is less than the significance level of 0.05. The odds of experiencing serious to critical injuries by the 1- to 3-year-old car seat users significantly increases when the driver age increases, since the estimate of driver age (AGE1) is positive (0.0707) with the p-value (0.0352) less than the significance level of 0.05. The crash mode is significant, since the p-value of rear-impact crash (0.0313) is less than the significance level of 0.05. The 1- to 3-year-old car seat users are significantly less likely to experience serious to critical injuries in rear-impact crashes than rollover events, since the estimate of rear-impact crashes (MODE=REAR) is negative (-1.4262) with the p-value (0.0313) less than the significance level of 0.05.

The effect of male drivers is significant in the analytical data sets of non-rollover crashes (see Section 5.1.1) and all crashes (see Section 5.1.2). The driver's gender is an important factor in serious to critical injuries experienced by 1- to 3-year-old car seat users.

5.2.1 Car Seats: 1- to 3-Year-Old Occupants in Non-Rollover Crashes (MAIS ≥ 3)

This section examined the effect of car seats on reducing serious to critical injuries experienced by the 1- to 3-year-old occupants in non-rollover crashes. The booster seats were used as the reference group of the car seats, and the effect of car seats on reducing serious to critical injuries was compared with the effect of booster seats in the analysis. An infant occupant's age (less than 1 year) was recorded as zero in NASS-CDS, and the analytical data set in this section did not include occupants younger than 12 months. The CRSs included the car seats and booster seats, and the 1- to 3-year-old CRS users in non-rollover crashes were specified from the entire NASS-CDS by using the domain variables in Section 3.2 and Section 4.2.1 and the domain variable of non-rollover crashes in Section 4. The analytical data set in this section was the same as the analytical data set in Section 4.2.1 except the MAIS threshold of occupant injury severity. Injuries with MAIS ≥ 3 were considered as serious to critical injuries in this section while injuries with MAIS ≥ 2 were considered as moderate to critical injuries in Section 4.2.1. The analysis results that were not related to moderate to critical injuries in Section 4.2.1 can be applied to this section.

This section examined the same distribution of MAIS-coded injuries as did Section 4.2.1. The weighted percentage of serious to critical injuries experienced by the 1- to 3-year-old CRS users in non-rollover crashes is 0.49 percent (0.21%+0.26%+0.02 %+0.00%, see Table 15 in Section 4.2.1) while the weighted percentage of none to moderate injuries experienced by the 1- to 3-year-old CRS users in non-rollover crashes is 99.51 percent (77.49%+21.61%+0.41%, see Table 15 in Section 4.2.1). The weighted percentage of serious to critical injuries (0.49%) is substantially less than the weighted percentage of none to moderate injuries (99.51%) in non-rollover crashes.

The weighted percentages of car seat and booster seat usages in Section 4.2.1 were applied to this section. The weighted percentage of car seat usage in non-rollover crashes was 84.35 percent (see Table 16 in Section 4.2.1) while the weighted percentage of booster seat usage in non-rollover crashes was 15.65 percent (see Table 16 in Section 4.2.1). The 1- to 3-year-old occupants who experienced non-rollover crashes used car seats more frequently than booster seats.

The following contingency table shows the weighted frequencies, unweighted frequencies, weighted percentages, and standard errors of serious to critical injuries experienced by the 1- to 3-year-old car seat and booster seat users in non-rollover crashes:

Table 74. Type of Child Restraint Systems and Status of Serious to Critical Injuries Experienced by 1- to 3-Year-Old Occupants in Non-Rollover Crashes

	Serious to Critical Injuries	**None to Moderate Injuries**	**Total**
Car Seat	1,849 (19) 0.47% (0.17%)	395,166 (779) 99.53% (0.17%)	39,7015 (798) 100%
Booster Seat	492.56 (9) 0.67% (0.35%)	73,185 (133) 99.33% (0.35%)	73,677 (142) 100%

There are nineteen 1- to 3-year-old car seat users in the analytical data set who experienced serious to critical injuries in non-rollover crashes, and the weighted frequency of serious to critical injuries experienced by the 1- to 3-year-old car seat users is 1,849. The weighted percentage of serious to critical injuries experienced by the car seat users is 0.47 percent ((1,849/397,015)*100%) with the standard error of 0.17 percent while the weighted percentage of serious to critical injuries experienced by the booster seat users is 0.67 percent ((492.56/73,677)*100%) with the standard error of 0.35 percent. The weighted percentage of serious to critical injuries experienced by the car seat users (0.47%) is less than the weighted percentage of serious to critical injuries experienced by the booster seat users (0.67%). The variation of experiencing serious to critical injuries by the car seat users is less than the variation of experiencing serious to critical injuries by the booster seat users, since the standard error in the car seat users (0.17%) is less than the standard error in the booster seat users (0.35%).

The effect of car seats on reducing serious to critical injuries experienced by the 1- to 3-year-old CRS users in non-rollover crashes was estimated by using the logistic regression analysis, and the effect of car seats was compared with the effect of booster seats in the analysis. The status of serious to critical injuries (MAIS3) in Section 3.5 was used as the dependent variable, and the driver's gender (MALE1), the driver age (AGE1), the non-rollover crash mode (MODE_COLL), the occupant age (AGE2), the occupant seat position (CENTER), and the type of CRS (CARSEAT) in Section 3.5 were used as the independent variables in the logistic regression analysis.

The domain variables in Section 3.2 and Section 4.2.1 and the domain variable of non-rollover crashes in Section 4 were used in the SAS survey analysis procedure to specify the analytical data set from the entire NASS-CDS. This section used the SAS SURVEYLOGISTIC procedure with ratio inflation factor (RATEGT) as the weight, PSU as the cluster and PSU STRATA as the strata to perform the logistic regression analysis. The following table shows the estimated parameters of independent variables in the full logistic regression model:

Table 75. Full Logistic Regression Model: 1- to 3-Year-Old Child Restraint System Users Experienced Serious to Critical Injuries in Non-Rollover Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_1_3=1 CRS_USER=1 COLLISION_GROUP=1

Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
MALE1=1	-0.7389	0.5404	-1.37	0.1917
AGE1	0.0734	0.0325	2.26	0.0392*
MODE_COLL=REAR	-0.3634	0.6731	-0.54	0.5972
MODE_COLL=SIDE	0.4555	0.6746	0.68	0.5099
AGE2	0.2567	0.3427	0.75	0.4654
CENTER=1	-0.8012	1.0024	-0.80	0.4366
CARSEAT=1	-0.0517	0.6993	-0.07	0.9421

The 1- to 3-year-old car seat users might be less likely to experience serious to critical injuries than the 1- to 3-year-old booster seat users, since the estimate of car seat (CARSEAT=1) is negative (-0.0517). The 1- to 3-year-old CRS users in center seats might be less likely to experience serious to critical injuries than the 1- to 3-year-old CRS users in outboard seats, since the estimate of center seat (CENTER=1) is negative (-0.8012).The likelihood of experiencing serious to critical injuries by the 1- to 3-year-old CRS users might significantly increase when the driver age increases, since the estimate of driver age (AGE1) is positive (0.0734) with the p-value (0.0392) less than the significance level of 0.05.

This section kept the type of CRS (CARSEAT) in the final logistic regression model and used the forward selection method to remove other independent variables that were not significant in the full logistic regression model. The following table shows the analysis results of the final logistic regression model:

Table 76. Final Logistic Regression Model: 1- to 3-Year-Old Child Restraint System Users Experienced Serious to Critical Injuries in Non-Rollover Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_1_3=1 CRS_USER=1 COLLISION_GROUP=1

Global Model Test				
	F Test		P-value	
Likelihood Ratio	2.18		0.1307	
Score	1.81		0.2005	
Wald	2.82		0.0936	
Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
AGE1	0.0719	0.0320	2.25	0.0399*
CARSEAT=1	-0.4900	0.6102	-0.80	0.4344
Odds Ratio Estimate				
Independent Variable	Estimate		95% Confidence Interval	
AGE1	1.075		(1.004, 1.150)	

CARSEAT=1	0.613	(0.167, 2.249)
Model Fitting Assessment		
C Statistics	0.566	

The final logistic regression model is not significant, since the p-values of the likelihood ratio test (0.1307), the score test (0.2005) and the Wald test (0.0936) are greater than the significance level of 0.05. The C-statistic is 0.566, and the area under the ROC curve is 0.566 when the final logistic regression model uses the driver age (AGE1) and the type of CRS (CARSEAT) as the independent variables. The final logistic regression model might not substantially fit the analytical data set.

The odds of experiencing serious to critical injuries by the 1- to 3-year-old CRS users significantly increases when the driver age increases, since the estimate of driver age (AGE1) is positive (0.0719) with the p-value (0.0399) less than the significance level of 0.05. Experience in the CRS installation might be associated with the driver age, since the older drivers might be less familiar with the CRS installation than the younger drivers. Klinich et al.[24] in 2012 indicated that the people with less experience in the car seat installation were significantly less likely to install car seats with sufficient tightness and snug hardness than the people with more experience in the car seat installation. The type of CRS (CARSEAT) is not significant, since its p-value (0.4344) is greater than the significance level of 0.05. The analysis results from NASS-CDS did not demonstrate that the car seats were effective in reducing serious to critical injuries in non-rollover crashes. The driver's gender, the non-rollover crash mode, the occupant age, and the occupant seat position are not significant, since their p-values are greater than the significance level of 0.05.

5.2.2 Car Seats: 1- to 3-Year-Old Occupants in All Crashes (MAIS ≥ 3)

This section examined the effect of car seats on reducing serious to critical injuries experienced by the 1- to 3-year-old occupants in all crashes. The booster seats were used as the reference group of the car seats, and the effect of car seats on reducing serious to critical injuries was compared with the effect of booster seats in the analysis.

The analytical data set in this section was specified from the entire NASS-CDS by using the domain variables in Section 3.2 and Section 4.2.1 and the domain variable of all crashes in Section 4.

The following contingency table shows the weighted frequencies, unweighted frequencies, weighted percentages, and standard errors of serious to critical injuries experienced by the 1- to 3-year-old CRS users in all crashes:

[24] Klinich, K. D., Manary, M. A., Flannagan, C. A. C., Ebert-Hamilton, S., Malik, L. A., Green, P. A., & Reed, M. P. (2012, July). Labels, instructions, and features of convertible child restraint systems (CRS): Evaluating their effect on CRS installation errors (Report No. DOT HS 811 627). National Highway Traffic Safety Administration. Available at www.nhtsa.gov/sites/nhtsa.dot.gov/files/811627.pdf

Table 77. Type of Child Restraint Systems and Status of Serious to Critical Injuries Experienced by 1- to 3-Year-Old Occupants in All Crashes

	Serious to Critical Injuries	**None to Moderate Injuries**	**Total**
Car Seat	2,219 (26) 0.52% (0.17%)	424,169 (893) 99.48% (0.17%)	426,389 (919) 100%
Booster Seat	492.56 (9) 0.64% (0.33%)	76,722 (153) 99.36% (0.33%)	77,215 (162) 100%

There are twenty-six 1- to 3-year-old car seat users in the analytical data set who experienced serious to critical injuries in all crashes, and the weighted frequency of serious to critical injuries experienced by the 1- to 3-year-old car seat users is 2,219. The weighted percentage of serious to critical injuries experienced by the car seat users is 0.52 percent ((2,219/426,389)*100%) with the standard error of 0.17 percent while the weighted percentage of serious to critical injuries experienced by the 1- to 3-year-old booster seat users is 0.64 percent ((492.56 /77,215)*100%) with the standard error of 0.33 percent. The weighted percentage of serious to critical injuries experienced by the car seat users (0.52%) is less than the weighted percentage of serious to critical injuries experienced by the booster seat users (0.64%). The variation of experiencing serious to critical injuries by the car seat users is less than the variation of experiencing serious to critical injuries by the booster seat users, since the standard error in the car seat users (0.17%) is less than the standard error in the booster seat users (0.33%).

The effect of car seats on reducing serious to critical injuries experienced by the 1- to 3-year-old CRS users in all crashes was estimated by using the logistic regression analysis, and the effect of car seats was compared with the effect of booster seats in the analysis. The status of serious to critical injuries (MAIS3) in Section 3.5 was used as the dependent variable, and the driver's gender (MALE1), the driver age (AGE1), the crash mode (MODE), the occupant age (AGE2), the occupant seat position (CENTER), and the type of CRS (CARSEAT) in Section 3.5 were used as the independent variables in the logistic regression analysis.

The domain variables in Section 3.2 and Section 4.2.1 and the domain variable of all crashes in Section 4 were used in the SAS survey analysis procedure to specify the analytical data set from the entire NASS-CDS. This section used the SAS SURVEYLOGISTIC procedure with RATEGT as the weight, PSU as the cluster and PSU STRATA as the strata to perform the logistic regression analysis. The following table shows the estimated parameters of independent variables in the full logistic regression model:

Table 78. Full Logistic Regression Model: 1- to 3-Year-Old Child Restraint System Users Experienced Serious to Critical Injuries in All Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_1_3=1 CRS_USER=1 CRASH _GROUP=1

Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
MALE1=1	-0.7614	0.5305	-1.44	0.1717
AGE1	0.0747	0.0290	2.57	0.0213*

Parameter Estimate				
MODE=FRONTAL	-1.0963	0.5831	-1.88	0.0797
MODE=REAR	-1.4751	0.6280	-2.35	0.0330*
MODE =SIDE	-0.6259	0.7797	-0.80	0.4347
AGE2	0.4124	0.3106	1.33	0.2041
CENTER=1	-0.2304	0.7657	-0.30	0.7676
CARSEAT=1	0.1049	0.6520	0.16	0.8743

The 1- to 3-year-old car seat users might not be less likely to experience serious to critical injuries than the 1- to 3-year-old booster seat users, since the estimate of car seat (CARSEAT=1) is positive (0.1049). The 1- to 3-year-old CRS users in center seats might be less likely to experience serious to critical injuries than the 1- to 3-year-old CRS users in outboard seats, since the estimate of center seat (CENTER=1) is negative (-0.2304).

The likelihood of experiencing serious to critical injuries by the 1- to 3-year-old CRS users might increase when the driver age increases, since the estimate of driver age (AGE1) is positive (0.0747) with the p-value (0.0213) less than the significance level of 0.05. The 1- to 3-year-old CRS users might be significantly less likely to experience serious to critical injuries in rear-impact non-rollover crashes than rollovers, since the estimate of rear-impact crash mode (MODE=REAR) is negative (-1.4751) with the p-value (0.0330) less than the significance level of 0.05.

This section kept the type of CRS (CARSEAT) in the final logistic regression model and used the forward selection method to remove other independent variables that were not significant in the full logistic regression model. The following table shows the analysis results of the final logistic regression model:

Table 79. Final Logistic Regression Model: 1- to 3-Year-Old Child Restraint System Users Experienced Serious to Critical Injuries in All Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_1_3=1 CRS_USER=1 CRASH _GROUP=1

Global Model Test				
	F Test		P-value	
Likelihood Ratio	1.14		0.3456	
Score	2.11		0.1409	
Wald	2.34		0.1116	
Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
AGE1	0.0717	0.0283	2.53	0.0230*
MODE=FRONTAL	-1.0182	0.5285	-1.93	0.0732
MODE=REAR	-1.4257	0.5798	-2.46	0.0266*
MODE=SIDE	-0.4965	0.7449	-0.67	0.5152
CARSEAT=1	-0.2557	0.6036	-0.42	0.6778
Odds Ratio Estimate				
Independent Variable	Estimate		95% Confidence Interval	
AGE1	1.074		(1.011, 1.141)	

MODE=FRONTAL	0.361	(0.117, 1.114)
MODE=REAR	0.240	(0.070, 0.827)
MODE=SIDE	0.609	(0.124, 2.978)
CARSEAT=1	0.774	(0.214, 2.803)
Model Fitting Assessment		
C Statistics	0.541	

The final logistic regression model is not significant, since the p-values of the likelihood ratio test (0.3456), the score test (0.1409) and the Wald test (0.1116) are greater than the significance level of 0.05. The C-statistic is 0.541, and the area under the ROC curve is 0.541 when the final logistic regression model uses the driver age (AGE1), the crash mode (MODE) and the type of CRS (CARSEAT) as the independent variables. The final logistic regression model might not substantially fit the analytical data set.

The type of CRS (CARSEAT) is not significant, since its p-value (0.6778) is greater than the significance level of 0.05. The analysis results from NASS-CDS did not demonstrate that the car seats were effective in reducing serious to critical injuries experienced by the 1- to 3-year-old CRS users in all crashes. The driver's gender, the occupant age and the occupant seat position are not significant, since their p-values are greater than the significance level of 0.05.

Driver age (AGE1) is significant, since its p-value (0.0230) is less than the significance level of 0.05. The odds of experiencing serious to critical injuries by the 1- to 3-year-old CRS users significantly increases when the driver age increases, since the estimate of driver age (AGE1) is positive (0.0717) with the p-value (0.0230) less than the significance level of 0.05. The crash mode is significant, since the p-value of rear-impact crash (0.0266) is less than the significance level of 0.05. The 1- to 3-year-old CRS users are significantly less likely to experience serious to critical injuries in rear-impact crashes than rollover events, since the estimate of rear-impact crashes (MODE=REAR) is negative (-1.4257) with the p-value (0.0266) less than the significance level of 0.05.

The effect of driver age is significant in the analytical data sets of non-rollover crashes (see Section 5.2.1) and all crashes (see Section 5.2.2). Driver age is an important factor in serious to critical injuries experienced by 1- to 3-year-old CRS users.

5.3.1 Car Seats: 3- to 5-Year-Old Occupants in Non-Rollover Crashes (MAIS ≥ 3)

This section examined the effect of car seats on reducing serious to critical injuries experienced by the 3- to 5-year-old occupants in non-rollover crashes. The booster seats were used as the reference group of the car seats, and the effect of car seats on reducing serious to critical injuries was compared with the effect of booster seats in the analysis.

The CRSs included the car seats and booster seats, and the 3- to 5-year-old CRS users in non-rollover crashes were specified from the entire NASS-CDS by using the domain variables in Section 3.2 and Section 4.3.1 and the domain variable of non-rollover crashes in Section 4. The analytical data set in this section was the same as the analytical data set in Section 4.3.1 except the MAIS threshold of occupant injury severity. Injuries with MAIS ≥ 3 were considered as serious to critical injuries in this section while injuries with MAIS ≥ 2 were considered as moderate to critical injuries in Section 4.3.1. The analysis results that were not related to moderate to critical injuries in Section 4.3.1 can be applied to this section.

This section examined the same distribution of MAIS-coded injuries as did Section 4.3.1. The weighted percentage of serious to critical injuries experienced by the 3- to 5-year-old CRS users in non-rollover crashes is 0.87 percent (0.76%+0.10%+0.01%+0%, see Table 23 in Section 4.3.1) while the weighted percentage of none to moderate injuries experienced by the 3- to 5-year-old CRS users in non-rollover crashes is 99.13 percent (72.86%+26.06%+0.21%, see Table 23 in Section 4.3.1). The weighted percentage of serious to critical injuries (0.87%) is substantially less than the weighted percentage of none to moderate injuries (99.13%) in non-rollover crashes.

The weighted percentages of car seat and booster seat usages in Section 4.3.1 were applied to this section. The weighted percentage of car seat usage was 38.66 percent (see Table 24 in Section 4.3.1) while the weighted percentage of booster seat usage was 61.34 percent (see Table 24 in Section 4.3.1). The 3- to 5-year-old occupants who experienced non-rollover crashes used booster seats more frequently than car seats.

The following contingency table shows the weighted frequencies, unweighted frequencies, weighted percentages, and standard errors of serious to critical injuries experienced by the 3- to 5-year-old car seat and booster seat users in non-rollover crashes:

Table 80. Type of Child Restraint Systems and Status of Serious to Critical Injuries Experienced by 3- to 5-Year-Old Occupants in Non-Rollover Crashes

	Serious to Critical Injuries	**None to Moderate Injuries**	**Total**
Car Seat	518.03 (8) 0.39% (0.16%)	132036 (277) 99.61% (0.16%)	132554 (285) 100%
Booster Seat	2508 (13) 1.19% (0.85%)	207843 (355) 98.81% (0.85%)	210350 (368) 100%

There are eight 3- to 5-year-old car seat users in the analytical data set who experienced serious to critical injuries in non-rollover crashes, and the weighted frequency of serious to critical injuries experienced by the 3- to 5-year-old car seat users is 518.03. The weighted percentage of serious to critical injuries experienced by the car seat users is 0.39 percent ((518.03/132554)*100%) with the standard error of 0.16 percent while the weighted percentage of serious to critical injuries experienced by the booster seat users is 1.19 percent ((2508/210350)*100%) with the standard error of 0.85 percent. The weighted percentage of serious to critical injuries experienced by the car seat users (0.39%) is less than the weighted percentage of serious to critical injuries experienced by the booster seat users (1.19%). The variation of experiencing serious to critical injuries by the car seat users is less than the variation of experiencing serious to critical injuries by the booster seat users, since the standard error in the car seat users (0.16%) is less than the standard error in the booster seat users (0.85%).

The effect of car seats on reducing serious to critical injuries experienced by the 3- to 5-year-old CRS users in non-rollover crashes was estimated by using the logistic regression analysis, and the effect of car seats was compared with the effect of booster seats in the analysis. The status of serious to critical injuries (MAIS3) in Section 3.5 was used as the dependent variable, and the driver's gender (MALE1), the driver age (AGE1), the non-rollover crash mode (MODE_COLL), the occupant age (AGE2), the occupant seat position (CENTER), and the type of CRS (CARSEAT) in Section 3.5 were used as the independent variables in the logistic regression analysis.

The domain variables in Section 3.2 and Section 4.3.1 and the domain variable of non-rollover crashes in Section 4 were used in the SAS survey analysis procedure to specify the analytical data set from the entire NASS-CDS. This section used the SAS SURVEYLOGISTIC procedure with ratio inflation factor (RATEGT) as the weight, PSU as the cluster and PSU STRATA as the strata to perform the logistic regression analysis. The following table shows the estimated parameters of independent variables in the full logistic regression model:

Table 81. Full Logistic Regression Model: 3- to 5-Year-Old Child Restraint System Users Experienced Serious to Critical Injuries in Non-Rollover Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_3_5=1 CRS_USER=1 COLLISION_GROUP=1

Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
MALE1=1	-1.3479	0.3788	-3.56	0.0029*
AGE1	-0.0370	0.0906	-0.41	0.6885
MODE_COLL=REAR	-0.6731	0.9414	-0.71	0.4856
MODE_COLL=SIDE	-1.0985	1.0576	-1.04	0.3154
AGE2	-0.2480	0.2420	-1.02	0.3217
CENTER=1	-0.3855	1.3516	-0.29	0.7794
CARSEAT=1	-1.2643	0.8013	-1.58	0.1355

The 3- to 5-year-old car seat users might be less likely to experience serious to critical injuries than the 3- to 5-year-old booster seat users, since the estimate of car seat (CARSEAT=1) is negative (-1.2643). The 3- to 5-year-old CRS users in center seats might be less likely to experience serious to critical injuries than the 3- to 5-year-old CRS users in outboard seats, since the estimate of center seat (CENTER=1) is negative (-0.3855). The CRS users who traveled with a male driver might be significantly less likely to experience serious to critical injuries than the CRS users who traveled with a female driver, since the estimate of male driver (MALE1=1) is negative (-1.3479) with the p-value (0.0029) less than the significance level of 0.05.

This section kept the type of CRS (CARSEAT) in the final logistic regression model and used the forward selection to remove other independent variables that were not significant in the full logistic regression model. The following table shows the analysis results of the final logistic regression model:

Table 82. Final Logistic Regression Model: 3- to 5-Year-Old Child Restraint System Users Experienced Serious to Critical Injuries in Non-Rollover Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_3_5=1 CRS_USER=1 COLLISION_GROUP=1

Global Model Test				
	F Test		P-value	
Likelihood Ratio	2.33		0.1509	
Score	5.22		0.0202	
Wald	5.44		0.0179	
Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
MALE1=1	-1.2893	0.3914	-3.29	0.0049*
CARSEAT=1	-1.2225	0.8240	-1.48	0.1586
Odds Ratio Estimate				
Independent Variable	Estimate		95% Confidence Interval	
MALE1=1	0.275		(0.120, 0.634)	
CARSEAT=1	0.294		(0.051, 1.705)	
Model Fitting Assessment				
C Statistics	0.524			

The final logistic regression model is not significant, since the p-value of the likelihood ratio test (0.1509) is greater than the significance level of 0.05. The C-statistic is 0.524, and the area under the ROC curve is 0.524 when the final logistic regression model uses the driver's gender (MALE1) and the type of CRS (CARSEAT) as the independent variables. The final logistic regression model might not substantially fit the analytical data set.

The 3- to 5-year-old CRS users who traveled with a male driver are significantly less likely to experience serious to critical injuries than the 3- to 5-year-old CRS users who traveled with a female driver, since the estimate of male driver (MALE1=1) is negative (-1.2893) with the p-value (0.0049) less than the significance level of 0.05. The estimated effect of male drivers on reducing serious to critical injuries might include effects of other variables that were not included in the logistic regression model. For example, the driving habits might be associated with occupant injury severity, and the driving habits of male drivers are different from the driving habits of female drivers when traveling with 3- to 5-year-old occupants.

The type of CRS (CARSEAT) is not significant, since its p-value (0.1586) is greater than the significance level of 0.05. The analysis results from NASS-CDS did not demonstrate that the car seats were effective in reducing serious to critical injuries in non-rollover crashes. Driver age, the non-rollover crash mode, the occupant age, and the occupant seat position are not significant, since their p-values are greater than the significance level of 0.05.

5.3.2 Car Seats: 3- to 5-Year-Old Occupants in All Crashes (MAIS ≥ 3)

This section examined the effect of car seats on reducing serious to critical injuries experienced by the 3- to 5-year-old occupants in all crashes. The booster seats were used as the reference group of the car seats, and the effect of car seats on reducing serious to critical injuries was compared with the effect of booster seats in the analysis.

The analytical data set in this section was specified from the entire NASS-CDS by using the domain variables in Section 3.2 and Section 4.3.1 and the domain variable of all crashes in Section 4.

The following contingency table shows the weighted frequencies, unweighted frequencies, weighted percentages, and standard errors of serious to critical injuries experienced by the 3- to 5-year-old CRS users in all crashes:

Table 83. Type of Child Restraint Systems and Status of Serious to Critical Injuries Experienced by 3- to 5-Year-Old Occupants in All Crashes

	Serious to Critical Injuries	**None to Moderate Injuries**	**Total**
Car Seat	732.58 (10) 0.51% (0.19%)	143799 (319) 99.49% (0.19%)	144532 (329) 100%
Booster Seat	2807 (18) 1.30% (0.82%)	212414 (387) 98.70% (0.82%)	215220 (405) 100%

There are ten 3- to 5-year-old car seat users in the analytical data set who experienced serious to critical injuries in all crashes, and the weighted frequency of serious to critical injuries experienced by the 3- to 5-year-old car seat users is 732.58. The weighted percentage of serious to critical injuries experienced by the car seat users is 0.51 percent ((732.58/144532)*100%) with the standard error of 0.19 percent while the weighted percentage of serious to critical injuries experienced by the 3- to 5-year-old booster seat users is 1.30 percent ((2807/215220)*100%) with the standard error of 0.82 percent. The weighted percentage of serious to critical injuries experienced by the car seat users (0.51%) is less than the weighted percentage of serious to critical injuries experienced by the booster seat users (1.30%). The variation of experiencing serious to critical injuries by the car seat users is less than the variation of experiencing serious to critical injuries by the booster seat users, since the standard error in the car seat users (0.19%) is less than the standard error in the booster seat users (0.82%).

The effect of car seats on reducing serious to critical injuries experienced by the 3- to 5-year-old CRS users in all crashes was estimated by using the logistic regression analysis, and the effect of car seats was compared with the effect of booster seats in the analysis. The status of serious to critical injuries (MAIS3) in Section 3.5 was used as the dependent variable, and the driver's gender (MALE1), the driver age (AGE1), the crash mode (MODE), the occupant age (AGE2), the occupant seat position (CENTER), and the type of CRS (CARSEAT) in Section 3.5 were used as the independent variables in the logistic regression analysis.

The domain variables in Section 3.2 and Section 4.3.1 and the domain variable of all crashes in Section 4 were used in the SAS survey analysis procedure to specify the analytical data set from the entire NASS-CDS. This section used the SAS SURVEYLOGISTIC procedure with RATEGT as the weight, PSU as the cluster and PSU STRATA as the strata to perform the logistic regression analysis. The following table shows the estimated parameters of independent variables in the full logistic regression model:

Table 84. Full Logistic Regression Model: 3- to 5-Year-Old Child Restraint System Users Experienced Serious to Critical Injuries in All Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_3_5=1 CRS_USER=1 CRASH_GROUP=1

Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
MALE1=1	-1.2967	0.3571	-3.63	0.0025*
AGE1	-0.0267	0.0761	-0.35	0.7301
MODE=FRONTAL	-1.2823	0.7517	-1.71	0.1087
MODE=REAR	-2.0042	0.6699	-2.99	0.0091*
MODE =SIDE	-2.3689	0.7786	-3.04	0.0082*
AGE2	-0.1789	0.1950	-0.92	0.3735
CENTER=1	-0.1060	1.0162	-0.10	0.9183
CARSEAT=1	-1.2179	0.5985	-2.03	0.0599

The 3- to 5-year-old car seat users might be significantly less likely to experience serious to critical injuries than the 3- to 5-year-old booster seat users, since the estimate of car seat (CARSEAT=1) is negative (-1.2179) with the p-value (0.0599) close to the significance level of 0.05. The 3- to 5-year-old CRS users in center seats might be less likely to experience serious to critical injuries than the 3- to 5-year-old CRS users in outboard seats, since the estimate of center seat (CENTER=1) is negative (-0.1060).

The 3- to 5-year-old CRS users who traveled with a male driver might be significantly less likely to experience serious to critical injuries than the 3- to 5-year-old CRS users who traveled with a female driver, since the estimate of male driver (MALE1=1) is negative (-1.2967) with the p-value (0.0025) less than the significance level of 0.05. The 3- to 5-year-old CRS users might be significantly less likely to experience serious to critical injuries in rear-impact non-rollover crashes than rollovers, since the estimate of rear-impact crash mode (MODE=REAR) is negative (-2.0042) with the p-value (0.0091) less than the significance level of 0.05. The 3- to 5-year-old CRS users might be significantly less likely to experience serious to critical injuries in side-impact non-rollover crashes than rollovers, since the estimate of side-impact crash mode (MODE=SIDE) is negative (-2.3689) with the p-value (0.0082) less than the significance level of 0.05.

This section kept the type of CRS (CARSEAT) in the final logistic regression model and used the forward selection method to remove other independent variables that were not significant in the full logistic regression model. The following table shows the analysis results of the final logistic regression model:

Table 85. Final Logistic Regression Model: 3- to 5-Year-Old Child Restraint System Users Experienced Serious to Critical Injuries in All Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_3_5=1 CRS_USER=1 CRASH_GROUP=1

Global Model Test				
	F Test		P-value	
Likelihood Ratio	1.26		0.2997	
Score	3.09		0.0551	
Wald	13.59		0.0002	
Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
MALE1=1	-1.4076	0.4509	-3.12	0.0070*
MODE=FRONTAL	-1.3164	0.7277	-1.81	0.0906
MODE=REAR	-2.1861	0.6459	-3.38	0.0041*
MODE=SIDE	-2.3781	0.7339	-3.24	0.0055*
CARSEAT=1	-1.1641	0.6879	-1.69	0.1113
Odds Ratio Estimate				
Independent Variable	Estimate		95% Confidence Interval	
MALE1=1	0.245		(0.094, 0.640)	
MODE=FRONTAL	0.268		(0.057, 1.265)	
MODE=REAR	0.112		(0.028, 0.445)	
MODE=SIDE	0.093		(0.019, 0.443)	
CARSEAT=1	0.312		(0.072, 1.353)	
Model Fitting Assessment				
C Statistics	0.562			

The final logistic regression model is not significant, since the p-values of the likelihood ratio test (0.2997) and the score test (0.0551) are greater than the significance level of 0.05. The C-statistic is 0.562, and the area under the ROC curve is 0.562 when the final logistic regression model uses the driver's gender (MALE1), the crash mode (MODE) and the type of CRS (CARSEAT) as the independent variables. The final logistic regression model might not substantially fit the analytical data set.

The type of CRS (CARSEAT) is not significant, since its p-value (0.1113) is greater than the significance level of 0.05. The analysis results from NASS-CDS did not demonstrate that the car seats were effective in reducing serious to critical injuries experienced by the 3- to 5-year-old CRS users in all crashes. Driver age, the occupant age and the occupant seat position are not significant, since their p-values are greater than the significance level of 0.05.

The driver's gender (MALE1) is significant, since its p-value (0.0070) is less than the significance level of 0.05. The 3- to 5-year-old CRS users who traveled with a male driver is significantly less likely to experience serious to critical injuries than the 3- to 5-year-old CRS users who traveled with a female driver, since the estimate of male driver (MALE1=1) is negative (-1.4076) with the p-value (0.0070) less than the significance level of 0.05. The crash mode is significant, since the p-values of rear-impact crash (MODE=REAR) and side-impact crash (MODE=SIDE) are less than the significance level of 0.05 (0.0041 in rear-impact crash and 0.0055 in side-impact crash). The 3- to 5-year-old CRS users are significantly less likely to experience serious to critical injuries in rear-impact and side-impact crashes than rollover events, since the estimates of rear-impact crashes (MODE=REAR) and side-impact crashes (MODE=SIDE) are negative (-2.1861 in rear-impact crash and -2.3781 in side-impact crash) with the p-values less than the significance level of 0.05 (0.0041 in rear-impact crash and 0.0055 in side-impact crash).The effect of male drivers is significant in the analytical data sets of non-rollover crashes (see Section 5.3.1) and all crashes (see Section 5.3.2). The driver's gender is an important factor in serious to critical injuries experienced by 3- to 5-year-old child restraint seat users.

5.4.1 Booster Seats: 4- to 8-Year-Old Occupants in Non-Rollover Crashes (MAIS ≥ 3)

This section examined the effect of booster seats on reducing serious to critical injuries experienced by the 4- to 8-year-old occupants in non-rollover crashes. The seat belts were used as the reference group of the booster seats, and the effect of booster seats on reducing serious to critical injuries was compared with the effect of seat belts in the analysis.

The 4- to 8-year-old booster seat and seat belt users were specified from the entire NASS-CDS by using the domain variables in Section 3.2 and Section 4.4.1 and the domain variable of non-rollover crashes in Section 4. The analytical data set in this section was the same as the analytical data set in Section 4.4.1 except the MAIS threshold of occupant injury severity. Injuries with MAIS ≥ 3 were considered as serious to critical injuries in this section while injuries with MAIS ≥ 2 were considered as moderate to critical injuries in Section 4.4.1. The analysis results that were not related to moderate to critical injuries in Section 4.4.1 can be applied to this section.

This section examined the same distribution of MAIS-coded injuries as did Section 4.4.1. The weighted percentage of serious to critical injuries experienced by the 4- to 8-year-old booster seat and seat belt users in non-rollover crashes is 0.41 percent (0.35%+0.01%+0.04%+0.01%, see Table 35 in Section 4.4.1) while the weighted percentage of none to moderate injuries experienced by the 4- to 8-year-old booster seat and seat belt users in non-rollover crashes is 99.58 percent (75.84%+23.11%+0.63%, see Table 35 in Section 4.4.1). The weighted percentage of serious to critical injuries (0.41%) is substantially less than the weighted percentage of none to moderate injuries (99.58 %) in non-rollover crashes.

The weighted percentages of booster seat and seat belt usages in Section 4.4.1 were applied to this section. The weighted percentage of booster seat usage was 28.39 percent (see Table 36 in Section 4.4.1) while the weighted percentage of seat belt usage was 71.61 percent (see Table 36 in Section 4.4.1). The 4- to 8-year-old occupants who experienced non-rollover crashes used seat belts more frequently than booster seats.

The following contingency table shows the weighted frequencies, unweighted frequencies, weighted percentages, and standard errors of serious to critical injuries experienced by the 4- to 8-year-old booster seat and seat belt users in non-rollover crashes:

Table 86. Type of Seat Restraints and Status of Serious to Critical Injuries Experienced by 4- to 8-Year-Old Occupants in Non-Rollover Crashes

	Serious to Critical Injuries	**None to Moderate Injuries**	**Total**
Booster Seat	2073 (7) 0.86% (0.69%)	238898 (428) 99.14% (0.69%)	240971 (435) 100%
Seat Belt	1448 (37) 0.24% (0.07%)	606329 (1059) 99.76% (0.07%)	607777 (1096) 100%

There are seven booster seat users 4- to 8 years old in the analytical data set who experienced serious to critical injuries in non-rollover crashes, and the weighted frequency of serious to critical injuries experienced by the 4- to 8-year-old booster seat users is 2073. The weighted percentage of serious to critical injuries experienced by the booster seat users is 0.86 percent ((2,073/240,971)*100%) with the standard error of 0.69 percent while the weighted percentage of serious to critical injuries experienced by the seat belt users is 0.24 percent ((1,448/607,777)*100%) with the standard error of 0.07 percent. The weighted percentage of serious to critical injuries experienced by the booster seat users (0.86%) is greater than the weighted percentage of serious to critical injuries experienced by the seat belt users (0.24%). The variation of experiencing serious to critical injuries by the booster users is greater than the variation of experiencing serious to critical injuries by the seat belt users, since the standard error in the booster seat users (0.69%) is greater than the standard error in the seat belt users (0.07%).

The weighted percentage of serious to critical injuries experienced by the booster seat users in Table 86 might be impacted by sampling weights, and this section examined the weighted percentage of serious to critical injuries experienced by the booster seat users at each age from four to eight. The following contingency table shows the weighted frequency, unweighted frequency, weighted percentage, and standard errors of serious to critical injuries experienced by the booster seat users at each age from four to eight:

Table 87. Occupant's Age and Status of Serious to Critical Injuries Experienced by 4- to 8-Year-Old Booster Seat Users in Non-Rollover Crashes

Age of Booster Seat User	**Serious to Critical Injuries**	**None to Minor Injuries**	**Total**
4	2,157 (7) 1.25% (1.07%)	170,217 (258) 98.75% (1.07%)	172,374 (265) 100%
5	268.29 (9) 0.18% (0.06%)	152,421 (311) 99.82% (0.06%)	152,689 (320) 100%
6	174.09 (7) 0.09% (0.08%)	194,065 (333) 99.91% (0.08%)	194,239 (340) 100%
7	292.74 (6) 0.17% (0.06%)	170,953 (324) 99.83% (0.06%)	171,246 (330) 100%
8	628.40 (15) 0.40% (0.08%)	157,572 (261) 99.60% (0.08%)	158,200 (276) 100%

There are seven booster seat users 4 years old in the analytical data set who experienced serious to critical injuries, and the weighted frequency of serious to critical injuries experienced by the 4-year-old booster seat users is 2,157. The weighted percentage of serious to critical injuries experienced by the 4-year-old booster seat users is 1.25 percent ((2,157/172,374)*100%) with the standard error of 1.07 percent while the weighted percentage of serious to critical injuries experienced by the 5-year-old booster seat users is 0.18 percent ((268.29/152,689)*100%) with the standard error of 0.06 percent. The variation of experiencing serious to critical injuries by the 4-year-old booster seat users is greater than the variations of experiencing serious to critical injuries by the booster seat users at the other ages in Table 87, since the standard error in 4-year-old booster seat users (1.07%) is greater than the standard errors in booster seat users at the other ages in Table 87 (0.06% at age 5, 0.08% at age 6, 0.06% at age 7, and 0.08% at age 8). The variation of experiencing serious to critical injuries by the 4-year-old booster seat users was impacted by the sampling weights, since the CV of sampling weights of 4-year-old booster seat users (256.98%, see Table 39 in Section 4.4.1) is greater than the CVs of sampling weights of the booster seat users at the other ages (173.70% at age 5, 137.81% at age 6, 163.29% at age 7, and 91.61% at age 8, see Table 39 in Section 4.4.1).

The effect of booster seats on reducing serious to critical injuries experienced by the 4- to 8-year-old booster seat and seat belt users in non-rollover crashes was estimated by using the logistic regression analysis, and the effect of booster seats was compared with the effect of seat belts in the analysis. The status of serious to critical injuries (MAIS3) in Section 3.5 was used as the dependent variable, and the driver's gender (MALE1), the driver age (AGE1), the non-rollover crash mode (MODE_COLL), the occupant age (AGE2), the occupant seat position (CENTER), and the type of seat restraints (BOOSTERSEAT) in Section 3.5 were used as the independent variables in the logistic regression analysis.

The domain variables in Section 3.2 and Section 4.4.1 and the domain variable of non-rollover crashes in Section 4 were used in the SAS survey analysis procedure to specify the analytical data set from the entire NASS-CDS. This section used the SAS SURVEYLOGISTIC procedure with ratio inflation factor (RATEGT) as the weight, PSU as the cluster and PSU STRATA as the strata to perform the logistic regression analysis. The following table shows the estimated parameters of independent variables in the full logistic regression model:

Table 88. Full Logistic Regression Model: 4- to 8-Year-Old Booster Seat and Seat Belt Users Experienced Serious to Critical Injuries in Non-Rollover Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_4_8=1 BOOSTER_SEATBELT=1 COLLISION_GROUP=1

Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
MALE1=1	-0.8038	0.8014	-1.00	0.3318
AGE1	-0.0651	0.1015	-0.64	0.5305
MODE_COLL=REAR	-0.8887	1.0099	-0.88	0.3927
MODE_COLL=SIDE	-1.4052	0.9751	-1.44	0.1701
AGE2	-0.2137	0.2523	-0.85	0.4103
CENTER=1	-0.6412	0.4843	-1.32	0.2053
BOOSTERSEAT=1	0.9471	0.7546	1.26	0.2286

The 4- to 8-year-old booster seat users might not be less likely to experience serious to critical injuries than the 4- to 8-year-old seat belt users, since the estimate of booster seat (BOOSTERSEAT=1) is positive (0.9471). The 4- to 8-year-old booster seat and seat belt users in center seats might be less likely to experience serious to critical injuries than the 4- to 8-year-old booster seat and seat belt users in outboard seats, since the estimate of center seat (CENTER=1) is negative (-0.6412).

This section kept the type of seat restraints (BOOSTERSEAT) in the final logistic regression model and used the forward selection method to remove other independent variables that were not significant in the full logistic regression model. Nevertheless, forward selection failed to produce a logistic regression model that included significant independent variables, since the sampling weights of the 4-year-old booster seat users inflated the estimated variance and impacted the significance of the analysis results.

Candidate logistic regression models were selected to examine the effects of independent variables on occupant injury severity. The C-statistics was used as the model selection criterion, since a logistic regression model fits the analytical data set better when the value of C-statistics increases. Appendix C listed the values of C-statistics of the logistic regression models that used a single or a combination of the independent variables in Section 3.5. The logistic regression models with the top four greatest values of C-statistics in Appendix C were selected as the candidate logistic regression models. The following table shows the values of C-statistics and the independent variables that were used in the candidate logistic regression models:

Table 89. Candidate Logistic Regression Models in ***Appendix C***

Independent Variables	C-statistics
MALE1 AGE1 BOOSTERSEAT	0.463
MALE1 AGE1 CENTER BOOSTERSEAT	0.467
AGE1 MODE_COLL CENTER BOOSTERSEAT	0.471
MALE1 AGE1 AGE2 CENTER BOOSTERSEAT	0.472

The C-statistic of the logistic regression model that used the driver's gender (MALE1), the driver age (AGE1) and the type of seat restraints (BOOSTERSEAT) as the independent variables is 0.463. The candidate logistic regression models in Table 89 have similar prediction performances, since their values of C-statistics are close. The logistic regression model that used the driver's gender (MALE1), the driver age (AGE1) and the type of seat restraints (BOOSTERSEAT) as the independent variables was selected as the final logistic regression model, since a logistic regression model with small number of independent variables is more easily to be interpreted than a logistic regression model with a large number of independent variables. The following table shows the estimated parameters of independent variables in the full logistic regression model:

Table 90. Final Logistic Regression Model: 4- to 8-Year-Old Booster Seat and Seat Belt Users Experienced Serious to Critical Injuries in Non-Rollover Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_4_8=1 BOOSTER_SEATBELT=1 COLLISION_GROUP=1

Global Model Test				
	F Test		P-value	
Likelihood Ratio	1.20		0.3129	
Score	1.76		0.2049	
Wald	1.18		0.3540	
Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
MALE1	-0.6280	0.7687	-0.82	0.4267
AGE1	-0.0719	0.1012	-0.71	0.4886
BOOSTERSEAT=1	1.4100	1.0290	1.37	0.1908
Odds Ratio Estimate				
Independent Variable	Estimate		95% Confidence Interval	
MALE1	0.534		(0.104, 2.747)	
AGE1	0.931		(0.750, 1.155)	
BOOSTERSEAT=1	4.096		(0.457, 36.719)	
Model Fitting Assessment				
C Statistics	0.463			

The final logistic regression model is not significant, since the p-values of the likelihood ratio test (0.3129), the score test (0.2049) and the Wald test (0.3540) are greater than the significance level of 0.05. The C-statistic is 0.463, and the area under the ROC curve is 0.463 when the final logistic regression model uses the driver's gender (MALE1), the driver age (AGE1) and the type of seat restraints (BOOSTERSEAT) as the independent variables. The final logistic regression model might not substantially fit the analytical data set.

The 4- to 8-year-old booster seat and seat belt users who traveled with a male driver might be less likely to experience serious to critical injuries than the 4- to 8-year-old booster seat and seat belt users who traveled with a female driver, since the estimate of male driver (MALE1=1) is negative (-0.6280). The likelihood of experiencing serious to critical injuries by the 4- to 8-year-old booster seat and seat belt users might increase when the driver age increases, since the estimate of driver age (AGE1) is negative (-0.0719).

The type of seat restraints (BOOSTERSEAT) is not significant, since its p-value (0.1908) is greater than the significance level of 0.05. The analysis results from NASS-CDS did not demonstrate that the booster seats were effective in reducing serious to critical injuries in non-rollover crashes.

Table 39 in Section 4.4.1 and Table 87 in this section showed that the sampling weights of the 4-year-old booster seat users impacted the standard error of experiencing serious to critical injuries by the 4- to 8-year-old booster seat users in non-rollover crashes. The sampling weights of the 4-year-old booster seat users also influenced the significance of the analysis results. Section 4.5.1 avoided the impact of sampling weights of the 4-year-old booster seat users by using the 5- to 8-

year-old booster seat and seat belt users to estimate the effect of booster seats on reducing serious to critical injuries in non-rollover crashes.

5.4.2 Booster Seats: 4- to 8-Year-Old Occupants in All Crashes (MAIS ≥ 3)

This section examined the effect of booster seats on reducing serious to critical injuries experienced by the 4- to 8-year-old occupants in all crashes. The seat belts were used as the reference group of the booster seats, and the effect of booster seats on reducing serious to critical injuries was compared with the effect of seat belts in the analysis.

The analytical data set in this section was specified from the entire NASS-CDS by using the domain variables in Section 3.2 and Section 4.4.1 and the domain variable of all crashes in Section 4.

The following contingency table shows the weighted frequencies, unweighted frequencies, weighted percentages, and standard errors of serious to critical injuries experienced by the 4- to 8-year-old booster seat and seat belt users in all crashes:

Table 91. Type of Seat Restraints and Status of Serious to Critical Injuries Experienced by 4- to 8-Year-Old Occupants in All Crashes

	Serious to Critical Injuries	**None to Moderate Injuries**	**Total**
Booster Seat	2,372 (12) 0.84% (0.59%)	281,565 (469) 99.16% (0.59%)	283,937 (481) 100%
Seat Belt	1,951 (45) 0.28% (0.09%)	682,939 (1188) 99.72% (0.09%)	684,890 (1233) 100%

There are 12 booster seat users 4- to 8 years old in the analytical data set who experienced serious to critical injuries in all crashes, and the weighted frequency of serious to critical injuries experienced by the 4- to 8-year-old booster seat users is 2,372. The weighted percentage of serious to critical injuries experienced by the booster seat users is 0.84 percent ((2,372/283,937)*100%) with the standard error of 0.59 percent while the weighted percentage of serious to critical injuries experienced by the 4- to 8-year-old seat belt users is 0.28 percent ((1,951/684,890)*100%) with the standard error of 0.09 percent. The weighted percentage of serious to critical injuries experienced by the booster seat users (0.84%) is greater than the weighted percentage of serious to critical injuries experienced by the seat belt users (0.28%). The variation of experiencing serious to critical injuries by the booster seat users is greater than the variation of experiencing serious to critical injuries by the seat belt users, since the standard error in the booster seat users (0.59%) is greater than the standard error in the seat belt users (0.09%).

The effect of booster seats on reducing serious to critical injuries experienced by the 4- to 8-year-old booster seat and seat belt users in all crashes was estimated by using the logistic regression analysis, and the effect of booster seats was compared with the effect of seat belts in the analysis. The status of serious to critical injuries (MAIS3) in Section 3.5 was used as the dependent variable, and the driver's gender (MALE1), the driver age (AGE1), the crash mode (MODE), the occupant age (AGE2), the occupant seat position (CENTER), and the type of seat restraints (BOOSTERSEAT) in Section 3.5 were used as the independent variables in the logistic regression analysis.

The domain variables in Section 3.2 and Section 4.4.1 and the domain variable of all crashes in Section 4 were used in the SAS survey analysis procedure to specify the analytical data set from the entire NASS-CDS. This section used the SAS SURVEYLOGISTIC procedure with RATEGT as the weight, PSU as the cluster and PSU STRATA as the strata to perform the logistic regression analysis. The following table shows the estimated parameters of independent variables in the full logistic regression model:

Table 92. Full Logistic Regression Model: 4- to 8-Year-Old Booster Seat and Seat Belt Users Experienced Serious to Critical Injuries in All Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_4_8=1 BOOSTER_SEATBELT=1 CRASH_GROUP=1

Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
MALE1=1	-0.6375	0.5612	-1.14	0.2738
AGE1	-0.0364	0.0697	-0.52	0.6092
MODE=FRONTAL	-1.0093	0.4425	-2.28	0.0376*
MODE=REAR	-1.9332	0.9580	-2.02	0.0619
MODE =SIDE	-2.3498	0.6741	-3.49	0.0033*
AGE2	-0.3493	0.1224	-2.85	0.0121*
CENTER=1	-1.0943	0.5415	-2.02	0.0615
BOOSTERSEAT=1	0.7911	0.6528	1.21	0.2443

The 4- to 8-year-old booster seat users might not be less likely to experience serious to critical injuries than the 4- to 8-year-old seat belt users, since the estimate of booster seat (BOOSTERSEAT=1) is positive (0.7911). The 4- to 8-year-old booster seat and seat belt users in center seats might be significantly less likely to experience serious to critical injuries than the 4- to 8-year-old booster seat and seat belt users in outboard seats, since the estimate of center seat (CENTER=1) is negative (-1.0943) with the p-value close to the significance level of 0.05.

The 4- to 8-year-old booster seat and seat belt users might be significantly less likely to experience serious to critical injuries in frontal-impact non-rollover crashes than rollovers, since the estimate of frontal-impact crash mode (MODE=FRONTAL) is negative (-1.0093) with the p-value (0.0376) less than the significance level of 0.05. The 4- to 8-year-old booster seat and seat belt users might be significantly less likely to experience serious to critical injuries in side-impact non-rollover crashes than rollovers, since the estimate of side-impact crash mode (MODE=SIDE) is negative (-2.3498) with the p-value (0.0033) less than the significance level of 0.05. The likelihood of experiencing serious to critical injuries by the 4- to 8-year-old booster seat and seat belt users might be significantly decrease when the occupant age increases, since the estimate of occupant's age is negative (-0.3493) with the p-value (0.0121) less than the significance level of 0.05.

This section kept the type of seat restraints (BOOSTERSEAT) in the final logistic regression model and used the forward selection method to remove other independent variables that were not significant in the full logistic regression model. The following table shows the analysis results of the final logistic regression model:

Table 93. Final Logistic Regression Model: 4- to 8-Year-Old Booster Seat and Seat Belt Users Experienced Serious to Critical Injuries in All Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_4_8=1 BOOSTER_SEATBELT=1 CRASH_GROUP=1

Global Model Test				
	F Test		P-value	
Likelihood Ratio	0.63		0.5669	
Score	5.99		0.0069	
Wald	3.76		0.0331	
Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
MODE=FRONTAL	-0.1284	0.9929	-0.13	0.8988
MODE=REAR	-1.1521	1.1653	-0.99	0.3385
MODE=SIDE	-1.2961	0.4203	-3.08	0.0076*
BOOSTERSEAT=1	0.9636	0.7774	1.24	0.2342
Odds Ratio Estimate				
Independent Variable	Estimate		95% Confidence Interval	
MODE=FRONTAL	0.879		(0.106, 7.300)	
MODE=REAR	0.316		(0.026, 3.787)	
MODE=SIDE	0.274		(0.112, 0.670)	
BOOSTERSEAT=1	2.621		(0.500, 13.743)	
Model Fitting Assessment				
C Statistics	0.475			

The final logistic regression model is not significant, since the p-value of the likelihood ratio test (0.5669) is greater than the significance level of 0.05. The C-statistic is 0.475, and the area under the ROC curve is 0.475 when the final logistic regression model uses the crash mode (MODE) and the type of seat restraints (BOOSTERSEAT) as the independent variables. The final logistic regression model might not substantially fit the analytical data set.

The type of seat restraints (BOOSTERSEAT) is not significant, since its p-value (0.2342) is greater than the significance level of 0.05. The analysis results from NASS-CDS did not demonstrate that the booster seats were effective in reducing serious to critical injuries experienced by the 4- to 8-year-old booster seat and seat belt users in all crashes. The driver’s gender, the driver age, the occupant age and the occupant seat position are not significant, since their p-values are greater than the significance level of 0.05.

The crash mode is significant, since the p-value of side-impact crash (0.0076) is less than the significance level of 0.05. The 4- to 8-year-old booster seat and seat belt users are significantly less likely to experience serious to critical injuries in side-impact crashes than rollover events, since the estimate of side-impact crash is negative (-1.2961) with the p-value (0.0076) less than the significance level of 0.05.

Table 39 in Section 4.4.1 and Table 91 in this section showed that the sampling weights of the 4-year-old booster seat users impacted the standard error of experiencing moderate to critical injuries experienced by the 4- to 8-year-old booster seat users in all crashes. The sampling weights of the 4-year-old booster seat users also influenced the significance of the analysis results. Section 5.5.2 used the 5- to 8-year-old booster seat and seat belt users to estimate the effect of booster seats on reducing moderate to critical injuries in all crashes.

The analysis results of the analytical data set of non-rollover crashes are different from the analysis results of the analytical data set of all crashes (see Section 5.4.1 and Section 5.4.2). The independent variables in Section 3.5 could not explain all variations that were related to occupant injury severity in rollover events, and those variations influenced the analysis results.

5.5.1 Booster Seats: 5- to 8-Year-Old Occupants in Non-Rollover Crashes (MAIS ≥ 3)

This section examined the effect of booster seats on reducing serious to critical injuries experienced by 5- to 8-year-old occupants in non-rollover crashes. The seat belts were used as a reference group of the booster seats, and the effect of booster seats on reducing serious to critical injuries was compared with the effect of seat belts in the analysis.

The 5- to 8-year-old booster seat and seat belt users were specified from the entire NASS-CDS by using the domain variables in Section 3.2 and Section 4.5.1 and the domain variable of non-rollover crashes in Section 4. The analytical data set in this section was the same as the analytical data set in Section 4.5.1 except the MAIS threshold of occupant injury severity. Injuries with MAIS ≥ 3 were considered as serious to critical injuries in this section while injuries with MAIS ≥ 2 were considered as moderate to critical injuries in Section 4.5.1. The analysis results that were not related to moderate to critical injuries in Section 4.5.1 can be applied to this section.

This section examined the same distribution of MAIS-coded injuries as did Section 4.5.1. The weighted percentage of serious to critical injuries experienced by the 5- to 8-year-old booster seat and seat belt users in non-rollover crashes is 0.20 percent (0.13%+0.02%+0.04%+0.01%, see Table 45 in Section 4.5.1) while the weighted percentage of none to medicate injuries experienced by the 5- to 8-year-old booster seat and seat belt users in non-rollover crashes is 99.80 percent (76.11%+22.94%+0.75%, see Table 45 in Section 4.5.1). The weighted percentage of serious to critical injuries (0.20%) is substantially less than the weighted percentage of none to medicate injuries (99.80%) in non-rollover crashes.

The weighted percentages of booster seat and seat belt usages in Section 4.5.1 were applied to this section. The weighted percentage of booster seat usage was 21.95 percent (see Table 46 in Section 4.5.1) while the weighted percentage of seat belt usage was 78.05 percent (see Table 46 in Section 4.5.1). The 5- to 8-year-old occupants who experienced non-rollover crashes used seat belts more frequently than booster seats.

The following contingency table shows the weighted frequencies, unweighted frequencies, weighted percentages, and standard errors of serious to critical injuries experienced by the 5- to 8-year-old booster seat and seat belt users in non-rollover crashes:

Table 94. Type of Seat Restraints and Status of Serious to Critical Injuries Experienced by 5- to 8-Year-Old Occupants in Non-Rollover Crashes

	Serious to Critical Injuries	**None to Moderate Injuries**	**Total**
Booster Seat	91.94 (4) 0.06% (0.03%)	148,404 (290) 99.94% (0.03%)	148,496 (294) 100%
Seat Belt	1,272 (33) 0.24% (0.06%)	526,607 (939) 99.76% (0.06%)	527,878 (972) 100%

There are four booster seat users 5- to 8 years old in the analytical data set who experienced serious to critical injuries in non-rollover crashes, and the weighted frequency of serious to critical injuries experienced by the 5- to 8-year-old booster seat users is 91.94. The weighted percentage of serious to critical injuries experienced by the booster seat users is 0.06 percent ((91.94/148,496)*100%) with the standard error of 0.03 percent while the weighted percentage of serious to critical injuries experienced by the seat belt users is 0.24 percent ((1,272/527,878)*100%) with the standard error of 0.06 percent. The weighted percentage of serious to critical injuries experienced by the booster seat users (0.06%) is less than the weighted percentage of serious to critical injuries experienced by the seat belt users (0.24%). The variation of experiencing serious to critical injuries by the booster users is greater than the variation of experiencing serious to critical injuries by the seat belt users, since the standard error in the booster seat users (0.03%) is greater than the standard error in the seat belt users (0.06%).

The effect of booster seats on reducing serious to critical injuries experienced by the 5- to 8-year-old booster seat and seat belt users in non-rollover crashes was estimated by using the logistic regression analysis, and the effect of booster seats was compared with the effect of seat belts in the analysis. The status of serious to critical injuries (MAIS3) in Section 3.5 was used as the dependent variable, and the driver's gender (MALE1), the driver age (AGE1), the non-rollover crash mode (MODE_COLL), the occupant age (AGE2), the occupant seat position (CENTER), and the type of seat restraints (BOOSTERSEAT) in Section 3.5 were used as the independent variables in the logistic regression analysis.

The domain variables in Section 3.2 and Section 4.5.1 and the domain variable of non-rollover crashes in Section 4 were used in the SAS survey analysis procedure to specify the analytical data set from the entire NASS-CDS. This section used the SAS SURVEYLOGISTIC procedure with ratio inflation factor (RATEGT) as the weight, PSU as the cluster and PSU STRATA as the strata to perform the logistic regression analysis. The following table shows the estimated parameters of independent variables in the full logistic regression model:

Table 95. Full Logistic Regression Model: 5- to 8-Year-Old Booster Seat and Seat Belt Users Experienced Serious to Critical Injuries in Non-Rollover Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_5_8=1 BOOSTER_SEATBELT=1 COLLISION_GROUP=1

Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
MALE1=1	0.2817	0.7431	0.38	0.7099
AGE1	-0.00354	0.0288	-0.12	0.9038
MODE_COLL=REAR	0.0631	1.0980	0.06	0.9549
MODE_COLL=SIDE	-0.2120	1.0365	-0.20	0.8407
AGE2	0.3184	0.3036	1.05	0.3109
CENTER=1	0.0109	0.6270	0.02	0.9864
BOOSTERSEAT=1	-1.1646	0.5544	-2.10	0.0530

The 5- to 8-year-old booster seat users might be significantly less likely to experience serious to critical injuries than the 5- to 8-year-old seat belt users, since the estimate of booster seat (BOOSTERSEAT=1) is negative (-1.1646) with the p-value (0.0530) close to the significance level of 0.05. The 5- to 8-year-old booster seat and seat belt users in center seats might not be less likely to experience serious to critical injuries than the 5- to 8-year-old booster seat and seat belt users in outboard seats, since the estimate of center seat (CENTER=1) is positive (0.0109).

This section kept the type of seat restraints (BOOSTERSEAT) in the final logistic regression model and used the forward selection method to remove other independent variables that were not significant in the full logistic regression model. The following table shows the analysis results of the final logistic regression model:

Table 96. Final Logistic Regression Model: 5- to 8-Year-Old Booster Seat and Seat Belt Users Experienced Serious to Critical Injuries in Non-Rollover Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_1_3=1 BOOSTER_SEATBELT=1 COLLISION_GROUP=1

Global Model Test				
	F Test		P-value	
Likelihood Ratio	0.67		0.4266	
Score	9.76		0.0070	
Wald	6.15		0.0255	
Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
BOOSTERSEAT=1	-1.3603	0.5484	-2.48	0.0255
Odds Ratio Estimate				
Independent Variable	Estimate		95% Confidence Interval	
BOOSTERSEAT=1	0.257		(0.080, 0.826)	
Model Fitting Assessment				
C Statistics	0.564			

The final logistic regression model is significant, since the p-value of the likelihood ratio test (0.4266) is greater than the significance level of 0.05. The C-statistic is 0.564, and the area under the ROC curve is 0.564 when the final logistic regression model uses the type of seat restraints (BOOSTERSEAT) as the independent variable. The final logistic regression model might not substantially fit the analytical data set.

The effect of booster seats (BOOSTERSEAT=1) on reducing serious to critical injuries is significant, since its p-value (0.0255) is less than the significance level of 0.05. The 5- to 8-year-old booster seat users are significantly less likely to experience serious to critical injuries than the 5- to 8-year-old seat belt users, since the estimate of booster seat (BOOSTERSEAT=1) is negative (-1.3603) with the p-value (0.0255) less than the significance level of 0.05. The driver's gender, the driver age, the non-rollover crash mode, the occupant age, and the occupant seat position are not significant, since their p-values are greater than the significance level of 0.05.

The ratio of the odds of experiencing serious to critical injuries by the booster seat users to the odds of experiencing serious to critical injuries by the seat belt users was estimated by applying Equation 1 and the final logistic regression model estimate of booster seat (-1.3603).

$$\left(\frac{\text{Odds}|_{\text{Booster Seat}}}{\text{Odds}|_{\text{Seat Belt}}}\right) = \text{Odds Ratio} = \exp(-1.3603) = 0.257$$

The effect of booster seats on reducing serious to critical injuries experienced by the 5- to 8-year-old booster seat and seat belt users was estimated by using Equation 2.

$$\text{Effect of Booster Seat} = \big(1 - \exp(-1.3603)\big) \cdot 100\ \% = 74.3\%$$

With other variables being held constant, the odds of experiencing serious to critical injuries by the 5- to 8-year-old booster seat users is 74.3 percent less than the odds of experiencing serious to critical injuries by the 5- to 8-year-old seat belt users. The estimated 95 percent confidence interval is between 17.4 percent ((1-0.826)*100%) and 92.0 percent ((1-0.080)*100%) based on the analytical data set from NASS-CDS.

5.5.2 Booster Seats: 5- to 8-Year-Old Occupants in All Crashes (MAIS ≥ 3)

This section examined the effect of booster seats on reducing serious to critical injuries experienced by the 5- to 8-year-old occupants in all crashes. The seat belts were used as the reference group of the booster seats, and the effect of booster seats on reducing serious to critical injuries was compared with the effect of seat belts in the analysis.

The analytical data set in this section was specified from the entire NASS-CDS by using the domain variables in Section 3.2 and Section 4.5.1 and the domain variable of all crashes in Section 4.

The following contingency table shows the weighted frequencies, unweighted frequencies, weighted percentages, and standard errors of serious to critical injuries experienced by the 5- to 8-year-old booster seat and seat belt users in all crashes:

Table 97. Type of Seat Restraints and Status of Serious to Critical Injuries Experienced by 5- to 8-Year-Old Occupants in All Crashes

	Serious to Critical Injuries	**None to Moderate Injuries**	**Total**
Booster Seat	181.02 (6) 0.10% (0.06%)	189,527 (319) 99.90% (0.06%)	189,708 (325) 100%
Seat Belt	1,736 (40) 0.29% (0.09%)	594,040 (1048) 99.71% (0.09%)	595,776 (1088) 100%

There are six booster seat users 5- to 8 years old in the analytical data set who experienced serious to critical injuries in all crashes, and the weighted frequency of serious to critical injuries experienced by the 5- to 8-year-old booster seat users is 181.02. The weighted percentage of serious to critical injuries experienced by the booster seat users is 0.10 percent ((181.02/189,708)*100%) with the standard error of 0.06 percent while the weighted percentage of serious to critical injuries experienced by the 5- to 8-year-old seat belt users is 0.29 percent ((1,736/595,776)*100%) with the standard error of 0.09 percent. The weighted percentage of serious to critical injuries experienced by the booster seat users (0.10%) is less than the weighted percentage of serious to critical injuries experienced by the seat belt users (0.29%). The variation of experiencing serious to critical injuries by the booster seat users is less than the variation of experiencing serious to critical injuries by the seat belt users, since the standard error in the booster seat users (0.06%) is less than the standard error in the seat belt users (0.09%).

The effect of booster seats on reducing serious to critical injuries experienced by the 5- to 8-year-old booster seat and seat belt users in all crashes was estimated by using the logistic regression analysis, and the effect of booster seats was compared with the effect of seat belts in the analysis. The status of serious to critical injuries (MAIS3) in Section 3.5 was used as the dependent variable, and the driver's gender (MALE1), the driver age (AGE1), the crash mode (MODE), the occupant age (AGE2), the occupant seat position (CENTER), and the type of seat restraints (BOOSTERSEAT) in Section 3.5 were used as the independent variables in the logistic regression analysis.

The domain variables in Section 3.2 and Section 4.5.1 and the domain variable of all crashes in Section 4 were used in the SAS survey analysis procedure to specify the analytical data set from the entire NASS-CDS. This section used the SAS SURVEYLOGISTIC procedure with RATEGT as the weight, PSU as the cluster and PSU STRATA as the strata to perform the logistic regression analysis. The following table shows the estimated parameters of independent variables in the full logistic regression model:

Table 98. Full Logistic Regression Model: 5- to 8-Year-Old Booster Seat and Seat Belt Users Experienced Serious to Critical Injuries in All Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_5_8=1 BOOSTER_SEATBELT=1 CRASH_GROUP=1

Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
MALE1=1	0.4975	0.2990	1.66	0.1169
AGE1	0.00214	0.0171	0.12	0.9023
MODE=FRONTAL	-1.0741	0.8658	-1.24	0.2338
MODE=REAR	-1.0488	1.3033	-0.80	0.4335
MODE =SIDE	-1.2021	0.7980	-1.51	0.1527
AGE2	-0.00721	0.2628	-0.03	0.9785
CENTER=1	-0.2660	0.5732	-0.46	0.6493
BOOSTERSEAT=1	-1.3736	0.6498	-2.11	0.0517

The 5- to 8-year-old booster seat users might be significantly less likely to experience serious to critical injuries than the 5- to 8-year-old seat belt users, since the estimate of booster seat (BOOSTERSEAT=1) is negative (-1.3736) with the p-value (0.0517) close to the significance level of 0.05. The 5- to 8-year-old booster seat and seat belt users in center seats might be less likely to experience serious to critical injuries than the 5- to 8-year-old booster seat and seat belt users in outboard seats, since the estimate of center seat (CENTER=1) is negative (-0.2660).

This section kept the type of seat restraints (BOOSTERSEAT) in the final logistic regression model and used the forward selection method to remove other independent variables that were not significant in the full logistic regression model. The following table shows the analysis results of the final logistic regression model.

Table 99. Final Logistic Regression Model: 5- to 8-Year-Old Booster Seat and Seat Belt Users Experienced Serious to Critical Injuries in All Crashes

DOMAIN: LIGHT_VEH=1 TOWED_VEH=1 PASS_GROUP=1 LEGAL_AGE=1 BELT_DRIVER=1 DR_GENDER=1 SEAT_GROUP=1 MAIS_GROUP=1 AGE_5_8=1 BOOSTER_SEATBELT=1 CRASH_GROUP=1

Global Model Test				
	F Test		P-value	
Likelihood Ratio	0.76		0.3965	
Score	7.32		0.0163	
Wald	4.71		0.0464	
Parameter Estimate				
Independent Variable	Estimate	Standard Error	t Test	P-value
BOOSTERSEAT=1	-1.1185	0.5154	-2.17	0.0464
Odds Ratio Estimate				
Independent Variable	Estimate		95% Confidence Interval	
BOOSTERSEAT=1	0.327		(0.109, 0.980)	
Model Fitting Assessment				
C Statistics	0.551			

The final logistic regression model is not significant, since the p-value of the likelihood ratio test (0.3965) is greater than the significance level of 0.05. The C-statistic is 0.551, and the area under the ROC curve is 0.551 when the final logistic regression model uses the type of seat restraints (BOOSTERSEAT) as the independent variables. The final logistic regression model might not substantially fit the analytical data set.

The effect of booster seats (BOOSTERSEAT=1) on reducing serious to critical injuries is significant, since its p-value (0.0464) is less than the significance level of 0.05. The 5- to 8-year-old booster seat users are significantly less likely to experience serious to critical injuries than the 5- to 8-year-old seat belt users, since the estimate of booster seat (BOOSTERSEAT=1) is negative (-1.1185) with the p-value (0.0464) less than the significance level of 0.05. The driver's gender, the driver age, the crash mode, the occupant age, and the occupant seat position are not significant, since their p-values are greater than the significance level of 0.05.

The ratio of the odds of experiencing serious to critical injuries by the booster seat users to the odds of experiencing serious to critical injuries by the seat belt users was estimated by applying Equation 1 and the final logistic regression model estimate of booster seat (-1.1185).

$$\left(\frac{\text{Odds}|\text{Booster Seat}}{\text{Odds}|\text{Seat Belt}}\right) = \text{Odds Ratio} = \exp(-1.1185) = 0.327$$

The effect of booster seats on reducing serious to critical injuries experienced by the 5- to 8-year-old booster seat and seat belt users was estimated by using Equation 2.

$$\text{Effect of Booster Seats} = \big(1 - \exp(-1.1185)\big) \cdot 100\% = 67.3\%$$

With other variables being held constant, the odds of experiencing serious to critical injuries by the 5- to 8-year-old booster seat users is 67.3 percent less than the odds of experiencing serious to critical injuries by the 5- to 8-year-old seat belt users. The estimated 95 percent confidence interval is between 2.0 percent ((1-0.980)*100%) and 89.1 percent ((1-0.109)*100%) based on the analytical data set from NASS-CDS.

The effect of booster seats on reducing serious to critical injuries is significant in the analytical data sets of non-rollover crashes and all crashes (see Section 5.5.1 and Section 5.5.2). The type of seat restraints is an important factor in serious to critical injuries experienced by 5- to 8-year-old booster seat and seat belt users.

5.6.1 Booster Seats: 7- to 8-Year-Old Occupants in Non-Rollover Crashes (MAIS ≥ 3)

This section examines the effect of booster seats on reducing serious to critical injuries experienced by the 7- to 8-year-old occupants in non-rollover crashes. The seat belts were used as the reference group of the booster seats, and the effect of booster seats on reducing serious to critical injuries was compared with the effect of seat belts in the analysis.

The 7- to 8-year-old booster seat and seat belt users were specified from the entire NASS-CDS by using the domain variables in Section 3.2 and Section 4.6 and the domain variable of non-rollover crashes in Section 4. The analytical data set in this section was the same as the analytical data set in Section 4.6.1 except the MAIS threshold of occupant injury severity. Injuries with MAIS ≥ 3 were considered as serious to critical injuries in this section while injuries with MAIS

≥ 2 were considered as moderate to critical injuries in Section 4.6.1. The analysis results that were not related to moderate to critical injuries in Section 4.6.1 can be applied to this section.

This section examined the same distribution of MAIS-coded injuries as did Section 4.6. The weighted percentage of serious to critical injuries experienced by the 7- to 8-year-old booster seat and seat belt users in non-rollover crashes is 0.29 percent (0.19%+0.02%+0.05%+0.03%, see Table 53 in Section 4.6.1) while the weighted percentage of none to moderate injuries experienced by the 7- to 8-year-old booster seat and seat belt users in non-rollover crashes is 99.71 percent (73.23%+25.28%+1.20%, see Table 53 in Section 4.6.1). The weighted percentage of serious to critical injuries (0.29%) is substantially less than the weighted percentage of none to moderate injuries (99.71%) in non-rollover crashes.

The weighted percentages of booster seat and seat belt usages in Section 4.6.1 were applied to this section. The weighted percentage of booster seat usage was 13.87 percent (see Table 54 in Section 4.6.1) while the weighted percentage of seat belt usage was 86.13 percent (see Table 54 in Section 4.6.1). The 7- to 8-year-old occupants who experienced non-rollover crashes used seat belts more frequently than booster seats in non-rollover crashes.

The following contingency table shows the weighted frequencies, unweighted frequencies, weighted percentages, and standard errors of serious to critical injuries experienced by the 7- to 8-year-old booster seat and seat belt users in non-rollover crashes:

Table 100. Type of Seat Restraints and Status of Serious to Critical Injuries Experienced by 7- to 8-Year-Old Occupants in Non-Rollover Crashes

	Serious to Critical Injuries	**None to Moderate Injuries**	**Total**
Booster Seat	0 (0) 0% (NA)	45,695 (68) 100% (NA)	45,695 (68) 100% (NA)
Seat Belt	921.14 (21) 0.32% (0.08%)	282,830 (517) 99.68% (0.08%)	283,751 (538) 100%

There are no 7- to 8-year-old booster seat users in the analytical data set who experienced serious to critical injuries in non-rollover crashes. The weighted percentage of serious to critical injuries experienced by the booster seat users is 0 percent ((0/45,695)*100%) while the weighted percentage of serious to critical injuries experienced by the seat belt users is 0.32 percent ((921.14/283,751)*100%). The weighted percentage of serious to critical injuries experienced by the booster seat users (0%) is less than the weighted percentage of serious to critical injuries experienced by the seat belt users (0.32%). The standard error of experiencing serious to critical injuries by the booster seat users could not be estimated, since there were no booster seat users who experienced serious to critical injuries in non-rollover crashes.

The effect of booster seats on reducing serious to critical injuries experienced by the 7- to 8-year-old booster seat and seat belt users could not be estimated by using the logistic regression analysis, since there were no booster seat users in the analytical data set who experienced serious to critical injuries. The estimated effect of booster seats on reducing serious to critical injuries is theoretically infinite in the analysis, since the weighted percentage of serious to critical injuries experienced by the 7- to 8-year-old booster seat users is 0 percent in the analytical data set from NASS-CDS.

5.6.2 Booster Seats: 7- to 8-Year-Old Occupants in All Crashes (MAIS ≥ 3)

This section examined the effect of booster seats on reducing serious to critical injuries experienced by the 7- to 8-year-old occupants in all crashes. The seat belts were used as the reference group of the booster seats, and the effect of booster seats on reducing serious to critical injuries was compared with the effect of seat belts in the analysis.

The analytical data set in this section was specified from the entire NASS-CDS by using the domain variables in Section 3.2 and Section 4.6.1 and the domain variable of all crashes in Section 4.

The following contingency table shows the weighted frequencies, unweighted frequencies, weighted percentages, and standard errors of serious to critical injuries experienced by the 5- to 8-year-old booster seat and seat belt users in all crashes:

Table 101. Type of Seat Restraints and Status of Serious to Critical Injuries Experienced by 7- to 8-Year-Old Occupants in All Crashes

	Moderate to Critical Injuries	**None to Minor Injuries**	**Total**
Booster Seat	0 (0) 0% (NA)	85,445 (80) 100% (NA)	85,445 (80) 100% (NA)
Seat Belt	1,179 (24) 0.35% (0.10%)	336,353 (576) 99.65% (0.10%)	337,532 (600) 100%

There are no 7- to 8-year-old booster seat users in the analytical data set who experienced serious to critical injuries in all crashes. The weighted percentage of serious to critical injuries experienced by the booster seat users is 0 percent ((0/85,445)*100%) while the weighted percentage of serious to critical injuries experienced by the seat belt users is 0.35 percent ((1,179/337,532)*100%). The weighted percentage of serious to critical injuries experienced by the booster seat users (0%) is less than the weighted percentage of serious to critical injuries experienced by the seat belt users (0.35%). The standard error of experiencing serious to critical injuries by the booster seat users could not be estimated, since there were no booster seat users who experienced serious to critical injuries in all crashes.

The effect of booster seats on reducing serious to critical injuries experienced by the 7- to 8-year-old booster seat and seat belt users could not be estimated by using the logistic regression analysis, since there were no booster seat users in the analytical data set who experienced serious to critical injuries. The estimated effect of booster seats on reducing serious to critical injuries is theoretically infinite in the analysis, since the weighted percentage of serious to critical injuries experienced by the 7- to 8-year-old booster seat users is 0 percent in the analytical data set from NASS-CDS.

The effect of booster seats on reducing serious to critical injuries experienced by 7- to 8-year-old occupants could not be estimated, since there were no booster seat users who experienced serious to critical injuries in the analytical data sets of non-rollover crashes and all crashes (see Section 5.6.1 and Section 5.6.2).

5.7 Summary: Child Restraint System Effectiveness With Respect to Serious to Critical Injuries (MAIS ≥ 3)

The NASS-CDS 1998-2015 was used to examine the effects of CRSs on reducing serious to critical injuries experienced by the 1- to 8-year-old occupants. Injuries with MAIS ≥ 3 were considered as serious to critical injuries. The effects of CRSs on reducing serious to critical injuries were separately examined in the analytical data sets of non-rollover crashes and all crashes. Crashed vehicles in the analytical data set of non-rollover crashes experienced no rollovers while crashed vehicles in the analytical data set of all crashes experienced non-rollover crashes and/or rollovers.

The CRSs included the car seats and booster seats, and the car seat categories included the rear-facing and forward-facing car seats. The 1- to 8-year-old occupants were separated into different age groups. The effects of CRSs on reducing serious to critical injuries experienced by the occupants in different age groups were separately examined in Section 5.1.1 to 5.6.2.

The effects of different types of CRSs on reducing serious to critical injuries were estimated by using logistic regression analysis. The SAS SURVEYLOGISTIC procedure was used to perform the logistic regression analysis. The logistic regression analysis also included other independent variables that might be associated with occupant injury severity. The driver's gender, the driver age, the crash mode, the occupant age, and the occupant seat position were used as the independent variables in the logistic regression analysis.

This section summarized the effects of CRSs and occupant's seat position, since the occupant seat position might influence the effects of CRSs. The following summary shows the analysis results of occupants in different age groups.

<u>Booster Seats: 5- to 8-Year-Old Occupants in Non-Rollover Crashes</u>

The seat belts were used as the reference group of the booster seats. The effect of booster seats on reducing serious to critical injuries experienced by the 5- to 8-year-old booster seat and seat belt users in non-rollover crashes was significantly greater than the effect of seat belts based on the analysis results from NASS-CDS.

Table 102. Booster Seats on Reducing Serious to Critical Injuries Experienced by 5- to 8-Year-Old Booster Seat and Seat Belt Users in Non-Rollover Crashes

Evaluated Group	Reference Group	Estimated Effect	95 % Confidence Interval
Booster Seat	Seat Belt	74.3%	(17.4%, 92.0%)

With other variables being held constant, the odds of experiencing serious to critical injuries by the 5- to 8-year-old booster seat users is 74.3 percent less than the odds of experiencing serious to critical injuries by the 5- to 8-year-old seat belt users. The estimated 95 percent confidence interval is between 17.4 percent and 92.0 percent based on the analytical data set from NASS-CDS.

Booster Seats: 5- to 8-Year-Old Occupants in All Crashes

The seat belts were used as the reference group of the booster seats. The effect of booster seats on reducing serious to critical injuries experienced by the 5- to 8-year-old booster seat and seat belt users in all crashes was significantly greater than the effect of seat belts based on the analysis results from NASS-CDS.

Table 103. Booster Seats on Reducing Serious to Critical Injuries Experienced by 5- to 8-Year-Old Booster Seat and Seat Belt Users in All Crashes

Evaluated Group	Reference Group	Estimated Effect	95 % Confidence Interval
Booster Seat	Seat Belt	67.3%	(2.0%, 89.1%)

With other variables being held constant, the odds of experiencing serious to critical injuries by the 5- to 8-year-old booster seat users is 67.3 percent less than the odds of experiencing serious to critical injuries by the 5- to 8-year-old seat belt users. The estimated 95 percent confidence interval is between 2.0 percent and 89.1 percent based on the analytical data set from NASS-CDS.

6 Analysis of Child Restraint System Effectiveness on Fatalities

This evaluation used the Fatality Analysis Reporting System (FARS) between 2009 and 2016 to examine the effects of CRSs on reducing fatalities experienced by 1- to 8-year-old occupants in crashes, since FARS began to collect data on booster seats starting in 2008. FARS does not distinguish rear-facing car seats from forward-facing car seats, and the effect of rear-facing car seats on reducing child occupant fatalities could not be examined in this analysis. FARS reports an occupant's age in whole years. For example, the age of a 23-month-old occupant was coded as a 1-year-old in FARS. As another example, FARS recorded an occupant's age as zero when an occupant's age was less than 12 months.

This evaluation separated 1- to 8-year-old occupants into the following age groups: 1- to 3-year-old, 3- to 5-year-old, 4- to 8-year-old, and 7- to 8-year-old. The analysis examined the effects of CRSs on reducing child occupant fatalities by using the double-pair comparison analysis[25] (Section 6.3), since the double-pair comparison analysis extends the analysis results based on FARS to other crashes. With a comparison control group, the double-pair comparison analysis estimated the effects of CRSs on reducing child occupant fatalities by dividing the fatality risk ratio of the evaluation group to the fatality risk ratio of the reference group.

The probability of experiencing fatalities by the child occupants in rollover events is greater than the probability of experiencing fatalities by the child occupants in non-rollover crashes (see Appendix D). The distribution of child occupant fatalities in rollover events is different from the distribution of child occupant fatalities in non-rollover crashes. Rollover events might impact the analysis results of the CRS effectiveness. This evaluation separately examined the effects of CRSs in the analytical data sets of fatal non-rollover crashes and all fatal crashes. The analytical

[25] Evans, L. (1986, June). Double pair comparison – a new method to determine how occupant characteristics affect fatality risk in traffic crashes. *Accident Analysis and Prevention, 18*(3), pp 217-227.

data sets of fatal non-rollover crashes and all fatal crashes were specified from FARS by the following crash condition.

Fatal non-rollover crashes: Crashed vehicles in the analytical data set of fatal non-rollover crashes experienced no rollover events.

All fatal crashes: Crashed vehicles in the analytical data set of all fatal crashes experienced non-rollover crashes and/or rollover events.

The following table shows the evaluated CRS and the reference group in each occupant age group:

Table 104. Evaluation Topics of Child Restraint System on Fatalities

Occupant's Age	Evaluated Child Restraint System	Reference Group
1 to 3	Car Seat	Booster Seat
3 to 5	Car Seat	Booster Seat
4 to 8	Booster Seat	Seat Belt
7 to 8	Booster Seat	Seat Belt

This evaluation considered the recorded presence (as indicated in FARS) of a CRS, but this evaluation did not take into account whether such CRSs were installed and used according to safety guidelines and the respective manufacturers' recommendations. Deviation from the proper use of CRSs might influence some of the effectiveness estimates shown in this evaluation.

6.1 Fatality Analysis Reporting System

FARS is a census of fatal traffic crashes within the 50 States, the District of Columbia, and Puerto Rico since 1975. The crashes in FARS must result in the death of at least one person[26] within 30 days of the crash.

NHTSA has a cooperative agreement with an agency in each State government to provide information in a standard format on fatal crashes occurring in the State. The data observations in FARS came from PCRs in the States, death certificates, State coroners and medical examiners, State driver and the vehicle registration records, and emergency medical service records.

6.2 Analytical Variables of Interest in FARS

The following vehicle, driver, and child occupant conditions were used to specify the analytical data set from FARS. Although FARS is a complete census of relevant fatal crashes, this analysis treated FARS observations as if they came from a simple random sample; domain variables were unnecessary.

GVWR of passenger vehicles

The analysis included the passenger vehicles with GVWR less than or equal to 10,000 pounds.

[26] The fatally injured person could be an occupant of a vehicle or a non-motorist.

Model years of passenger vehicles

Drivers with the seat belt and frontal air bag protection were used as the comparison control group in the double-pair comparison analysis (see Section 6.3). NHTSA[27] required all passenger vehicles to be equipped with the frontal air bags starting with model year 1999. This analysis included vehicles with model years (MYs) from 1999 to 2017.

Number of 1- to 8-year-old occupants

There must be at least one 1- to 8-year-old occupant in a passenger vehicle.

Driver's age

The analysis included the drivers with the age greater than or equal to 16 years old.

Belted driver

The analysis included the drivers with the seat belt protection.

Child occupant's seat restraint

The 1- to 8-year-old occupants in the analysis used car seats, booster seats or seat beltsin the fatal crash.

Child occupant's seat position

The analysis included the 1- to 8-year-old occupants in the second or the third row of vehicles.

This section applied the above vehicle, driver and occupant conditions to the FARS analytical data set. The following table shows the frequencies and percentages of car seat, booster seat and seat belt usages in at each age from 1-year-old to 8-year-old:

Table 105. Seat Restraints Used by 1- to 8-Year-Old Occupants in Fatal Crashes

Occupant's Age	Car Seat	Booster Seat	Seat Belt	Total
1	671 (86.92%)	15 (1.94%)	86 (11.14)	772 (100%)
2	579 (78.24%)	44 (5.95%)	117 (15.81%)	740 (100%)
3	502 (64.11%)	106 (13.54%)	175 (22.35%)	783 (100%)
4	373 (41.63%)	198 (22.10%)	325 (36.27%)	896 (100%)
5	210 (23.31%)	245 (27.19%)	446 (49.50%)	901 (100%)
6	109 (11.20%)	198 (20.35%)	666 (68.45%)	973 (100%)

[27] National Highway Traffic Safety Administration. (n.a.) Air bags [Web page and portal]. Available at https://www.nhtsa.gov/equipment/air-bags.

Occupant's Age	Car Seat	Booster Seat	Seat Belt	Total
7	49 (4.94%)	144 (14.53%)	798 (80.52%)	991 (100%)
8	16 (1.54%)	72 (6.93%)	951 (91.53%)	1,039 (100%)

There are six hundred seventy-one 1-year-old car seat users 1 year old in the FARS analytical dataset. The percentage of car seat usage in the 1-year-old occupants is 86.92 percent ((671/772)*100%) while the percentage of booster seat usage in the 1-year-old occupants is 1.94 percent ((15/772)*100%). The percentage of car seat usage decreases when the occupant age increases while the percentage of seat belt usage increases when the occupant age increases. The percentage of booster seat usage increases up to age five and then decreases starting at age six.

6.3 Analytical Method: Double-Pair Comparison Analysis

The double-pair comparison analysis was used to estimate the effects of CRSs on reducing fatalities experienced by the 1- to 8-year-old occupants, since the double-pair comparison analysis can extend the statistical analysis results based on fatal crashes to other crashes.

There were confounding variables in fatal crashes that might be related to the child occupant fatalities. The double-pair comparison analysis eliminated effects of confounding variables by using a comparison control group. The drivers with seat belt and frontal air bag protection were used as the comparison control group in the analysis, since seat belts[28] and frontal air bags[29] were the safety equipment that significantly reduced driver fatalities.

The double-pair comparison analysis included the following fatal crashes in FARS 2009-2016:

1. The driver with seat belt and frontal air bag protection was killed, but the 1- to 8-year-old occupant with a seat restraint was not killed.
2. The driver with seat belt and frontal air bag protection was not killed, but the 1- to 8-year-old occupant with a seat restraint was killed.
3. The driver with seat belt and frontal air bag protection was killed, and the 1- to 8-year-old occupant with a seat restraint was also killed.

The double-pair comparison analysis assumed that the driver fatalities were independent of the type of seat restraints used by the 1- to 8-year-old occupants.

This section uses the car seats and booster seats as an example to illustrate the double-pair comparison analysis. The booster seats were used as the reference group of the car seats, and the effect of car seats on reducing child occupant fatalities was compared with the effect of booster seats in the double-pair comparison analysis. The drivers in the following tables were under seat

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[28] Kahane, C. J. (2000, December). *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. Available at https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/809199.

[29] Kahane, C. J. (1996, August). *Fatality reduction by air bags: analyses of accident data through early 1996* (Report No. DOT HS 808 470). National Highway Traffic Safety Administration. Available at https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/808470.

belt and frontal air bag protection, and the following notations denote the numbers of driver and child occupant fatalities:

n_1: The number of fatalities experienced by the car seat users.

n_2: The number of fatalities experienced by the drivers that traveled with a car seat user.

n_3: The number of fatalities experienced by the booster seat users.

n_4: The number of fatalities experienced by the drivers that traveled with a booster seat user.

Table 106. Example of Double-Pair Comparison Contingency Table (Car Seats Versus Booster Seats)

	Child Occupant Fatality	**Driver Fatality**	**Child Occupant/Driver Risk Ratio**
Car Seat Users	n_1	n_2	n_1 / n_2
Booster Seat Users	n_3	n_4	n_3 / n_4

The risk ratio of the fatalities experienced by the car seat users to the fatalities experienced by the drivers that traveled with a car seat user is n_1/n_2. The risk ratio of the fatalities experienced by the booster seat users to the fatalities experienced by the drivers that traveled with a booster seat user is n_3/n_4. The effect of car seats on reducing child occupant fatalities is estimated by the following equation.

Equation 3

$$\text{Effect of Car Seats}$$
$$= \left(\frac{\text{Risk Ratio in Booster Seat Users} - \text{Risk Ratio in Car Seat Users}}{\text{Risk Ratio in Booster Seat Users}}\right) \cdot 100\%$$
$$= (1 - \frac{n_1 \,/\, n_2}{n_3 \,/\, n_4}) \cdot 100\%$$

The risk ratio of fatalities experienced by the car seat users is $((1 - \frac{n_1 \,/\, n_2}{n_3 \,/\, n_4}) \cdot 100)$ percent less than the risk ratio of fatalities experienced by the booster seat users.

The analytical data set in the double-pair comparison contingency table might include other variables that are associated with child occupant fatalities, but the double-pair comparison analysis cannot examine the effects of other variables on reducing child occupant fatalities. The logistic regression analysis was used to analyze the analytical data set in the double-pair comparison contingency table in the following sections, since the logistic regression analysis can examine the effects of CRSs and other variables on reducing child occupant fatalities.

Data observations in a double-pair comparison contingency table might not always be mutually independent. For example, a fatal crash with both driver and child occupant killed contributes two data observations to the double-pair comparison contingency table: one data observation belongs to the driver fatality, and the other data observation belongs to the child occupant fatality. As another example, the driver fatality is compared and counted multiple times when there is more than one 1- to 8-year-old occupant in the crashed vehicle.

Data dependency issues might bias the analysis results, and this evaluation used the jackknife technique to verify the analysis results of the logistic regression analysis. The following section introduced the analysis of jackknife technique.

6.4 Analytical Method: Jackknife Logistic Regression Analysis

Suppose *X* is a sample with *n* data observations $(x_1, x_2, \ldots x_n)$, and $\hat{\theta}$ is a linear estimator that can be expressed as a function of *X*. The jackknife technique focuses on the samples that leave out one data observation at a time. The jackknife samples are expressed as the following.

$$X_{(i)} = (x_1, x_2, \ldots x_{i-1}, x_{i+1}, \ldots x_n), \text{ for } i = 1,2, \ldots n$$

The i^{th} jackknife sample consists of the $(n-1)$ data observations with the i^{th} data observation removed. Let $\widehat{\theta_{(\iota)}}$ be the i^{th} jackknife replication of $\hat{\theta}$.

This section used the jackknife pseudo-values to present the estimated jackknife confidence interval. The following is the definition of jackknife pseudo-value.

$$\widetilde{\theta_\iota} = n\hat{\theta} - (n-1)\widehat{\theta_{(\iota)}}, \text{ for } i = 1,2, \ldots n.$$

The jackknife pseudo-values, $\widetilde{\theta_\iota}$ are assumed to be mutually independent. There are *n* jackknife pseudo-values, and the standard error of the jackknife estimator, $\widehat{SE_{Jack}}$ can be presented by the jackknife pseudo-values.

$$\widehat{SE_{Jack}} = \{\textstyle\sum_1^n (\widetilde{\theta_\iota} - \tilde{\theta})^2 / \{(n-1)n\}\}^{1/2}, \text{ where } \tilde{\theta} = \textstyle\sum_1^n \widetilde{\theta_\iota}/n$$

Setting the significance level at *α*, the estimated $(1-\alpha)$ percent jackknife confidence interval is $\tilde{\theta} \pm t_{n-1}^{(1-\alpha/2)} \widehat{SE_{Jack}}$, where $t_{n-1}^{(1-\alpha/2)}$ is the $(1-\alpha/2)^{th}$ percentile of the *t* distribution on $n-1$ degrees of freedom. The estimated $(1-\alpha)$ percent jackknife confidence interval is under the assumption of independence.

The analysis results of the logistic regression analysis might be significantly biased by data dependency issues when the estimated confidence interval built by the logistic regression model is not consistent with the estimated jackknife confidence interval.

6.5 Analytical Variables for the Fatality Analysis

The analytical data set in the double-pair comparison analysis were also analyzed by the logistic regression analysis. The following dependent and independent variables were used in the logistic regression analysis.

<u>Dependent Variable</u>

The fatality statuses of driver and child occupant in a fatal crash were used as the dependent variable in the logistic regression analysis. The following variable was used as the dependent variable in the analysis.

$$\text{KILL} = \begin{cases} 1, \text{if the driver was killed} \\ 2, \text{if the child occupant was killed} \end{cases}$$

Independent Variable

The driver's gender (MALE1), the driver age (AGE1), the occupant age (AGE2), the occupant seat position (CENTER), the type of CRSs (CAR SEAT), and the type of seat restraints (BOOSTERSEAT) in Section 3.5 were used as the independent variables in the logistic regression analysis. The crash mode was not included in the logistic regression analysis, since there were no variables in FARS that can indicate the direction of the highest impact force striking the vehicle in fatal crashes.

7 Child Restraint System Effectiveness: Fatalities

FARS 2009-2016 was used to examine the effects of CRSs on reducing fatalities experienced by the 1- to 8-year old occupants. The 1- to 8-year old occupants were separated into different age groups based on the evaluation topics in Table 104. The effects of CRSs on reducing fatalities experienced by the child occupants in different age groups were separately examined in the analytical data sets of fatal non-rollover crashes and all fatal crashes (see Section 6).

This evaluation used the double-pair comparison analysis to examine the effects of CRS on reducing child occupant fatalities, and the analysis results based on fatal non-rollover crashes and all crashes can be extended to non-rollover crashes and all crashes.

7.1.1 Car Seats: 1- to 3-Year-Old Occupants in Non-Rollover Crashes

This section examined the effect of car seats on reducing fatalities experienced by the 1- to 3-year-old occupants in non-rollover crashes by using the analytical data set of fatal non-rollover crashes in FARS. The booster seats were used as the reference group of the car seats, and the effect of car seats on reducing child occupant fatalities was compared with the effect of booster seats in the analysis. An infant occupant's age (less than 1 year) was recorded as zero in FARS, and the analytical data set in this section did not include child occupants who were younger than 12 months.

The analytical data set in this section was specified from FARS by using the vehicle, driver and occupant conditions in Section 6.2 and the condition of crash mode in Section 6. The CRS users included the car seat and booster seat users, and the analytical data set only included the 1- to 3-year-old CRS users who experienced fatal non-rollover crashes. The data observations in the analytical data set satisfied the following conditions.

Vehicle Condition

The collision-crashed passenger vehicles with the GVWR less than 10,000 pounds were manufactured between MY 1999 and 2017. The collision-crashed passenger vehicles experienced no rollovers. There was at least one 1- to 3-year-old CRS user in the collision-crashed passenger vehicle.

Driver Condition

The driver was under seat belt and frontal air bag protection. The driver was at least 16 years old.

Occupant Condition

The 1- to 3-year-old CRS user sat in the second or the third row of the passenger vehicle in the fatal non-rollover crash.

The following table shows the frequencies and percentages of car seat and booster seat usages in the analytical data set:

Table 107. Car Seats and Booster Seats Used by 1- to 3-Year-Old Occupants in Fatal Non-Rollover Crashes

	Frequency	**Percentage**
Car Seat	1,480	91.70%
Booster Seat	134	8.30%
Total	1,614	100%

There are one thousand four hundred eighty 1- to 3-year-old car seat users in the analytical data set. The percentage of car seat usage is 91.70 percent ((1,480/1,614)*100%) while the percentage of booster seat usage is 8.30 percent ((134/1,614)*100%). The 1- to 3-year-old occupants who experienced fatal non-rollover crashes used car seats more frequently than booster seats.

The following contingency table shows the frequencies and percentages of fatalities experienced by the 1- to 3-year-old car seat and booster seat users in fatal non-rollover crashes:

Table 108. Type of Child Restraint Systems and Status of Fatalities Experienced by 1- to 3-Year-Old Occupants in Fatal Non-Rollover Crashes

	Fatality	**Non-fatality**	**Total**
Car Seat	143 9.68%	1,335 90.32%	1,478 100%
Booster Seat	26 19.40%	108 80.60%	134 100%

There are one hundred forty-three 1- to 3-year-old car seat users in the analytical data set who experienced fatalities in fatal non-rollover crashes. The percentage of fatalities experienced by the car seat users is 9.68 percent ((143/1,478)*100%) while the percentage of fatalities experienced by the booster seat users is 19.40 percent ((26/134)*100%). The car seat users are less likely to experience fatalities in fatal non-rollover crashes than the booster seat users.

The effect of car seats on reducing fatalities experienced by the 1- to 3-year-old CRS users was estimated by the double-pair comparison analysis. The fatal non-rollover crashes in the analytical data set that matched one of the following events were included in the double-pair comparison analysis.

1. The 1- to 3-year-old CRS user was killed, but the driver with seat belt and frontal air bag protection was not killed.
2. The 1- to 3-year-old CRS user was not killed, but the driver with seat belt and frontal air bag protection was killed.

3. Both 1- to 3-year-old CRS user and driver with seat belt and frontal air bag protection were killed.

The following table shows the frequencies and risk ratios of fatalities experienced by the 1- to 3-year-old car seat and booster seat users in the double-pair comparison analysis:

Table 109. Double-Pair Comparison Contingency Table of 1- to 3-Year-Old Child Restraint System Users in Fatal Non-Rollover Crashes

	Child Occupant Fatality	**Driver Fatality**	**Child Occupant/Driver Risk Ratio**
Car Seat	142	206	0.69
Booster Seat	26	18	1.44

The drivers with seat belt and frontal air bag protection were used as the comparison control group in Table 109. The risk ratio of the fatalities experienced by the 1- to 3-year-old car seat users to the fatalities experienced by the drivers is 0.69 (142/206). The risk ratio of the fatalities experienced by the 1- to 3-year-old booster seat users to the fatalities experienced by the drivers is 1.44 (26/18). The risk ratio of the car seat users (0.69) is less than the risk ratio of the booster seat users (1.44).

The effect of car seats on reducing fatalities experienced by the 1- to 3-year-old CRS users in non-rollover crashes was estimated by using Equation 3.

$$\text{Effect of Car Seats} = \left(1 - \left(\frac{142}{206}\right) / \left(\frac{26}{18}\right)\right) \cdot 100\% = 52.08\%$$

The risk ratio of fatalities experienced by the 1- to 3-year-old car seat users is 52.08 percent less than the risk ratio of fatalities experienced by the 1- to 3-year-old booster seat users.

The effect of car seats on reducing fatalities experienced by the 1- to 3-year-old CRS users in non-rollover crashes was also estimated by applying the logistic regression analysis to the analytical data set in Table 109, and the effect of car seats was compared with the effect of booster seats in the analysis. The fatality statuses of driver and child occupant (KILL) in Section 6.5 were used as the dependent variable, and the driver's gender (MALE1), the driver age (AGE1), the occupant age (AGE2), the occupant seat position (CENTER), and the type of CRS (CARSEAT) in Section 3.5 were used as the independent variables in the logistic regression analysis.

This section used the SAS LOGISTIC procedure to perform the logistic regression analysis. The following table shows the estimated parameters of independent variables in the full logistic regression model:

Table 110. Full Logistic Regression Model: 1- to 3-Year-Old Child Restraint System Users Experienced Fatalities in Non-Rollover Crashes

Parameter Estimate				
Independent Variable	Estimate	Standard Error	Chi-Square Test	P-value
MALE1=1	0.1712	0.2214	0.5977	0.4395

Parameter Estimate				
AGE1	-0.0148	0.00863	2.9474	0.0860
AGE2	-0.0292	0.1321	0.0487	0.8253
CENTER=1	-0.4437	0.2607	2.8957	0.0888
CARSEAT=1	-0.6834	0.3412	4.0109	0.0452*

The 1- to 3-year-old car seat users might be significantly less likely to experience fatalities than the 1- to 3-year-old booster seat users, since the estimate of car seat (CARSEAT=1) is negative (-0.6834) with the p-value (0.0452) less than the significance level of 0.05. The 1- to 3-year-old CRS users in center seats might be significantly less likely to experience fatalities than the 1- to 3-year-old CRS users in outboard seats, since the estimate of center seat (CENTER=1) is negative (-0.4437) with the p-value (0.0888) close to the significance level of 0.05.

This section kept the type of CRS (CARSEAT) in the final logistic regression model and used the forward selection method to remove other independent variables that were not significant in the full logistic regression model. The following table shows the analysis results of the final logistic regression model:

Table 111. Final Logistic Regression Model: 1- to 3-Year-Old Child Restraint System Users Experienced Fatalities in Non-Rollover Crashes

Global Model Test				
	Chi-Square Test		P-value	
Likelihood Ratio	5.2726		0.0217	
Score	5.3335		0.0209	
Wald	5.1670		0.0230	
Parameter Estimate				
Independent Variable	Estimate	Standard Error	Chi-Square Test	P-value
CARSEAT=1	-0.7398	0.3254	5.1670	0.0230*
Odds Ratio Estimate				
Independent Variable	Estimate		95% Confidence Interval	
CARSEAT=1	0.477		(0.252, 0.903)	
Model Fitting Assessment				
C Statistics	0.537			

The final logistic regression model is significant, since the p-values of the likelihood ratio test (0.0217), the score test (0.0209) and the Wald test (0.0230) are less than the significance level of 0.05. The C-statistic is 0.537, and the area under the ROC curve is 0.537 when the final logistic regression model uses the type of CRS (CARSEAT) as the independent variable. The final logistic regression model might not substantially fit the analytical data set.

The effect of car seats (CARSEAT=1) on reducing child occupant fatalities is significant, since its p-value (0.0230) is less than the significance level of 0.05. The 1- to 3-year-old car seat users are significantly less likely to experience fatalities than the 1- to 3-year-old booster seat users, since the estimate of car seat (CARSEAT=1) is negative (-0.7398) with the p-value (0.0230) less than the significance level of 0.05. The driver's gender, the driver age, the occupant age, and the occupant seat position are not significant, since their p-values are greater than the significance level of 0.05.

The ratio of the odds of experiencing fatalities by the car seat users to the odds of experiencing fatalities by the booster seat users was estimated by applying Equation 1 and the final logistic regression model estimate of car seat (-0.7398).

$$\left(\frac{\text{Odds}|\text{Car Seat}}{\text{Odds}|\text{Booster Seat}}\right) = \text{Odds Ratio} = \exp(-0.7398) = 0.477$$

The effect of car seats on reducing fatalities experienced by the 1- to 3-year-old CRS users was estimated by using Equation 2.

$$\text{Effect of Car Seats} = \left(1 - \exp(-0.7398)\right) \cdot 100\% = 52.3\%$$

With other variables being held constant, the odds of experiencing fatalities by the 1- to 3-year-old car seat users is 52.3 percent less than the odds of experiencing fatalities by the 1- to 3-year-old booster seat users. The estimated 95 percent confidence interval is between 9.7 percent ((1-0.903)*100%) and 74.8 percent ((1-0.252)*100%) based on the analytical data set from FARS.

The estimated effect of car seats on reducing child occupant fatalities was 52.3 percent by using the logistic regression analysis while the estimated effect of car seats on reducing child occupant fatalities was 52.08 percent by using the double-pair comparison contingency table (see Table 109). The analysis results of the logistic regression analysis and double-pair comparison contingency table were consistent. This section adopted the analysis results of the logistic regression analysis, since the logistic regression analysis also examined the effects of other independent variables on reducing child occupant fatalities.

Data observations in the double-pair comparison contingency table might not always be mutually independent, and data dependency issues might bias the analysis results. The analytical data set in the double-pair comparison contingency table (see Table 109) was analyzed by using the jackknife technique to verify the analysis results of the final logistic regression model. If the estimated confidence interval built by the final logistic regression model is consistent with the estimated confidence interval built by the jackknife logistic regression model, then there are no significant data dependency issues.

This section used the SAS SURVEYLOGISTIC procedure with VARMETHOD=JACKKNIFE to perform the jackknife logistic regression analysis. The analysis did not use the sampling weight, cluster and strata statements, since data observations in FARS was considered as simple random samples. The following table shows the estimated confident interval of car seat effectiveness by using the jackknife logistic regression model:

Table 112. Jackknife Logistic Regression Model: Car Seat Effectiveness in 1- to 3-Year-Old Child Restraint System Users in Non-Rollover Crashes

Odds Ratio Estimate		
Independent Variable	Estimate	95% Confidence Interval
CARSEAT=1	0.477	(0.249, 0.916)

The estimated confidence interval of car seat effectiveness is between 8.4 percent ((1-0.916)*100%) and 75.1 percent ((1-0.249)*100%) by using the jackknife logistic regression model. The estimated confidence interval built by the jackknife logistic regression model (8.4% to 75.1 %) is consistent with the estimated confidence interval built by the final logistic regression model (9.7% to 74.8%). The estimated effectiveness of car seats in reducing child occupant fatalities was not significantly impacted by data dependency issues. This section adopted the analysis results of the final logistic regression model, since the jackknife technique has various forms, such as JK2[30] and JKd.[31]

7.1.2 Car Seats: 1- to 3-Year-Old Occupants in All Crashes

This section examined the effect of car seats on reducing fatalities experienced by the 1- to 3-year-old occupants in all crashes by using the analytical data set of all fatal crashes in FARS. The booster seats were used as the reference group of the car seats, and the effect of car seats on reducing child occupant fatalities was compared with the effect of booster seats in the analysis. An infant occupant's age (less than 1 year) was recorded as zero in FARS, and the analytical data set in this section did not include child occupants who were younger than 12 months.

The analytical data set in this section was specified from FARS by using the vehicle, driver and occupant conditions in Section 6.2 and the condition of crash mode in Section 6. The CRS users included the car seat and booster seat users, and the analytical data set only included the 1- to 3-year-old CRS users who experienced fatal non-rollover crashes and/or rollover events.

The effect of car seats on reducing fatalities experienced by the 1- to 3-year-old CRS users was estimated by the double-pair comparison analysis. The fatal crashes in the analytical data set that matched one of the following events were included in the double-pair comparison analysis.

1. The 1- to 3-year-old CRS user was killed, but the driver with seat belt and frontal air bag protection was not killed.
2. The 1- to 3-year-old CRS user was not killed, but the driver with seat belt and frontal air bag protection was killed.
3. Both 1- to 3-year-old CRS user and driver with seat belt and frontal air bag protection were killed.

The following table shows the frequencies and risk ratios of fatalities experienced by the 1- to 3-year-old car seat and booster seat users in the double-pair comparison analysis:

Table 113. Double-Pair Comparison Contingency Table of 1- to 3-Year-Old Child Restraint System Users in All Fatal Crashes

	Child Occupant Fatality	**Driver Fatality**	**Child Occupant/Driver Risk Ratio**
Car Seat	176	262	0.67
Booster Seat	35	25	1.4

[30] JK2 is a jackknife method that drops two data observations at one time and keeps others until each data observation has been dropped once.
[31] JKd is a jackknife method that drops *d* data observations at one time and keeps others until each data observation has been dropped once.

The drivers with seat belt and frontal air bag protection were used as the comparison control group in Table 113. The risk ratio of the fatalities experienced by the 1- to 3-year-old car seat users to the fatalities experienced by the drivers is 0.67 (176/262). The risk ratio of the fatalities experienced by the 1- to 3-year-old booster seat users to the fatalities experienced by the drivers is 1.4 (35/25). The risk ratio of the car seat users (0.67) is less than the risk ratio of the booster seat users (1.4).

The effect of car seats on reducing fatalities experienced by the 1- to 3-year-old CRS users in all crashes was estimated by using Equation 3.

$$\text{Effect of Car Seats} = \left(1 - \left(\frac{176}{262}\right) / \left(\frac{35}{25}\right)\right) \cdot 100\% = 52.14\%$$

The risk ratio of fatalities experienced by the 1- to 3-year-old car seat users is 52.14 percent less than the risk ratio of fatalities experienced by the 1- to 3-year-old booster seat users.

The effect of car seats on reducing fatalities experienced by the 1- to 3-year-old CRS users in all crashes was also estimated by applying the logistic regression analysis to the analytical data set in Table 113, and the effect of car seats was compared with the effect of booster seats in the analysis. The fatality statuses of driver and child occupant (KILL) in Section 6.5 were used as the dependent variable, and the driver's gender (MALE1), the driver age (AGE1), the occupant age (AGE2), the occupant seat position (CENTER), and the type of CRS (CARSEAT) in Section 3.5 were used as the independent variables in the logistic regression analysis.

This section used the SAS LOGISTIC procedure to perform the logistic regression analysis. The following table shows the estimated parameters of independent variables in the full logistic regression model:

Table 114. Full Logistic Regression Model: 1- to 3-Year-Old Child Restraint System Users Experienced Fatalities in All Crashes

Parameter Estimate				
Independent Variable	Estimate	Standard Error	Chi-Square Test	P-value
MALE=1	-0.00877	0.1941	0.0020	0.9640
AGE1	-0.0136	0.00787	3.0056	0.0830
AGE2	-0.0392	0.1188	0.1088	0.7415
CENTER=1	-0.5907	0.2329	6.4335	0.0112*
CARSEAT=1	-0.6479	0.2940	4.8569	0.0275*

The 1- to 3-year-old car seat users might be significantly less likely to experience fatalities than the 1- to 3-year-old booster seat users, since the estimate of car seat (CARSEAT=1) is negative (-0.6479) with the p-value (0.0275) less than the significance level of 0.05. The 1- to 3-year-old CRS users in center seats might be significantly less likely to experience fatalities than the 1- to 3-year-old CRS users in outboard seats, since the estimate of center seat (CENTER=1) is negative (-0.5907) with the p-value (0.0112) less than the significance level of 0.05.

This section kept the type of CRS (CARSEAT) in the final logistic regression model and used the forward selection method to remove other independent variables that were not significant in the full logistic regression model. The following table shows the analysis results of the final logistic regression model:

Table 115. Final Logistic Regression Model: 1- to 3-Year-Old Child Restraint System Users Experienced Fatalities in All Crashes

Global Model Test				
	Chi-Square Test		P-value	
Likelihood Ratio	13.1818		0.0014	
Score	13.0487		0.0015	
Wald	12.6525		0.0018	
Parameter Estimate				
Independent Variable	Estimate	Standard Error	Chi-Square Test	P-value
CENTER=1	-0.5608	0.2302	5.9376	0.0148*
CARSEAT=1	-0.6399	0.2825	5.1322	0.0235*
Odds Ratio Estimate				
Independent Variable	Estimate		95% Confidence Interval	
CENTER=1	0.571		(0.364, 0.896)	
CARSEAT=1	0.527		(0.303, 0.917)	
Model Fitting Assessment				
C Statistics	0.579			

The final logistic regression model is significant, since the p-values of the likelihood ratio test (0.0014), the score test (0.0015) and the Wald test (0.0018) are less than the significance level of 0.05. The C-statistic is 0.579, and the area under the ROC curve is 0.579 when the final logistic regression model uses the type of CRS (CARSEAT) and the occupant seat position (CENTER) as the independent variables. The final logistic regression model might not substantially fit the analytical data set.

The effect of car seats (CARSEAT=1) on reducing child occupant fatalities is significant, since its p-value (0.0235) is less than the significance level of 0.05. The 1- to 3-year-old car seat users are significantly less likely to experience fatalities than the 1- to 3-year-old booster seat users, since the estimate of car seat (CARSEAT=1) is negative (-0.6399) with the p-value (0.0235) less than the significance level of 0.05. The driver's gender, the driver age and the occupant age are not significant, since their p-values are greater than the significance level of 0.05.

The ratio of the odds of experiencing fatalities by the car seat users to the odds of experiencing fatalities by the booster seat users was estimated by applying Equation 1 and the final logistic regression model estimate of car seat ((-0.6399).

$$\left(\frac{\text{Odds}|\text{Car Seat}}{\text{Odds}|\text{Booster Seat}}\right) = \text{Odds Ratio} = \exp((-0.6399) = 0.527$$

The effect of car seats on reducing fatalities experienced by the 1- to 3-year-old CRS users was estimated by using Equation 2.

$$\text{Effect of Car Seats} = \left(1 - \exp(-0.6399)\right) \cdot 100\% = 47.3\%$$

With other variables being held constant, the odds of experiencing fatalities by the 1- to 3-year-old car seat users is 47.3 percent less than the odds of experiencing fatalities by the 1- to 3-year-old booster seat users. The estimated 95 percent confidence interval is between 8.3 percent ((1-0.917)*100%) and 69.7 percent ((1-0.303)*100%) based on the analytical data set from FARS.

The estimated effect of car seats on reducing child occupant fatalities was 47.3 percent by using the logistic regression analysis while the estimated effect of car seats on reducing child occupant fatalities was 52.14 percent by using the double-pair comparison contingency table (see Table 113). The analysis results of the logistic regression analysis and double-pair comparison contingency table were consistent.

The occupant's seat position is considered as an important variable, since it might influence the effect of car seats on reducing child occupant fatalities. The ratio of the odds of experiencing fatalities by the 1- to 3-year-old CRS users in center seats to the odds of experiencing fatalities by the 1- to 3-year-old CRS users in outboard seats was estimated by applying Equation 1 and the final logistic regression model estimate of center seat (-0.5608).

$$\left(\frac{\text{Odds}|\text{Center Seat}}{\text{Odds}|\text{Outboard Seat}}\right) = \text{Odds Ratio} = \exp(-0.5608) = 0.571$$

The effect of center seats on reducing fatalities experienced by the 1- to 3-year-old CRS users was estimated by using Equation 2.

$$\text{Effect of Center Seats} = \left(1 - \exp(-0.5608)\right) \cdot 100\% = 42.9\%$$

With other variables being held constant, the odds of experiencing fatalities by the 1- to 3-year-old CRS users in center seats is 42.9 percent less than the odds of experiencing fatalities by the 1- to 3-year-old CRS users in outboard seats. The estimated 95 percent confidence interval is between 10.4 percent ((1-0.896)*100%) and 63.6 percent ((1-0.364)*100%) based on the analytical data set from FARS.

The jackknife technique was used to examine the impact of data dependency issues on the analysis results of the final logistic regression model in Table 115. This section used the SAS SURVEYLOGISTIC procedure with VARMETHOD=JACKKNIFE to perform the jackknife logistic regression analysis. There were no statements of sampling weight, cluster and strata, since data observations in FARS was considered as simple random samples. The following table shows the estimated confident interval of car seat effectiveness by using the jackknife logistic regression model:

Table 116. Jackknife Logistic Regression Model: Car Seat and Center Seat Effectiveness in 1- to 3-Year-Old Child Restraint System Users in All Crashes

Odds Ratio Estimate		
Independent Variable	Estimate	95% Confidence Interval
CENTER=1	0.571	(0.362, 0.900)
CARSEAT=1	0.527	(0.300, 0.927)

The estimated confidence interval of car seat effectiveness is between 7.3 percent ((1-0.927)*100%) and 70.0 percent ((1-0.300)*100%) by using the jackknife logistic regression model. The estimated confidence interval built by the jackknife logistic regression model (7.3% to 70.0%) is consistent with the estimated confidence interval built by the final logistic regression model (8.3% to 69.7). The estimated confidence interval of center seat effectiveness is between 10.0 percent ((1-0.900)*100%) and 63.8 percent ((1-0.362)*100%) by using the jackknife logistic regression model. The estimated confidence interval built by the jackknife logistic regression model (10.0% to 63.8%) is consistent with the estimated confidence interval built by the final logistic regression model (10.4% to 63.6%). The estimated effectiveness of car seats and center seats in reducing child occupant fatalities was not significantly impacted by data dependency issues. This section adopted the analysis results of the final logistic regression model, since the jackknife technique has various forms.

The estimated effect of car seats on reducing child occupant fatalities in non-rollover crashes (52.3%, see Section 7.1.1) is close to the estimated effect of car seats on reducing child occupant fatalities in all crashes (47.3%, see Section 7.1.2), since the comparison control group (driver with seat belt and frontal air bag protection) eliminated confounding variables that are related to child occupant fatalities in rollovers.

7.2.1 Car Seats: 3- to 5-Year-old Occupants in Non-Rollover Crashes

This section examined the effect of car seats on reducing fatalities experienced by the 3- to 5-year-old occupants in non-rollover crashes by using the analytical data set of fatal non-rollover crashes in FARS. The booster seats were used as the reference group of the car seats, and the effect of car seats on reducing child occupant fatalities was compared with the effect of booster seats in the analysis.

The analytical data set in this section was specified from FARS by using the vehicle, driver and occupant conditions in Section 6.2 and the condition of crash mode in Section 6. The CRS users included the car seat and booster seat users, and the analytical data set only included the 3- to 5-year-old CRS users who experienced fatal non-rollover crashes. The data observations in the analytical data set satisfied the following conditions.

<u>Vehicle condition</u>

The collision-crashed passenger vehicle with the GVWR less than 10,000 pounds was manufactured between MY 1999 and 2017. The collision-crashed passenger vehicle experienced no rollovers. There was at least one 3- to 5-year-old CRS user in the collision-crashed passenger vehicle.

<u>Driver condition</u>

The driver was under seat belt and frontal air bag protection. The driver was at least 16 years old.

<u>Occupant condition</u>

The 3- to 5-year-old CRS user sat in the second or the third row of the passenger vehicle in the fatal non-rollover crash.

The following table shows the frequencies and percentages of car seat and booster seat usages in the analytical data set:

Table 117. Car Seats and Booster Seats Used by 3- to 5-Year-Old Occupants in Fatal Non-Rollover Crashes

	Frequency	**Percentage**
Car Seat	933	67.95%
Booster Seat	440	32.05%
Total	1,373	100%

There are 933 car seat users 3- to 5 years old in the analytical data set. The percentage of car seat usage is 67.95 percent ((933/1,373)*100%) while the percentage of booster seat usage is 32.05 percent ((440/1,373)*100%). The 3- to 5-year-old occupants who experienced fatal non-rollover crashes used car seats more frequently than booster seats.

The following contingency table shows the frequencies and percentages of fatalities experienced by the 3- to 5-year-old car seat and booster seat users in fatal non-rollover crashes:

Table 118. Type of Child Restraint Systems and Status of Fatalities Experienced by 3- to 5-Year-Old Occupants in Fatal Non-Rollover Crashes

	Fatality	**Non-fatality**	**Total**
Car Seat	92 9.91%	836 90.09%	928 100%
Booster Seat	77 17.58%	361 82.42%	438 100%

There are 92 car seat users 3- to 5 years old in the analytical data set who experienced fatalities in fatal non-rollover crashes. The percentage of fatalities experienced by the car seat users is 9.91 percent ((92/928)*100%) while the percentage of fatalities experienced by the booster seat users is 17.58 percent ((77/438)*100%). The car seat users are less likely to experience fatalities in fatal non-rollover crashes than the booster seat users.

The effect of car seats on reducing fatalities experienced by the 3- to 5-year-old CRS users was estimated by using the double-pair comparison analysis, since the double-pair comparison analysis can extend the analysis results based on FARS to other crashes. The fatal non-rollover crashes in the analytical data set that matched to one of the following events were included in the double-pair comparison analysis:

1. The 3- to 5-year-old CRS user was killed, but the driver with seat belt and frontal air bag protection was not killed.
2. The 3- to 5-year-old CRS user was not killed, but the driver with seat belt and frontal air bag protection was killed.
3. Both 3- to 5-year-old CRS user and driver with seat belt and frontal air bag protection were killed.

The following table shows the frequencies and risk ratios of fatalities experienced by the 3-to 5-year-old car seat and booster seat users in the double-pair comparison analysis:

Table 119. Double-Pair Comparison Contingency Table of 3- to 5-Year-Old Child Restraint System Users in Fatal Non-Rollover Crashes

	Child Occupant Fatality	**Driver Fatality**	**Child Occupant/Driver Risk Ratio**
Car Seat	92	131	0.70
Booster Seat	76	63	1.21

The drivers with seat belt and frontal air bag protection were used as the comparison control group in Table 119. The risk ratio of the fatalities experienced by the 3- to 5-year-old car seat users to the fatalities experienced by the drivers is 0.70 (92/131). The risk ratio of the fatalities experienced by the 3- to 5-year-old booster seat users to the fatalities experienced by the drivers is 1.21 (76/63). The risk ratio of the car seat users (0.70) is less than the risk ratio of the booster seat users (1.21).

The effect of car seats on reducing fatalities experienced by the 3- to 5-year-old CRS users in non-rollover crashes was estimated by using Equation 3.

$$\text{Effect of Car Seats} = \left(1 - \left(\frac{92}{131}\right) / \left(\frac{76}{63}\right)\right) \cdot 100\% = 42.15\%$$

The risk ratio of fatalities experienced by the 3- to 5-year-old car seat users is 42.15 percent less than the risk ratio of fatalities experienced by the 3- to 5-year-old booster seat users.

The effect of car seats on reducing fatalities experienced by the 3- to 5-year-old CRS users in non-rollover crashes was also estimated by applying the logistic regression analysis to the analytical data set in Table 119, and the effect of car seats was compared with the effect of booster seats in the analysis. The fatality statuses of driver and child occupant (KILL) in Section 6.5 were used as the dependent variable, and the driver's gender (MALE1), the driver age (AGE1), the occupant age (AGE2), the occupant seat position (CENTER), and the type of CRS (CARSEAT) in Section 3.5 were used as the independent variables in the logistic regression analysis.

This section used the SAS LOGISTIC procedure to perform the logistic regression analysis. The following table shows the estimated parameters of independent variables in the full logistic regression model:

Table 120. Full Logistic Regression Model: 3- to 5-Year-Old Child Restraint System Users Experienced Fatalities in Non-Rollover Crashes

Parameter Estimate				
Independent Variable	Estimate	Standard Error	Chi-Square Test	P-value
MALE1=1	-0.1370	0.2381	0.3310	0.5651
AGE1	-0.0278	0.00860	10.4515	0.0012*
AGE2	-0.0425	0.1431	0.0883	0.7664
CENTER=1	-0.1197	0.2920	0.1682	0.6818
CARSEAT=1	-0.5023	0.2317	4.7010	0.0301*

The 3- to 5-year-old car seat users might be significantly less likely to experience fatalities than the 3- to 5-year-old booster seat users, since the estimate of car seat (CARSEAT=1) is negative (-0.5023) with the p-value (0.0301) less than the significance level of 0.05. The 3- to 5-year-old CRS users in center seats might be less likely to experience fatalities than the 3- to 5-year-old CRS users in outboard seats, since the estimate of center seat (CENTER=1) is negative (-0.1197). The likelihood of experiencing fatalities by the 3- to 5-year-old CRS users might significantly decrease when the driver age increases, since the estimate of driver age (AGE1) is negative (-0.0278) with the p-value (0.0012) less than the significance level of 0.05.

This section kept the type of CRS (CARSEAT) in the final logistic regression model and used the forward selection method to remove other independent variables that were not significant in the full logistic regression model. The following table shows the analysis results of the final logistic regression model:

Table 121. Final Logistic Regression Model: 3- to 5-Year-Old Child Restraint System Users Experienced Fatalities in Non-Rollover Crashes

Global Model Test				
	Chi-Square Test		P-value	
Likelihood Ratio	18.5474		<.0001	
Score	17.9678		0.0001	
Wald	17.0888		0.0002	
Parameter Estimate				
Independent Variable	Estimate	Standard Error	Chi-Square Test	P-value
AGE1	-0.0287	0.00848	11.4838	0.0007*
CARSEAT=1	-0.4957	0.2219	4.9888	0.0255*
Odds Ratio Estimate				
Independent Variable	Estimate		95% Confidence Interval	
AGE1	0.972		(0.956, 0.988)	
CARSEAT=1	0.609		(0.394, 0.941)	
Model Fitting Assessment				
C Statistics	0.624			

The final logistic regression model is significant, since the p-values of the likelihood ratio test (<.0001), the score test (0.0001) and the Wald test (0.0002) are less than the significance level of 0.05. The C-statistic is 0.624, and the area under the ROC curve is 0.624 when the final logistic regression model uses the type of CRS (CARSEAT) and the driver age (AGE1) as the independent variables. The final logistic regression model might not substantially fit the analytical data set.

The effect of car seats (CARSEAT=1) on reducing child occupant fatalities is significant, since its p-value (0.0255) is less than the significance level of 0.05. The 3- to 5-year-old car seat users are significantly less likely to experience fatalities than the 3- to 5-year-old booster seat users, since the estimate of car seat (CARSEAT=1) is negative (-0.4957) with the p-value (0.0255) less than the significance level of 0.05. The driver gender, the occupant age, and the occupant seat position are not significant, since their p-values are greater than the significance level of 0.05.

The ratio of the odds of experiencing fatalities by the car seat users to the odds of experiencing fatalities by the booster seat users was estimated by applying Equation 1 and the final logistic regression model estimate of car seat (-0.4957).

$$\left(\frac{\text{Odds}|\text{Car Seat}}{\text{Odds}|\text{Booster Seat}}\right) = \text{Odds Ratio} = \exp(-0.4957) = 0.609$$

The effect of car seats on reducing fatalities experienced by the 3- to 5-year-old CRS users was estimated by using Equation 2.

$$\text{Effect of Car Seats} = \left(1 - \exp(-0.4957)\right) \cdot 100\% = 39.1\%$$

With other variables being held constant, the odds of experiencing fatalities by the 3- to 5-year-old car seat users is 39.1 percent less than the odds of experiencing fatalities by the 3- to 5-year-old booster seat users. The estimated 95 percent confidence interval is between 5.9 percent ((1-0.941)*100%) and 60.6 percent ((1-0.394)*100%) based on the analytical data set from FARS.

The estimated effect of car seats on reducing child occupant fatalities was 39.1 percent by using the logistic regression analysis while the estimated effect of car seats on reducing child occupant fatalities was 42.15 percent by using the double-pair comparison contingency table (see Table 119). The analysis results of the logistic regression analysis and double-pair comparison contingency table were close. This section adopted the analysis results of the logistic regression analysis, since the logistic regression analysis also examined the effects of other independent variables on reducing child occupant fatalities.

The odds of experiencing fatalities by the 3- to 5-year-old CRS users significantly decreases when the driver age increases, since the estimate of driver age (AGE1) is negative (-0.0287) with the p-value (0.0007) less than the significance level of 0.05.

The jackknife technique was used to verify the analysis results of the final logistic regression model, since the analysis results of the final logistic regression analysis might be impacted by data dependency issues. This section used the SAS SURVEYLOGISTIC procedure with VARMETHOD=JACKKNIFE to perform the jackknife logistic regression analysis. The analysis did not use the sampling weight, cluster and strata statements, since data observations in FARS was considered as simple random samples. The following table shows the estimated confident interval of car seat effectiveness by using the jackknife logistic regression model:

Table 122. Jackknife Logistic Regression Model: Car Seat Effectiveness in 3- to 5-Year-Old Child Restraint System Users in Non-Rollover Crashes

Odds Ratio Estimate		
Independent Variable	Estimate	95% Confidence Interval
CARSEAT=1	0.609	(0.393, 0.944)

The estimated confidence interval of car seat effectiveness is between 5.6 percent ((1-0.944)*100%) and 60.7 percent ((1-0.393)*100%) by using the jackknife logistic regression model. The estimated confidence interval built by the jackknife logistic regression model (5.6% to 60.7%) is consistent with the estimated confidence interval built by the final logistic regression model (5.9% to 60.6%). The estimated effectiveness of car seats in reducing child occupant fatalities was not substantially impacted by data dependency issues. This section adopted the analysis results of the final logistic regression model, since the jackknife technique has various forms.

7.2.2 Car Seats: 3- to 5-Year-Old Occupants in All Crashes

This section examined the effect of car seats on reducing fatalities experienced by the 3- to 5-year-old occupants in all crashes by using the analytical data set of all fatal crashes in FARS. The booster seats were used as the reference group of the car seats, and the effect of car seats on reducing child occupant fatalities was compared with the effect of booster seats in the analysis.

The analytical data set in this section was specified from FARS by using the vehicle, driver and occupant conditions in Section 6.2 and the condition of crash mode in Section 6. The CRS users included the car seat and booster seat users, and the analytical data set only included the 3- to 5-year-old CRS users who experienced fatal non-rollover crashes and/or rollover events.

The effect of car seats on reducing fatalities experienced by the 3- to 5-year-old CRS users was estimated by the double-pair comparison analysis. The fatal crashes in the analytical data set that matched one of the following events were included in the double-pair comparison analysis.

1. The 3- to 5-year-old CRS user was killed, but the driver with seat belt and frontal air bag protection was not killed.
2. The 3- to 5-year-old CRS user was not killed, but the driver with seat belt and frontal air bag protection was killed.
3. Both 3- to 5-year-old CRS user and driver with seat belt and frontal air bag protection were killed.

The following table shows the frequencies and risk ratios of fatalities experienced by the 3- to 5-year-old car seat and booster seat users in the double-pair comparison analysi:

Table 123. Double-Pair Comparison Contingency Table of 3- to 5-Year-Old Child Restraint System Users in All Fatal Crashes

	Child Occupant Fatality	Driver Fatality	Child Occupant/Driver Risk Ratio
Car Seat	115	170	0.68
Booster Seat	106	85	1.25

The drivers with seat belt and frontal air bag protection were used as the comparison control group in Table 123. The risk ratio of the fatalities experienced by the 3- to 5-year-old car seat users to the fatalities experienced by the drivers is 0.68 (115/170). The risk ratio of the fatalities experienced by the 3- to 5-year-old booster seat users to the fatalities experienced by the drivers is 1.25 (106/85). The risk ratio of the car seat users (0.68) is less than the risk ratio of the booster seat users (1.25).

The effect of car seats on reducing fatalities experienced by the 3- to 5-year-old CRS users in all crashes was estimated by using Equation 3.

$$\text{Effect of Car Seats} = \left(1 - \left(\frac{115}{170}\right) / \left(\frac{106}{85}\right)\right) \cdot 100\% = 45.6\%$$

The risk ratio of fatalities experienced by the 3- to 5-year-old car seat users is 45.6 percent less than the risk ratio of fatalities experienced by the 3- to 5-year-old booster seat users.

The effect of car seats on reducing fatalities experienced by the 3- to 5-year-old CRS users in all crashes was also estimated by applying the logistic regression analysis to the analytical data set in Table 123, and the effect of car seats was compared with the effect of booster seats in the analysis. The fatality statuses of driver and child occupant (KILL) in Section 6.5 were used as the dependent variable, and the driver's gender (MALE1), the driver age (AGE1), the occupant age (AGE2), the occupant seat position (CENTER), and the type of CRS (CARSEAT) in Section 3.5 were used as the independent variables in the logistic regression analysis.

This section used the SAS LOGISTIC procedure to perform the logistic regression analysis. The following table shows the estimated parameters of independent variables in the full logistic regression model:

Table 124. Full Logistic Regression Model: 3- to 5-Year-Old Child Restraint System Users Experienced Fatalities in All Crashes

Parameter Estimate				
Independent Variable	Estimate	Standard Error	Chi-Square Test	P-value
MALE1=1	-0.2998	0.2036	2.1677	0.1409
AGE1	-0.0265	0.00778	11.5833	0.0007*
AGE2	-0.0410	0.1257	0.1062	0.7445
CENTER=1	-0.0433	0.2628	0.0271	0.8692
CARSEAT=1	-0.5884	0.2030	8.4019	0.0037*

The 3- to 5-year-old car seat users might be significantly less likely to experience fatalities than the 3- to 5-year-old booster seat users, since the estimate of car seat (CARSEAT=1) is negative (-0.5884) with the p-value (0.0301) less than the significance level of 0.05. The 3- to 5-year-old CRS users in center seats might be less likely to experience fatalities than the 3- to 5-year-old CRS users in outboard seats, since the estimate of center seat (CENTER=1) is negative (-0.0433). The likelihood of experiencing fatalities by the 3- to 5-year-old CRS users might significantly decrease when the driver age increases, since the estimate of driver age (AGE1) is negative (-0.0265) with the p-value (0.0007) less than the significance level of 0.05.

This section kept the type of CRS (CARSEAT) in the final logistic regression model and used the forward selection method to remove other independent variables that were not significant in the full logistic regression model. The following table shows the analysis results of the final logistic regression model:

Table 125. Final Logistic Regression Model: 3- to 5-Year-Old Child Restraint System Users Experienced Fatalities in All Crashes

Global Model Test				
	Chi-Square Test		P-value	
Likelihood Ratio	25.1970		<.0001	
Score	24.4298		<.0001	
Wald	23.2492		<.0001	
Parameter Estimate				
Independent Variable	Estimate	Standard Error	Chi-Square Test	P-value
AGE1	-0.0283	0.00767	13.6507	0.0002*
CARSEAT=1	-0.5633	0.1922	8.5873	0.0034*
Odds Ratio Estimate				
Independent Variable	Estimate		95% Confidence Interval	
AGE1	0.972		(0.958, 0.987)	
CARSEAT=1	0.569		(0.391, 0.830)	
Model Fitting Assessment				
C Statistics	0.629			

The final logistic regression model is significant, since the p-values of the likelihood ratio test (<.0001), the score test (<.0001) and the Wald test (<.0001) are less than the significance level of 0.05. The C-statistic is 0.629, and the area under the ROC curve is 0.629 when the final logistic regression model uses the type of CRS (CARSEAT) and the driver age (AGE1) as the independent variables. The final logistic regression model might not substantially fit the analytical data set.

The effect of car seats (CARSEAT=1) on reducing child occupant fatalities is significant, since its p-value (0.0034) is less than the significance level of 0.05. The 3- to 5-year-old car seat users are significantly less likely to experience fatalities than the 3- to 5-year-old booster seat users, since the estimate of car seat (CARSEAT=1) is negative (-0.5633) with the p-value (0.0034) less than the significance level of 0.05. The driver gender, the occupant age, and the occupant seat position are not significant, since their p-values are greater than the significance level of 0.05.

The ratio of the odds of experiencing fatalities by the car seat users to the odds of experiencing fatalities by the booster seat users was estimated by applying Equation 1 and the final logistic regression model estimate of car seat (-0.5633).

$$\left(\frac{\text{Odds}|\text{Car Seat}}{\text{Odds}|\text{Booster Seat}}\right) = \text{Odds Ratio} = \exp(-0.5633) = 0.569$$

The effect of car seats on reducing fatalities experienced by the 3- to 5-year-old CRS users was estimated by using Equation 2.

$$\text{Effect of Car Seats} = \big(1 - \exp(-0.5633)\big) \cdot 100\% = 43.1\%$$

With other variables being held constant, the odds of experiencing fatalities by the 3- to 5-year-old car seat users is 43.1 percent less than the odds of experiencing fatalities by the 3- to 5-year-old booster seat users. The estimated 95 percent confidence interval is between 17 percent ((1-0.830)*100%) and 60.9 percent ((1-0.391)*100%) based on the analytical data set from FARS.

The estimated effect of car seats on reducing child occupant fatalities was 43.1 percent by using the logistic regression analysis while the estimated effect of car seats on reducing child occupant fatalities was 45.6 percent by using the double-pair comparison contingency table (see Table 123). The analysis results of the logistic regression analysis and double-pair comparison contingency table were close. This section adopted the analysis results of the logistic regression analysis, since the logistic regression analysis also examined the effects of other independent variables on reducing child occupant fatalities.

The odds of experiencing fatalities by the 3- to 5-year-old CRS users significantly decreases when the driver age increases, since the estimate of driver age (AGE1) is negative (-0.0283) with the p-value (0.0002) less than the significance level of 0.05.

The jackknife technique was used to verify the analysis results of the final logistic regression model, since the analysis results of the final logistic regression analysis might be impacted by data dependency issues. This section used the SAS SURVEYLOGISTIC procedure with VARMETHOD=JACKKNIFE to perform the jackknife logistic regression analysis. The analysis did not use the sampling weight, cluster and strata statements, since data observations in FARS was considered as simple random samples. The following table shows the estimated confident interval of car seat effectiveness by using the jackknife logistic regression model:

Table 126. Jackknife Logistic Regression Model: Car Seat Effectiveness in 3- to 5-Year-Old Child Restraint System Users in All Crashes

Odds Ratio Estimate		
Independent Variable	Estimate	95% Confidence Interval
CARSEAT=1	0.569	(0.390, 0.831)

The estimated confidence interval of car seat effectiveness is between 16.9 percent ((1-0.831)*100%) and 61 percent ((1-0.390)*100%) by using the jackknife logistic regression model. The estimated confidence interval built by the jackknife logistic regression model (16.9% to 61%) is consistent with the estimated confidence interval built by the final logistic regression model (17% to 60.9%). The estimated effectiveness of car seats in reducing child occupant fatalities was not substantially impacted by data dependency issues. This section adopted the analysis results of the final logistic regression model, since the jackknife technique has various forms.

The estimated effect of car seats on reducing child occupant fatalities in non-rollover crashes (39.1%, see Section 7.2.1) is close to the estimated effect of car seats on reducing child occupant fatalities in all crashes (43.1%, see Section 7.2.2), since the comparison control group (driver with seat belt and frontal air bag protection) eliminated confounding variables that are related to child occupant fatalities in rollovers.

7.3.1 Booster Seats: 4- to 8-Year-Old Occupants in Non-Rollover Crashes

This section examined the effect of booster seats on reducing fatalities experienced by the 4- to 8-year-old occupants in non-rollover crashes by using the analytical data set of fatal non-rollover crashes in FARS. The seat belts were used as the reference group of the booster seats, and the effect of booster seats on reducing child occupant fatalities was compared with the effect of seat belts in the analysis.

The analytical data set in this section was specified from FARS by using the vehicle, driver and occupant conditions in Section 6.2 and the condition of crash mode in Section 6. The analytical data set only included the 4- to 8-year-old booster seat and seat belt users who experienced fatal non-rollover crashes. The data observations in the analytical data set satisfied the following conditions.

<u>Vehicle condition</u>

The collision-crashed passenger vehicle with the GVWR less than 10,000 pounds was manufactured between MY 1999 and 2017. The collision-crashed passenger vehicle experienced no rollovers. There was at least one 4- to 8-year-old booster seat or seat belt user in the collision-crashed passenger vehicle.

<u>Driver condition</u>

The driver was under seat belt and frontal air bag protection. The driver was at least 16 years old.

<u>Occupant condition</u>

The 4- to 8-year-old booster seat or seat belt user sat in the second or the third row of the passenger vehicle in the fatal non-rollover crash.

The following table shows the frequencies and percentages of booster seat and seat belt usages in the analytical data set:

Table 127. Booster Seats and Seat Belts Used by 4- to 8-Year-Old Occupants in Fatal Non-Rollover Crashes

	Frequency	**Percentage**
Booster Seat	695	20.44%
Seat Belt	2,706	79.56%
Total	3,401	100%

There are six hundred ninety-five 4- to 8-year-old booster seat users in the analytical data set. The percentage of booster seat usage is 20.44 percent ((695/3,401)*100%) while the percentage of seat belt usage is 79.56 percent ((2,706/3,403)*100%). The 4- to 8-year-old occupants who experienced fatal non-rollover crashes used seat belts more frequently than booster seats.

The following contingency table shows the frequencies and percentages of fatalities experienced by the 4- to 8-year-old booster seat and seat belt users in fatal non-rollover crashes:

Table 128. Type of Seat Restraints and Status of Fatalities Experienced by 4- to 8-Year-Old Occupants in Fatal Non-Rollover Crashes

	Fatality	Non-fatality	Total
Booster Seat	104 15.01%	589 84.99%	693 100%
Seat Belt	216 8.02%	2,478 91.98%	2,694 100%

There are 104 booster seat users 4- to 8 years old in the analytical data set who experienced fatalities in fatal non-rollover crashes. The percentage of fatalities experienced by the booster seat users is 15.01 percent ((104/693)*100%) while the percentage of fatalities experienced by the seat belt users is 8.02 percent ((216/2,694)*100%). The booster seat users are more likely to experience fatalities in fatal non-rollover crashes than the seat belt users.

The effect of booster seats on reducing fatalities experienced by the 4- to 8-year-old booster seat and seat belt users was estimated by using the double-pair comparison analysis, since the double-pair comparison analysis can extend the analysis results based on FARS to other non-rollover crashes. The fatal non-rollover crashes in the analytical data set that matched one of the following events were included in the double-pair comparison analysis:

1. The 4- to 8-year-old booster seat or seat belt user was killed, but the driver with seat belt and frontal air bag protection was not killed.
2. The 4- to 8-year-old booster seat or seat belt user was not killed, but the driver with seat belt and frontal air bag protection was killed.
3. Both 4- to 8-year-old booster seat or seat belt user and driver with seat belt and frontal air bag protection were killed.

The following table shows the frequencies and risk ratios of fatalities experienced by the 4- to 8-year-old booster seat and seat belt users in the double-pair comparison analysis:

Table 129. Double-Pair Comparison Contingency Table of 4- to 8-Year-Old Booster Seat and Seat Belt Users in Fatal Non-Rollover Crashes

	Child Occupant Fatality	Driver Fatality	Child Occupant/Driver Risk Ratio
Booster Seat	103	105	0.98
Seat Belt	215	316	0.68

The drivers with seat belt and frontal air bag protection were used as the comparison control group in Table 129. The risk ratio of the fatalities experienced by the 4- to 8-year-old booster seat users to the fatalities experienced by the drivers is 0.98 (103/105). The risk ratio of the fatalities experienced by the 4- to 8-year-old seat belt users to the fatalities experienced by the drivers is 0.68 (215/316). The risk ratio of the booster seat users (0.98) is greater than the risk ratio of the seat belt users (0.68).

The effect of booster seats on reducing fatalities experienced by the 4- to 8-year-old booster seat and seat belt users in non-rollover crashes was estimated by using Equation 3.

$$\text{Effect of Booster Seats} = \left(1 - \left(\frac{103}{105}\right) / \left(\frac{215}{316}\right)\right) \cdot 100\% = -44.1\%$$

The risk ratio of fatalities experienced by the 4- to 8-year-old booster seat users is 44.1 percent greater than the risk ratio of fatalities experienced by the 4- to 8-year-old seat belt users. The effect of booster seats on reducing child occupant fatalities is not greater than the effect of seat belts.

The effect of booster seats on reducing fatalities experienced by the 4- to 8-year-old booster seat and seat belt users in non-rollover crashes was also estimated by applying the logistic regression analysis to the analytical data set in Table 129, and the effect of booster seats was compared with the effect of seat belts in the analysis. The fatality statuses of driver and child occupant (KILL) in Section 6.5 were used as the dependent variable, and the driver's gender (MALE1), the driver age (AGE1), the occupant age (AGE2), the occupant seat position (CENTER), and the type of seat restraints (BOOSTERSEAT) in Section 3.5 were used as the independent variables in the logistic regression analysis.

This section used the SAS LOGISTIC procedure to perform the logistic regression analysis. The following table shows the estimated parameters of independent variables in the full logistic regression model:

Table 130. Full Logistic Regression Model: 4- to 8-Year-Old Booster Seat and Seat Belt Users Experienced Fatalities in Non-Rollover Crashes

Parameter Estimate				
Independent Variable	Estimate	Standard Error	Chi-Square Test	P-value
MALE1=1	0.0287	0.1599	0.0322	0.8576
AGE1	-0.0425	0.00650	42.7545	<.0001*
AGE2	0.0190	0.0585	0.1058	0.7449
CENTER=1	0.0766	0.2302	0.1108	0.7393
BOOSTERSEAT=1	0.3677	0.2531	2.1108	0.1463

The 4- to 8-year-old booster seat users might not be less likely to experience fatalities than the 4- to 8-year-old seat belt users, since the estimate of booster seat (BOOSTERSEAT=1) is positive (0.3677). The 4- to 8-year-old booster seat and seat belt users in center seats might not be less likely to experience fatalities than the 4- to 8-year-old booster seat and seat belt users in outboard seats, since the estimate of center seat (CENTER=1) is positive (0.0766). The likelihood of experiencing fatalities by the 4- to 8-year-old booster seat and seat belt users might significantly decrease when the driver age increases, since the estimate of driver age (AGE1) is negative (-0.0425) with the p-value (<.0001) less than the significance level of 0.05.

This section kept the type of seat restraints (BOOSTERSEAT) in the final logistic regression model and used the forward selection method to remove other independent variables that are not significant in the full logistic regression model. The following table shows the analysis results of the final logistic regression model:

Table 131. Final Logistic Regression Model: 4- to 8-Year-Old Booster Seat and Seat Belt Users Experienced Fatalities in Non-Rollover Crashes

Global Model Test				
	Chi-Square Test		P-value	
Likelihood Ratio	5.4232		0.0664	
Score	5.3741		0.0681	
Wald	5.3698		0.0682	
Parameter Estimate				
Independent Variable	Estimate	Standard Error	Chi-Square Test	P-value
AGE1	-0.0420	0.00636	43.6048	<.0001*
BOOSTERSEAT=1	0.3459	0.2531	2.5433	0.1108
Odds Ratio Estimate				
Independent Variable	Estimate		95% Confidence Interval	
AGE1	0.959		(0.947, 0.971)	
BOOSTERSEAT=1	1.413		(0.921, 2.168)	
Model Fitting Assessment				
C Statistics	0.647			

The final logistic regression model is not significant, since the p-values of the likelihood ratio test (0.0664), the score test (0.0681) and the Wald test (0.0682) are less than the significance level of 0.05. The C-statistic is 0.647, and the area under the ROC curve is 0.647 when the final logistic regression model uses the driver age (AGE1) and the type of seat restraints (BOOSTERSEAT) as the independent variables. The final logistic regression model might not substantially fit the analytical data set.

The odds of experiencing fatalities by the 4- to 8-year-old booster seat and seat belt users significantly decreases when the driver age increases, since the estimate of driver age (AGE1) is negative (-0.0420) with the p-value (<.0001) less than the significance level of 0.05.

The type of seat restraints (BOOSTERSEAT) is not significant, since its p-value (0.1108) is greater than the significance level of 0.05. The analysis results from FARS did not demonstrate that the booster seats were effective in reducing fatalities experienced by the 4- to 8-year-old occupants in non-rollover crashes. The driver gender, the occupant age, and the occupant seat position are not significant, since their p-values are greater than the significance level of 0.05.

7.3.2 Booster Seats: 4- to 8-Year-Old Occupants in All Crashes

This section examined the effect of booster seats on reducing fatalities experienced by the 4- to 8-year-old occupants in all crashes by using the analytical data set of all fatal crashes in FARS. The seat belts were used as the reference group of the booster seats, and the effect of booster seats on reducing child occupant fatalities was compared with the effect of seat belts in the analysis.

The analytical data set in this section was specified from FARS by using the vehicle, driver and occupant conditions in Section 6.2 and the condition of crash mode in Section 6. The analytical data set only included the 4- to 8-year-old booster seat and seat belt users who experienced fatal non-rollover crashes and/or rollovers events.

The effect of booster seats on reducing fatalities experienced by the 4- to 8-year-old booster seat and seat belt users was estimated by the double-pair comparison analysis. The fatal crashes in the analytical data set that matched one of the following events were included in the double-pair comparison analysis.

1. The 4- to 8-year-old booster seat or seat belt user was killed, but the driver with seat belt and frontal air bag protection was not killed.
2. The 4- to 8-year-old booster seat or seat belt user was not killed, but the driver with seat belt and frontal air bag protection was killed.
3. Both 4- to 8-year-old booster seat or seat belt user and driver with seat belt and frontal air bag protection were killed.

The following table shows the frequencies and risk ratios of fatalities experienced by the 4- to 8-year-old booster seat and seat belt users in the double-pair comparison analysis:

Table 132. Double-Pair Comparison Contingency Table of 4- to 8-Year-Old Booster Seat and Seat Belt Users in All Fatal Crashes

	Child Occupant Fatality	**Driver Fatality**	**Child Occupant/Driver Risk Ratio**
Booster Seat	149	141	1.06
Seat Belt	273	415	0.66

The drivers with seat belt and frontal air bag protection were used as the comparison control group in Table 132. The risk ratio of the fatalities experienced by the 4- to 8-year-old booster seat users to the fatalities experienced by the drivers is 1.06 (149/141). The risk ratio of the fatalities experienced by the 4- to 8-year-old seat belt users to the fatalities experienced by the drivers is 0.66 (273/415). The risk ratio of the booster seat users (1.06) is greater than the risk ratio of the seat belt users (0.66).

The effect of booster seats on reducing fatalities experienced by the 4- to 8-year-old booster seat and seat belt users in all crashes was estimated by using Equation 3.

$$\text{Effect of Booster Seats} = \left(1 - \left(\frac{149}{141}\right) / \left(\frac{273}{415}\right)\right) \cdot 100\% = -60.6\%$$

The risk ratio of fatalities experienced by the 4- to 8-year-old booster seat users is 60.6 percent greater than the risk ratio of fatalities experienced by the 4- to 8-year-old seat belt users. The effect of booster seats on reducing child occupant fatalities are not be greater than the effect of seat belts.

The effect of booster seats on reducing fatalities experienced by the 4- to 8-year-old booster seat and seat belt users in all crashes was also estimated by applying the logistic regression analysis to the analytical data set in Table 132, and the effect of booster seats was compared with the effect of seat belts in the analysis. The fatality statuses of driver and child occupant (KILL) in Section 6.5 were used as the dependent variable, and the driver's gender (MALE1), the driver age (AGE1), the occupant age (AGE2), the occupant seat position (CENTER), and the type of seat restraints (BOOSTERSEAT) in Section 3.5 were used as the independent variables in the logistic regression analysis.

This section used the SAS LOGISTIC procedure to perform the logistic regression analysis. The following table shows the estimated parameters of independent variables in the full logistic regression model:

Table 133. Full Logistic Regression Model: 4- to 8-Year-Old Booster Seat and Seat Belt Users Experienced Fatalities in All Crashes

Parameter Estimate				
Independent Variable	Estimate	Standard Error	Chi-Square Test	P-value
MALE1=1	-0.0468	0.1368	0.1172	0.7321
AGE1	-0.0358	0.00553	41.9958	<.0001*
AGE2	0.0106	0.0512	0.0430	0.8358
CENTER=1	-0.1392	0.2003	0.4830	0.4871
BOOSTERSEAT=1	0.4560	0.2748	2.7536	0.0970

The 4- to 8-year-old booster seat users might not be less likely to experience fatalities than the 4- to 8-year-old seat belt users, since the estimate of booster seat (BOOSTERSEAT=1) is positive (0.4560). The 4- to 8-year-old booster seat and seat belt users in center seats might be less likely to experience fatalities than the 4- to 8-year-old booster seat and seat belt users in outboard seats, since the estimate of center seat (CENTER=1) is negative (-0.1392). The likelihood of experiencing fatalities by the 4- to 8-year-old booster seat and seat belt users might significantly decrease when the driver age increases, since the estimate of driver age (AGE1) is negative (-0.0358) with the p-value (<.0001) less than the significance level of 0.05.

This section kept the type of seat restraints (BOOSTERSEAT) in the final logistic regression model and used the forward selection method to remove other independent variables that were not significant in the full logistic regression model. The following table shows the analysis results of the final logistic regression model:

Table 134. Final Logistic Regression Model: 4- to 8-Year-Old Booster Seat and Seat Belt Users Experienced Fatalities in All Crashes

Global Model Test		
	Chi-Square Test	P-value
Likelihood Ratio	5.4867	0.0644
Score	5.4985	0.0640
Wald	5.4971	0.0640

Parameter Estimate				
Independent Variable	Estimate	Standard Error	Chi-Square Test	P-value
AGE1	-0.0358	0.00543	43.5482	<.0001*
BOOSTERSEAT=1	0.4561	0.2672	2.9137	0.0878

Odds Ratio Estimate		
Independent Variable	Estimate	95% Confidence Interval
AGE1	0.965	(0.955, 0.975)

BOOSTERSEAT=1	1.578	(0.935, 2.664)
Model Fitting Assessment		
C Statistics	0.658	

The final logistic regression model is not significant, since the p-values of the likelihood ratio test (0.0644), the score test (0.0640) and the Wald test (0.0640) are less than the significance level of 0.05. The C-statistic is 0.658, and the area under the ROC curve is 0.658 when the final logistic regression model uses the driver age (AGE1) and the type of seat restraints (BOOSTERSEAT) as the independent variables. The final logistic regression model might not substantially fit the analytical data set.

The odds of experiencing fatalities by the 4- to 8-year-old booster seat and seat belt users significantly decreases when the driver age increases, since the estimate of driver age (AGE1) is negative (-0.0358) with the p-value (<.0001) less than the significance level of 0.05.

The type of seat restraints (BOOSTERSEAT) is not significant, since its p-value (0.0878) is greater than the significance level of 0.05. The analysis results from FARS did not demonstrate that the booster seats were effective in reducing fatalities experienced by the 4- to 8-year-old occupants in all crashes. The driver gender, the occupant age, and the occupant seat position are not significant, since their p-values are greater than the significance level of 0.05.

The analysis results of the double-pair comparison contingency table and logistic regression analysis indicated that the effect of booster seats on reducing child occupant fatalities might not be greater than the effect of seat belts (see Section 7.3.1 and Section 7.3.2). The effect of booster seats on reducing child occupant fatalities might be underestimated, since FARS did not distinguish between the presence of a booster seat and its proper use. The missing seat restraints might also bias the estimated effect of booster seats on reducing child occupant fatalities. The following table shows the frequencies and percentages of booster seats, seat belts and unknown seat restraints that were used by the 4- to 8-year-old occupants in each State based on FARS 2009-2016 and MY 1999-2017:

Table 135. Type of Seat Restraints used by 4- to 8-Year-Old Occupants in FARS 2009-2016 and MY 1999-2017

State	Booster Seat	Seat Belt	Unknown
Alabama	16 (16.84 %)	72 (75.79 %)	7 (7.37 %)
Alaska	2 (11.76 %)	9 (52.94 %)	6 (35.29 %)
Arizona	4 (2.92 %)	71 (51.82 %)	62 (45.26 %)
Arkansas	7 (7.37 %)	43 (45.26 %)	45 (47.37 %)
California	8 (1.52 %)	245 (46.40 %)	275 (52.08 %)
Colorado	20 (27.40 %)	35 (47.95 %)	18 (24.66 %)
Connecticut	3 (9.38 %)	16 (50.00 %)	13 (40.63 %)
Delaware	4 (25.00 %)	8 (50.00 %)	4 (25.00 %)
District of Columbia	0 (0.00 %)	0 (0.00 %)	1 (100.00 %)
Florida	40 (10.42 %)	295 (76.82 %)	49 (12.76 %)
Georgia	35 (15.84 %)	110 (49.77 %)	76 (34.39%)
Hawaii	2 (22.22 %)	5 (55.56 %)	2 (22.22 %)
Idaho	10 (38.46 %)	14 (53.85 %)	2 (7.69%)
Illinois	4 (2.92%)	72 (52.55 %)	61 (44.53 %)
Indiana	1 (1.56 %)	34 (53.13 %)	29 (45.31 %)
Iowa	4 (16.00 %)	13 (52.00 %)	8 (32.00 %)
Kansas	29 (52.73 %)	21 (38.18 %)	5 (9.09 %)

State	Booster Seat	Seat Belt	Unknown
Kentucky	23 (17.16 %)	76 (56.72 %)	35 (26.12 %)
Louisiana	6 (5.61 %)	69 (64.49 %)	32 (29.91 %)
Maine	5 (35.71 %)	8 (57.14 %)	1 (7.14 %)
Maryland	15 (18.52 %)	29 (35.80 %)	37 (45.68 %)
Massachusetts	0 (0.00 %)	11 (36.67 %)	19 (63.33 %)
Michigan	8 (5.44 %)	68 (46.26 %)	71 (48.30 %)
Minnesota	19 (38.00 %)	18 (36.00 %)	13 (26.00 %)
Mississippi	0 (0.00 %)	50 (53.19 %)	44 (46.81 %)
Missouri	29 (28.16 %)	54 (52.43 %)	20 (19.42 %)
Montana	6 (37.50 %)	10 (62.50 %)	0 (0.00%)
Nebraska	4 (28.57 %)	6 (42.86 %)	4 (28.57 %)
Nevada	4 (8.51 %)	34 (72.34 %)	9 (19.15 %)
New Hampshire	1 (7.69 %)	4 (30.77 %)	8 (61.54 %)
New Jersey	7 (7.37 %)	35 (36.84 %)	53 (55.79 %)
New Mexico	2 (2.86 %)	57 (81.43 %)	11 (15.71 %)
New York	4 (2.68 %)	81 (54.36 %)	64 (42.95 %)
North Carolina	21 (8.33 %)	110 (43.65 %)	121 (48.02 %)
North Dakota	6 (60.00 %)	4 (40.00 %)	0 (0.00 %)
Ohio	36 (21.69 %)	84 (50.60 %)	46 (27.71 %)
Oklahoma	12 (15.00 %)	64 (80.00 %)	4 (5.00 %)
Oregon	9 (16.36 %)	20 (36.36 %)	26 (47.27 %)
Pennsylvania	2 (1.19 %)	60 (35.71 %)	106 (63.10 %)
Rhode Island	0 (0.00 %)	4 (80.00 %)	1 (20.00 %)
South Carolina	2 (1.31 %)	94 (61.44 %)	57 (37.25 %)
South Dakota	0 (0.00 %)	8 (66.67 %)	4 (33.33%)
Tennessee	60 (40.27 %)	76 (51.01 %)	13 (8.72 %)
Texas	137 (23.83 %)	391 (68.00 %)	47 (8.17 %)
Utah	17 (40.48 %)	24 (57.14 %)	1 (2.38 %)
Vermont	1 (50.00 %)	1 (50.00 %)	0 (0.00 %)
Virginia	20 (33.90 %)	21 (35.59 %)	18 (30.51 %)
Washington	37 (44.05%)	26 (30.95 %)	21 (25.00 %)
West Virginia	4 (23.53 %)	13 (76.47 %)	0 (0.00 %)
Wisconsin	4 (5.00 %)	32 (40.00 %)	44 (55.00 %)
Wyoming	5 (62.50 %)	3 (37.50 %)	0 (0.00 %)

FARS 2009-2016 and MY 1999-2017 provided limited information about the type of seat restraints that were used by the 4- to 8-year-old occupants in fatal crashes, since the percentages of unknown seat restraints were substantial in some densely populated States. For example, the percentages of unknown seat restraints in California (52.08 %), Illinois (44.53 %) and New Jersey (55.79 %) are close to 50 percent. The unknown seat restraints caused missing data and reduced sample size of the analytical data set, and the reduced sample size might inflate the variance estimate and influence the significance of booster seat effectiveness in the logistic regression analysis.

Booster seats might be more likely to be recorded as unknown seat restraints than seat belts in FARS. For example, police officers and emergency medical technicians routinely carry child occupants in their CRSs away from the crash scene, but the CRSs might be discarded after the crash. In these cases, data of CRSs might not be collected even though it was used. As another example, some States[32] did not have a booster seat category in their PCRs, and the data from these States provided limited information about booster seat usage. The type of seat restraints in

[32] Arizona, California, Colorado, Georgia, Illinois, Indiana, Louisiana, Massachusetts, Mississippi, Nevada, New Jersey, New York, North Carolina, Oregon, Pennsylvania, Puerto Rico, South Carolina, South Dakota, Vermont, and Virgin Islands.

the double-pair comparison contingency tables (see Table 129 and Table 132) might not be missing at random, and the issue of data missing not at random might bias the estimated effect of booster seats on reducing child occupant fatalities. As a result, the estimated effect of booster seats on reducing fatalities experienced by the 4- to 8-year-old occupants might be influenced by the substantial rate of missing data and the issue of data missing not at random.

7.4.1 Booster Seats: 7- to 8-Year-Old Occupants in Non-Rollover Crashes

This section examined the effect of booster seats on reducing fatalities experienced by the 7- to 8-year-old occupants in non-rollover crashes by using the analytical data set of fatal non-rollover crashes in FARS. The seat belts were used as the reference group of the booster seats, and the effect of booster seats on reducing child occupant fatalities was compared with the effect of seat belts in the analysis.

The analytical data set in this section was specified from FARS by using the vehicle, driver and occupant conditions in Section 6.2 and the condition of crash mode in Section 6. The analytical data set only included the 7- to 8-year-old booster seat and seat belt users who experienced fatal non-rollover crashes. The data observations in the analytical data set satisfied the following conditions.

<u>Vehicle condition</u>

The collision-crashed passenger vehicle with the GVWR less than 10,000 pounds was manufactured between MY 1999 and 2017. The collision-crashed passenger vehicle experienced no rollovers. There was at least one 7- to 8-year-old booster seat or seat belt user in the collision-crashed passenger vehicle.

<u>Driver condition</u>

The driver was under seat belt and frontal air bag protection. The driver was at least 16 years old.

<u>Occupant condition</u>

The 7- to 8-year-old booster seat or seat belt user sat in the second or the third row of the passenger vehicle in the fatal non-rollover crash.

The following table shows the frequencies and percentages of booster seat and seat belt usages in the analytical data set:

Table 136. Booster Seats and Seat Belts Used by 7- to 8-Year-Old Occupants in Fatal Non-Rollover Crashes

	Frequency	**Percentage**
Booster Seat	181	10.86 %
Seat Belt	1,485	89.14 %
Total	1,666	100 %

There are 181 booster seat users 7- to 8 years old in the analytical data set. The percentage of booster seat usage is 10.86 percent ((181/1,666)*100%) while the percentage of seat belt usage is

89.14 percent ((1,485/1,666)*100%). The 7- to 8-year-old occupants who experienced fatal non-rollover crashes used seat belts more frequently than booster seats.

The following contingency table shows the frequencies and percentages of fatalities experienced by the 7- to 8-year-old booster seat and seat belt users in fatal non-rollover crashes:

Table 137. Type of Seat Restraints and Status of Fatalities Experienced by 7- to 8-Year-Old Occupants in Fatal Non-Rollover Crashes

	Fatality	**Non-fatality**	**Total**
Booster Seat	22 12.15%	159 87.85%	181 100%
Seat Belt	119 8.04%	1,361 91.96%	1,480 100 %

There are 22 booster seat users 7- to 8 years old in the analytical data set who experienced fatalities in fatal non-rollover crashes. The percentage of fatalities experienced by the booster seat users is 12.15 percent ((22/181)*100%) while the percentage of fatalities experienced by the seat belt users is 8.04 percent ((119/1480)*100%). The booster seat users are more likely to experience fatalities in fatal non-rollover crashes than the seat belt users.

The effect of booster seats on reducing fatalities experienced by the 7- to 8-year-old booster seat and seat belt users was estimated by using the double-pair comparison analysis, since the double-pair comparison analysis can extend the analysis results based on FARS to other non-rollover crashes. The fatal non-rollover crashes in the analytical data set that matched one of the following events were included in the double-pair comparison analysis:

1. The 7- to 8-year-old booster seat or seat belt user was killed, but the driver with seat belt and frontal air bag protection was not killed.
2. The 7- to 8-year-old booster seat or seat belt user was not killed, but the driver with seat belt and frontal air bag protection was killed.
3. Both 7- to 8-year-old booster seat or seat belt user and driver with seat belt and frontal air bag protection were killed.

The following table shows the frequencies and risk ratios of fatalities experienced by the 7- to 8-year-old booster seat and seat belt users in the double-pair comparison analysis:

Table 138. Double-Pair Comparison Contingency Table of 7- to 8-Year-Old Booster Seat and Seat Belt Users in Fatal Non-Rollover Crashes

	Child Occupant Fatality	**Driver Fatality**	**Child Occupant/Driver Risk Ratio**
Booster Seat	22	28	0.79
Seat Belt	118	173	0.68

The drivers with seat belt and frontal air bag protection were used as the comparison control group in Table 138. The risk ratio of the fatalities experienced by the 7- to 8-year-old booster seat users to the fatalities experienced by the drivers is 0.79 (22/28). The risk ratio of the fatalities experienced by the 7- to 8-year-old seat belt users to the fatalities experienced by the drivers is 0.68 (118/173). The risk ratio of the booster seat users (0.79) is greater than the risk ratio of the seat belt users (0.68).

The effect of booster seats on reducing fatalities experienced by the 7- to 8-year-old booster seat and seat belt users in non-rollover crashes was estimated by using Equation 3.

$$\text{Effect of Booster Seats} = \left(1 - \left(\frac{22}{28}\right) / \left(\frac{118}{173}\right)\right) \cdot 100\% = -16.2\%$$

The risk ratio of fatalities experienced by the 7- to 8-year-old booster seat users is 16.2 percent greater than the risk ratio of fatalities experienced by the 7- to 8-year-old seat belt users. The effect of booster seats on reducing child occupant fatalities is not greater than the effect of seat belts.

The effect of booster seats on reducing fatalities experienced by the 7- to 8-year-old booster seat and seat belt users in non-rollover crashes was also estimated by applying the logistic regression analysis to the analytical data set in Table 138, and the effect of booster seats was compared with the effect of seat belts in the analysis. The fatality statuses of driver and child occupant (KILL) in Section 6.5 were used as the dependent variable, and the driver's gender (MALE1), the driver age (AGE1), the occupant age (AGE2), the occupant seat position (CENTER), and the type of seat restraints (BOOSTERSEAT) in Section 3.5 were used as the independent variables in the logistic regression analysis.

This section used the SAS LOGISTIC procedure to perform the logistic regression analysis. The following table shows the estimated parameters of independent variables in the full logistic regression model:

Table 139. Full Logistic Regression Model: 7- to 8-Year-Old Booster Seat and Seat Belt Users Experienced Fatalities in Non-Rollover Crashes

Parameter Estimate				
Independent Variable	Estimate	Standard Error	Chi-Square Test	P-value
MALE1=1	0.3004	0.2340	1.6471	0.1994
AGE1	-0.0442	0.00981	20.3002	<.0001*
AGE2	0.0972	0.2310	0.1772	0.6738
CENTER=1	0.3206	0.3349	0.9164	0.3384
BOOSTERSEAT=1	0.1621	0.3218	0.2539	0.6143

The 7- to 8-year-old booster seat users might not be less likely to experience fatalities than the 7- to 8-year-old seat belt users, since the estimate of booster seat (BOOSTERSEAT=1) is positive (0.1621). The 7- to 8-year-old booster seat and seat belt users in center seats might not be less likely to experience fatalities than the 7- to 8-year-old booster seat and seat belt users in outboard seats, since the estimate of center seat (CENTER=1) is positive (0.3206). The likelihood of experiencing fatalities by the 7- to 8-year-old booster seat and seat belt users might significantly decrease when the driver age increases, since the estimate of driver age (AGE1) is negative (-0.0442) with the p-value (<.0001) less than the significance level of 0.05.

This section kept the type of seat restraints (BOOSTERSEAT) in the final logistic regression model and used the forward selection method to remove other independent variables that are not significant in the full logistic regression model. The following table shows the analysis results of the final logistic regression model:

Table 140. Final Logistic Regression Model: 7- to 8-Year-Old Booster Seat and Seat Belt Users Experienced Fatalities in Non-Rollover Crashes

Global Model Test				
	Chi-Square Test		P-value	
Likelihood Ratio	22.3785		<.0001	
Score	20.7786		<.0001	
Wald	19.2400		<.0001	
Parameter Estimate				
Independent Variable	Estimate	Standard Error	Chi-Square Test	P-value
AGE1	-0.0417	0.00954	19.0754	<.0001*
BOOSTERSEAT=1	0.1741	0.3177	0.3004	0.5836
Odds Ratio Estimate				
Independent Variable	Estimate		95% Confidence Interval	
AGE1	0.959		(0.941, 0.977)	
BOOSTERSEAT=1	1.190		(0.639, 2.219)	
Model Fitting Assessment				
C Statistics	0.634			

The final logistic regression model is significant, since the p-values of the likelihood ratio test (<.0001), the score test (<.0001) and the Wald test (<.0001) are less than the significance level of 0.05. The C-statistic is 0.634, and the area under the ROC curve is 0.634 when the final logistic regression model uses the driver age (AGE1) and the type of seat restraints (BOOSTERSEAT) as the independent variables. The final logistic regression model might not substantially fit the analytical data set.

The odds of experiencing fatalities by the 7- to 8-year-old booster seat and seat belt users significantly decreases when the driver age increases, since the estimate of driver age (AGE1) is negative (-0.0417) with the p-value (<.0001) less than the significance level of 0.05.

The type of seat restraints (BOOSTERSEAT) is not significant, since its p-value (0.5836) is greater than the significance level of 0.05. The analysis results from FARS did not demonstrate that the booster seats were effective in reducing fatalities experienced by the 7- to 8-year-old occupants in non-rollover crashes. The driver's gender, the occupant age and the occupant seat position are not significant, since their p-values are greater than the significance level of 0.05.

7.4.2 Booster Seats: 7- to 8-Year-Old Occupants in All Crashes

This section examined the effect of booster seats on reducing fatalities experienced by the 7- to 8-year-old occupants in all crashes by using the analytical data set of all fatal crashes in FARS. The seat belts were used as the reference group of the booster seats, and the effect of booster seats on reducing child occupant fatalities was compared with the effect of seat belts in the analysis.

The analytical data set in this section was specified from FARS by using the vehicle, driver and occupant conditions in Section 6.2 and the condition of crash mode in Section 6. The analytical data set only included the 7- to 8-year-old booster seat and seat belt users who experienced fatal non-rollover crashes and/or rollovers events.

The effect of booster seats on reducing fatalities experienced by the 7- to 8-year-old booster seat and seat belt users was estimated by the double-pair comparison analysis. The fatal crashes in the analytical data set that matched one of the following events were included in the double-pair comparison analysis:

1. The 7- to 8-year-old booster seat or seat belt user was killed, but the driver with seat belt and frontal air bag protection was not killed.
2. The 7- to 8-year-old booster seat or seat belt user was not killed, but the driver with seat belt and frontal air bag protection was killed.
3. Both 7- to 8-year-old booster seat or seat belt user and driver with seat belt and frontal air bag protection were killed.

The following table shows the frequencies and risk ratios of fatalities experienced by the 7- to 8-year-old booster seat and seat belt users in the double-pair comparison analysis:

Table 141. Double-Pair Comparison Contingency Table of 7- to 8-Year-Old Booster Seat and Seat Belt Users in All Fatal Crashes

	Child Occupant Fatality	**Driver Fatality**	**Child Occupant/Driver Risk Ratio**
Booster Seat	33	33	1
Seat Belt	145	223	0.65

The drivers with seat belt and frontal air bag protection were used as the comparison control group in Table 141. The risk ratio of the fatalities experienced by the 7- to 8-year-old booster seat users to the fatalities experienced by the drivers is 1 (33/33). The risk ratio of the fatalities experienced by the 7- to 8-year-old seat belt users to the fatalities experienced by the drivers is 0.65 (145/223). The risk ratio of the booster seat users (1) is greater than the risk ratio of the seat belt users (0.65).

The effect of booster seats on reducing fatalities experienced by the 7- to 8-year-old booster seat and seat belt users in all crashes was estimated by using Equation 3.

$$\text{Effect of Car Seats} = \left(1 - \left(\frac{33}{33}\right) / \left(\frac{145}{223}\right)\right) \cdot 100\% = -53.8\%$$

The risk ratio of fatalities experienced by the 7- to 8-year-old booster seat users is 53.8 percent greater than the risk ratio of fatalities experienced by the 7- to 8-year-old seat belt users. The effect of booster seats on reducing child occupant fatalities are not be greater than the effect of seat belts.

The effect of booster seats on reducing fatalities experienced by the 7- to 8-year-old booster seat and seat belt users in all crashes was also estimated by applying the logistic regression analysis to the analytical data set in Table 141, and the effect of booster seats was compared with the effect of seat belts in the analysis. The fatality statuses of driver and child occupant (KILL) in Section 6.5 were used as the dependent variable, and the driver's gender (MALE1), the driver age (AGE1), the occupant age (AGE2), the occupant seat position (CENTER), and the type of seat restraints (BOOSTERSEAT) in Section 3.5 were used as the independent variables in the logistic regression analysis.

This section used the SAS LOGISTIC procedure to perform the logistic regression analysis. The following table shows the estimated parameters of independent variables in the full logistic regression model:

Table 142. Full Logistic Regression Model: 7- to 8-Year-Old Booster Seat and Seat Belt Users Experienced Fatalities in All Crashes

Parameter Estimate				
Independent Variable	Estimate	Standard Error	Chi-Square Test	P-value
MALE1=1	0.1597	0.2024	0.6225	0.4301
AGE1	-0.0312	0.00808	14.8576	0.0001*
AGE2	0.1150	0.2021	0.3238	0.5694
CENTER=1	0.00393	0.2877	0.0002	0.9891
BOOSTERSEAT=1	0.4718	0.2761	2.9190	0.0875

The 7- to 8-year-old booster seat users might not be less likely to experience fatalities than the 7- to 8-year-old seat belt users, since the estimate of booster seat (BOOSTERSEAT=1) is positive (0.4718). The 7- to 8-year-old booster seat and seat belt users in center seats might not be less likely to experience fatalities than the 7- to 8-year-old booster seat and seat belt users in outboard seats, since the estimate of center seat (CENTER=1) is positive (0.00393). The likelihood of experiencing fatalities by the 7- to 8-year-old booster seat and seat belt users might significantly decrease when the driver age increases, since the estimate of driver age (AGE1) is negative (-0.0312) with the p-value (0.0001) less than the significance level of 0.05.

This section kept the type of seat restraints (BOOSTERSEAT) in the final logistic regression model and used the forward selection method to remove other independent variables that were not significant in the full logistic regression model. The following table shows the analysis results of the final logistic regression model:

Table 143. Final Logistic Regression Model: 7- to 8-Year-Old Booster Seat and Seat Belt Users Experienced Fatalities in All Crashes

Global Model Test				
	Chi-Square Test		P-value	
Likelihood Ratio	18.4931		<.0001	
Score	17.6901		0.0001	
Wald	16.8622		0.0002	
Parameter Estimate				
Independent Variable	Estimate	Standard Error	Chi-Square Test	P-value
AGE1	-0.0305	0.00799	14.5296	0.0001
BOOSTERSEAT=1	0.4701	0.2737	2.9495	0.0859

Odds Ratio Estimate		
Independent Variable	Estimate	95% Confidence Interval
AGE1	0.970	(0.955, 0.985)
BOOSTEREAT=1	1.600	(0.936, 2.736)
Model Fitting Assessment		
C Statistics	0.617	

The final logistic regression model is significant, since the p-values of the likelihood ratio test (<.0001), the score test (0.0001) and the Wald test (0.0002) are less than the significance level of 0.05. The C-statistic is 0.617, and the area under the ROC curve is 0.617 when the final logistic regression model uses the driver age (AGE1) and the type of seat restraints (BOOSTERSEAT) as the independent variables. The final logistic regression model might not substantially fit the analytical data set.

The odds of experiencing fatalities by the 7- to 8-year-old booster seat and seat belt users significantly decreases when the driver age increases, since the estimate of driver age (AGE1) is negative (-0.0305) with the p-value (0.0001) less than the significance level of 0.05.

The type of seat restraints (BOOSTERSEAT) is not significant, since its p-value (0.0859) is greater than the significance level of 0.05. The analysis results from FARS did not demonstrate that the booster seats were effective in reducing fatalities experienced by the 7- to 8-year-old occupants in all crashes. The driver's gender, the occupant age and the occupant seat position are not significant, since their p-values are greater than the significance level of 0.05.

The analysis results of the double-pair comparison contingency table and logistic regression analysis indicated that the effect of booster seats on reducing child occupant fatalities might not be greater than the effect of seat belts (see Section 7.4.1 and Section 7.4.2). The effect of booster seats on reducing child occupant fatalities might be underestimated, since FARS did not distinguish between the presence of a booster seat and its proper use. The missing seat restraints might also bias the estimated effect of booster seats on reducing child occupant fatalities. The following table shows the frequencies and percentages of booster seats, seat belts and unknown seat restraints that were used by the 7- to 8-year-old occupants in each State based on FARS 2009-2016 and MY 1999-2017:

Table 144. Type of Seat Restraints used by 7- to 8-Year-Old Occupants in FARS 2009-2016 and MY 1999-2017

State	Booster Seat	Seat Belt	Missing
Alabama	3 (6.38 %)	43 (91.49 %)	1 (2.13 %)
Alaska	0 (0.00 %)	3 (75.00 %)	1 (25.00 %)
Arizona	1 (2.33 %)	36 (83.72 %)	6 (13.95 %)
Arkansas	1 (3.33 %)	27 (90.00 %)	2 (6.67 %)
California	1 (0.50 %)	150 (74.63 %)	50 (24.48 %)
Colorado	4 (14.29 %)	24 (85.71 %)	0 (0.00 %)
Connecticut	0 (0.00 %)	10 (83.33 %)	2 (16.67 %)
Delaware	0 (0.00 %)	5 (83.33 %)	1 (16.67 %)
District of Columbia	0 (0.00 %)	0 (0.00 %)	1 (100.00 %)
Florida	8 (4.97 %)	147 (91.30 %)	6 (3.73 %)
Georgia	12 (13.64 %)	62 (70.45 %)	14 (15.91 %)
Hawaii	1 (20.00 %)	4 (80.00 %)	0 (0.00 %)
Idaho	0 (0.00 %)	9 (100.00 %)	0 (0.00 %)

State	Booster Seat	Seat Belt	Missing
Illinois	2 (4.00 %)	36 (72.00 %)	12 (24.00 %)
Indiana	0 (0.00 %)	23 (79.31 %)	6 (20.69 %)
Iowa	2 (28.57 %)	3 (42.86 %)	2 (28.57 %)
Kansas	7 (33.33 %)	14 (66.67 %)	0 (0.00 %)
Kentucky	5 (9.62 %)	41 (78.85 %)	6 (11.54 %)
Louisiana	1 (2.22 %)	40 (88.89 %)	4 (8.89 %)
Maine	1 (14.29 %)	6 (85.71 %)	0 (0.00 %)
Maryland	3 (11.11 %)	14 (51.85 %)	10 (37.04 %)
Massachusetts	0 (0.00 %)	9 (56.25 %)	7 (43.75 %)
Michigan	2 (3.33 %)	44 (73.33 %)	14 (23.33 %)
Minnesota	7 (28.00 %)	14 (56.00 %)	4 (16.00 %)
Mississippi	0 (0.00 %)	20 (76.92 %)	6 (23.08 %)
Missouri	6 (14.63 %)	31 (75.61 %)	4 (9.76 %)
Montana	3 (37.50 %)	5 (62.50 %)	0 (0.00 %)
Nebraska	1 (14.29 %)	4 (57.14 %)	2 (28.57 %)
Nevada	1 (5.00 %)	18 (90.00 %)	1 (5.00 %)
New Hampshire	0 (0.00 %)	3 (60.00 %)	2 (40.00 %)
New Jersey	2 (5.13 %)	22 (56.41 %)	15 (38.46 %)
New Mexico	1 (3.70 %)	23 (85.19 %)	3 (11.11 %)
New York	4 (6.78 %)	44 (74.58 %)	11 (18.64 %)
North Carolina	7 (8.05 %)	63 (72.41 %)	17 (19.54 %)
North Dakota	3 (60.00 %)	2 (40.00 %)	0 (0.00 %)
Ohio	9 (15.00 %)	43 (71.67 %)	8 (13.33 %)
Oklahoma	4 (13.79 %)	25 (86.21 %)	0 (0.00 %)
Oregon	6 (28.57 %)	12 (57.14 %)	3 (14.29 %)
Pennsylvania	0 (0.00 %)	33 (55.00 %)	27 (45.00 %)
Rhode Island	0 (0.00 %)	2 (100.00 %)	0 (0.00 %)
South Carolina	2 (3.17 %)	51 (80.95 %)	10 (15.87 %)
South Dakota	0 (0.00 %)	3 (75 .00 %)	1 (25.00 %)
Tennessee	24 (36.36 %)	40 (60.61 %)	2 (3.03 %)
Texas	29 (11.46 %)	209 (82.61 %)	15 (5.93 %)
Utah	3 (17.65 %)	14 (82.35 %)	0 (0.00 %)
Vermont	0 (0.00 %)	1 (100.00 %)	0 (0.00 %)
Virginia	4 (20 .00 %)	13 (65.00 %)	3 (15 .00 %)
Washington	9 (30.00 %)	18 (60.00 %)	3 (10.00 %)
West Virginia	1 (16.67 %)	5 (83.33 %)	0 (0.00 %)
Wisconsin	1 (3.85 %)	15 (57.69 %)	10 (38.46 %)
Wyoming	0 (0.00 %)	3 (100.00 %)	0 (0.00 %)

FARS 2009-2016 and MY 1999-2017 provided limited information about the type of seat restraints that were used by the 7- to 8-year-old occupants in fatal crashes, since the percentages of unknown seat restraints were substantial in some densely populated States. For example, the percentages of unknown seat restraints in Maryland (37.04 %), Massachusetts (43.75 %) and New Jersey (38.46 %) are close to 40 percent. The unknown seat restraints might inflate the variance estimate and influence the significance of booster seat effectiveness in the logistic regression analysis.

The seat restraints in Table 143 might not be missing at random, since booster seats might be more likely to be recorded as unknown seat restraints than seat belts in FARS. For example, the booster seats might be disposed before police officers collected the information about the seat restraints. As another example, the information about booster seats was limited in States that did not have a booster seat category in their PCRs. As a result, the estimated effect of booster seats on reducing fatalities experienced by the 7- to 8-year-old occupants might be influenced by the substantial rate of missing data and the issue of data missing not at random.

7.5 Summary: Child Restraint System Effectiveness With Respect to Child Occupant Fatalities

FARS distinguished car seats from booster seats starting in 2008, and the FARS data from 2009-2016 was used to examine the effects of CRSs on reducing child fatalities. The effects of CRSs on reducing child occupant fatalities were separately examined in the analytical data sets of fatal non-rollover crashes and all fatal crashes. Crashed vehicles in the analytical data set of fatal non-rollover crashes experienced no rollovers while crashed vehicles in the analytical data set of all fatal crashes experienced fatal non-rollover crashes and/or rollovers.

The CRSs included the car seats and booster seats. The 1- to 8-year-old occupants were separated into different age groups. The effects of CRSs on reducing fatalities experienced by the child occupants in different age groups were separately examined in Section 7.1.1 to 7.4.2.

The effects of different types of CRSs on reducing child occupant fatalities were estimated by using the double-pair comparison analysis. The double-pair comparison analysis extends the analysis results based on fatal crashes to both fatal and non-fatal crashes. Based on the analytical data set of the double-pair comparison, logistic regression analysis was also used to examine the effectiveness of CRSs in child occupant fatalities. The SAS LOGISTIC procedure was used to perform the logistic regression analysis. The logistic regression analysis examined the effects of other independent variables associated with child occupant fatalities. The driver's gender, the driver age, the occupant age, and the occupant seat position were used as the independent variables in the logistic regression analysis.

This section summarizes the effects of CRSs and occupant's seat position, since the occupant seat position might influence the effects of CRSs. The following summary shows the analysis results of occupants in different age groups.

<u>Car Seats: 1- to 3-Year-Old Occupants in Non-Rollover Crashes</u>

The booster seats were used as the reference group of the car seats. The effect of car seats on reducing fatalities experienced by the 1- to 3-year-old CRS users in non-rollover crashes was significantly greater than the effect of booster seats based on the analysis results from FARS.

Table 145. Car Seats on Reducing Fatalities Experienced by 1- to 3-Year-Old Child Restraint System Users in Non-Rollover Crashes

Evaluated Group	Reference Group	Estimated Effect	95 % Confidence Interval
Car Seat	Booster Seat	52.3%	(9.7%, 74.8%)

With other variables being held constant, the odds of experiencing fatalities by the 1- to 3-year-old car seat users is 52.3 percent less than the odds of experiencing fatalities by the 1- to 3-year-old booster seat users. The estimated 95 percent confidence interval is between 9.7 percent and 74.8 percent based on the analytical data set from FARS.

Car Seats: 1- to 3-Year-Old Occupants in All Crashes

The booster seats were used as the reference group of the car seats. The effect of car seats on reducing fatalities experienced by the 1- to 3-year-old CRS users in all crashes was significantly greater than the effect of booster seats based on the analysis results from FARS.

Table 146. Car Seats on Reducing Fatalities Experienced by 1- to 3-Year-Old Child Restraint System Users in All Crashes

Evaluated Group	Reference Group	Estimated Effect	95 % Confidence Interval
Car Seat	Booster Seat	47.3%	(8.3%, 96.7%)

With other variables being held constant, the odds of experiencing fatalities by the 1- to 3-year-old car seat users is 47.3 percent less than the odds of experiencing fatalities by the 1- to 3-year-old booster seat users. The estimated 95 percent confidence interval is between 8.3 percent and 96.7 percent based on the analytical data set from FARS.

The outboard seats were used as the reference group of the center seats. The effect of center seats on reducing fatalities experienced by the 1- to 3-year-old CRS users in all crashes was significantly greater than the effect of outboard seats based on the analysis results from FARS.

Table 147. Center Seats on Reducing Fatalities Experienced by 1- to 3-Year-Old Child Restraint System Users in All Crashes

Evaluated Group	Reference Group	Estimated Effect	95 % Confidence Interval
Center Seat	Outboard Seat	42.9%	(10.4%, 63.6%)

With other variables being held constant, the odds of experiencing fatalities by the 1- to 3-year-old CRS users in center seats is 42.9 percent less than the odds of experiencing fatalities by the 1- to 3-year-old CRS users in outboard seats. The estimated 95 percent confidence interval is between 10.4 percent and 63.6 percent based on the analytical data set from FARS.

Car Seats: 3- to 5-Year-Old Occupants in Non-Rollover Crashes

The booster seats were used as the reference group of the car seats. The effect of car seats on reducing fatalities experienced by the 3- to 5-year-old CRS users in non-rollover crashes was significantly greater than the effect of booster seats based on the analysis results from FARS.

Table 148. Car Seats on Reducing Fatalities Experienced by 3- to 5-Year-Old Child Restraint System Users in Non-Rollover Crashes

Evaluated Group	Reference Group	Estimated Effect	95 % Confidence Interval
Car Seat	Booster Seat	39.1%	(5.9%, 60.6%)

With other variables being held constant, the odds of experiencing fatalities by the 3- to 5-year-old car seat users is 39.1 percent less than the odds of experiencing fatalities by the 3- to 5-year-old booster seat users. The estimated 95 percent confidence interval is between 5.9 percent and 60.6 percent based on the analytical data set from FARS.

Car Seats: 3- to 5-Year-Old Occupants in All Crashes

The booster seats were used as the reference group of the car seats. The effect of car seats on reducing fatalities experienced by the 3- to 5-year-old CRS users in all crashes was significantly greater than the effect of booster seats based on the analysis results from FARS.

Table 149. Car Seats on Reducing Fatalities Experienced by 3- to 5-Year-Old Child Restraint System Users in All Crashes

Evaluated Group	Reference Group	Estimated Effect	95 % Confidence Interval
Car Seat	Booster Seat	43.1%	(17%, 60.9%)

With other variables being held constant, the odds of experiencing fatalities by the 3- to 5-year-old car seat users is 43.1 percent less than the odds of experiencing fatalities by the 3- to 5-year-old booster seat users. The estimated 95 percent confidence interval is between 17 percent and 60.9 percent based on the analytical data set from FARS.

8 Conclusion

It is certainly possible that the effectiveness of child safety systems could be underestimated due to their improper use or installation. Improper use of CRSs could decrease their effectiveness at reducing injuries and fatalities. Greenwell[33] (2015) estimated the nationwide rate of misused CRSs at 46 percent. This evaluation cannot resolve potential underestimation of CRS effectiveness, since there are no variables in NASS-CDS and FARS describing the installation and usage of CRSs.

The effects of CRSs on 1- to 8-year-old occupants in different age groups were separately examined. This evaluation examined the analytical data set both with and without rollover crashes, since the distributions of injury severity and fatalities in rollover events were different from the distributions of injury severity and fatalities in non-rollover crashes.

The effect of car seats on reducing fatalities experienced by 1- to 3-year-old children is significant. The following table shows the estimated effectiveness of car seats in fatal crashes for non-rollover crashes and crashes including rollovers:

Fatalities in Non-Rollover Crashes			
Evaluated Group	Reference Group	Estimated Effect	95 % Confidence Interval
Car Seat	Booster Seat	52.3%	(9.7%, 74.8%)
Fatalities in All Crashes			
Evaluated Group	Reference Group	Estimated Effect	95 % Confidence Interval
Car Seat	Booster Seat	47.3%	(8.3%, 96.7%)

[33] Greenwell, K. N. (2015, May). *Results of the National Child Restraint Use Special Study* (Report No. DOT HS 812 142). National Highway Traffic Safety Administration. Available at https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812142.

The effect of car seats on reducing fatalities experienced by the 3- to 5-year-old children is significant. The following table shows the estimated effectiveness of car seats in fatal crashes for non-rollover crashes and crashes including rollovers:

Fatalities in Non-Rollover Crashes			
Evaluated Group	Reference Group	Estimated Effect	95 % Confidence Interval
Car Seat	Booster Seat	39.1%	(5.9%, 60.6%)
Fatalities in All Crashes			
Evaluated Group	Reference Group	Estimated Effect	95 % Confidence Interval
Car Seat	Booster Seat	43.1%	(17%, 60.9%)

The effect of booster seats on reducing moderate to critical injuries (injuries with MAIS ≥ 2) experienced by the 5- to 8-year-old occupants is significant. The following table shows the estimated effectiveness of booster seats on reducing moderate to critical injuries experienced by the 5- to 8-year-old occupants based on the analytical data set from NASS-CDS:

Moderate to Critical Injuries in Non-Rollover Crashes			
Evaluated Group	Reference Group	Estimated Effect	95 % Confidence Interval
Booster Seat	Seat Belt	74.9%	(49.9%, 87.4%)
Moderate to Critical Injuries in All Crashes			
Evaluated Group	Reference Group	Estimated Effect	95 % Confidence Interval
Booster Seat	Seat Belt	65.5%	(6.6%, 87.3%)

The effect of booster seats on reducing serious to critical injuries (injuries ≥ 3) experienced by the 5- to 8-year-old occupants is significant. The following table shows the estimated effectiveness of booster seats on reducing serious to critical injuries experienced by the 5- to 8-year-old occupants based on the analytical data set from NASS-CDS:

Serious to Critical Injuries in Non-Rollover Crashes			
Evaluated Group	Reference Group	Estimated Effect	95 % Confidence Interval
Booster Seat	Seat Belt	74.3%	(17.4%, 92.0%)
Serious to Critical Injuries in All Crashes			
Evaluated Group	Reference Group	Estimated Effect	95 % Confidence Interval
Booster Seat	Seat Belt	67.3%	(2.0%, 89.1%)

The effect of booster seats on reducing moderate to critical injuries experienced by the 7- to 8-year-old occupants is significant. The following table shows the estimated effectiveness of booster seats on reducing moderate to critical injuries experienced by the 7- to 8-year-old occupants based on the analytical data set from NASS-CDS:

Moderate to Critical Injuries in Non-Rollover Crashes			
Evaluated Group	Reference Group	Estimated Effect	95 % Confidence Interval
Booster Seat	Seat Belt	85.6%	(22.2%, 97.3%)
Moderate to Critical Injuries in All Crashes			
Evaluated Group	Reference Group	Estimated Effect	95 % Confidence Interval
Booster Seat	Seat Belt	Not significant	-

APPENDIX A

The following table shows the crash modes and the status of moderate to critical injuries experienced by the 1- to 8-year-old occupants in NASS-CDS 1998-2015:

	Moderate to Critical Injuries	**None to Minor Injuries**	**Total**
Frontal-Impact Crash	11,160 (98) 1.29% (0.34%)	851,027 (1719) 98.71% (0.34%)	133,728 (1817) 100%
Rear-Impact Crash	1,124 (20) 0.62% (0.21%)	179,847 (299) 99.38% (0.21%)	180,970 (319) 100%
Side-Impact Crash	2,248 (38) 0.60% (0.20%)	369,566 (549) 99.40% (0.20%)	371,814 (587) 100%
Rollover	3,399 (34) 2.08% (1.06)	159,683 (319) 97.92% (1.06%)	163,082 (353) 100%

The weighted percentage of moderate to critical injuries in rollovers (2.08%) is greater than the weighted percentages in non-rollover crashes (1.29% in frontal-impact crashes, 0.62% in rear-impact crashes and 0.60% in side-impact crashes). The standard error of experiencing moderate to critical injuries in rollovers (1.06%) is greater than the standard errors of experiencing moderate to critical injuries in non-rollover crashes (0.34% in frontal-impact crashes, 0.21% in rear-impact crashes and 0.20% in side-impact crashes).

	Serious to Critical Injuries	**None to Moderate Injuries**	**Total**
Frontal-Impact Crash	4,524 (44) 0.52% (0.23%)	857,663 (1773) 99.48% (0.23%)	862,187 (1817) 100%
Rear-Impact Crash	530.57100 (13) 0.30% (0.08%)	180,440 (306) 99.70% (0.08%)	180,970 (319) 100%
Side-Impact Crash	1,263 (21) 0.34% (0.17%)	370,551 (566) 99.66% (0.17%)	371,814 (587) 100%
Rollover	161,787 (331) 0.79% (0.38%)	1,295 (22) 99.21% (0.38%)	163,082 (353) 100%

The weighted percentage of serious to critical injuries in rollovers (0.79%) is greater than the weighted percentages in non-rollover crashes (0.52% in frontal-impact crashes, 0.30% in rear-impact crashes and 0.34% in side-impact crashes). The standard error of experiencing serious to critical injuries in rollovers (0.38%) is greater than the standard errors of experiencing serious to critical injuries in non-rollover crashes (0.23% in frontal-impact crashes, 0.08% in rear-impact crashes and 0.17% in side-impact crashes).

APPENDIX B

The logistic regression analysis was applied to the analytical data set of the 3- to 5-year-old child restraint system users in NASS-CDS 1998-2015 to select candidate models.

The driver's gender (MALE1), the driver age (AGE1), the non-rollover crash mode (MODE_COLL), the passenger age (AGE2), the passenger seat position (CENTER), and the type of CRS (CARSEAT) were used as the independent variables.

Keep type of CRS (CARSEAT) in each logistic regression model, the following logistic regression models used a single or a combination of the dependent variables. The independent variables in the logistic regression model and the C-statistics were presented in the following tables:

Logistic Regression Models with one Independent Variable	
Independent Variables	C-statistic
CARSEAT	0.489
Logistic Regression Models with two Independent Variables	
Independent Variables	C-statistic
MALE1 CARSEAT	0.485
AGE1 CARSEAT	0.489
MODE_COLL CARSEAT	0.455
AGE2 CARSEAT	0.523
CENTER CARSEAT	0.489
Logistic Regression Models with three Independent Variables	
Independent Variables	C-statistic
MALE1 AGE1 CARSEAT	0.502
MALE1 MODE_COLL CARSEAT	0.453
MALE1 AGE2 CARSEAT	0.489
MALE1 CENTER CARSEAT	0.485
AGE1 MODE_COLL CARSEAT	0.451
MODE_COLL AGE2 CARSEAT	0.449
AGE2 CENTER CARSEAT	0.522
AGE1 AGE2 CARSEAT	0.518
MODE_COLL CENTER CARSEAT	0.461
AGE1 CENTER CARSEAT	0.485
Logistic Regression Models with four Independent Variables	
Independent Variables	C-statistic
MODE_COLL AGE2 CENTER CARSEAT	0.473
AGE1 AGE2 CENTER CARSEAT	0.522
AGE1 MODE_COLL CENTER CARSEAT	0.462
MALE1 AGE2 CENTER CARSEAT	0.492
MALE1 MODE_COLL CENTER CARSEAT	0.451
MALE1 MODE_COLL AGE2 CARSEAT	0.463
MALE1 AGE1 CENTER CARSEAT	0.493
MALE1 AGE1 AGE2 CARSEAT	0.511

MALE1 AGE1 MODE_COLL CARSEAT	0.457
AGE1 MODE_COLL AGE2 CARSEAT	0.457
Logistic Regression Models with five Independent Variables	
Independent Variables	C-statistic
AGE1 MODE_COLL AGE2 CENTER CARSEAT	0.455
MALE1 MODE_COLL AGE2 CENTER CARSEAT	0.463
MALE1 AGE1 AGE2 CENTER CARSEAT	0.502
MALE1 AGE1 MODE_COLL CENTER CARSEAT	0.456
MALE1 AGE1 MODE_COLL AGE2 CARSEAT	0.471
Logistic Regression Models with six Independent Variables	
Independent Variables	C-statistic
MALE1 AGE1 MODE_COLL AGE2 CENTER CARSEAT	0.471

APPENDIX C

The logistic regression analysis was applied to the analytical data set of the 4- to 8-year-old seat restraint users in NASS-CDS 1998-2015 to select candidate models.

The driver's gender (MALE1), the driver age (AGE1), the non-rollover crash mode (MODE_COLL), the passenger age (AGE2), the passenger seat position (CENTER), and the type of seat restraints (BOOSTERSEAT) were used as the independent variables.

Keep type of seat restraints (BOOSTERSEAT) in each logistic regression model, the following logistic regression models used a single or a combination of the dependent variables. The independent variables in the logistic regression model and the C-statistics were presented in the following tables:

Logistic Regression Models with one Independent Variable	
Independent Variables	C-statistic
BOOSTERSEAT	0.436
Logistic Regression Models with two Independent Variables	
Independent Variables	C-statistic
MALE1 BOOSTERSEAT	0.431
AGE1 BOOSTERSEAT	0.474
MODE_COLL BOOSTERSEAT	0.400
AGE2 BOOSTERSEAT	0.422
CENTER BOOSTERSEAT	0.429
Logistic Regression Models with three Independent Variables	
Independent Variables	C-statistic
MALE1 AGE1 BOOSTERSEAT	0.463
MALE1 MODE_COLL BOOSTERSEAT	0.424
MALE1 AGE2 BOOSTERSEAT	0.429
MALE1 CENTER BOOSTERSEAT	0.433
AGE1 MODE_COLL BOOSTERSEAT	0.464
MODE_COLL AGE2 BOOSTERSEAT	0.396
AGE2 CENTER BOOSTERSEAT	0.424
AGE1 AGE2 BOOSTERSEAT	0.457
MODE_COLL CENTER BOOSTERSEAT	0.384
AGE1 CENTER BOOSTERSEAT	0.464
Logistic Regression Models with four Independent Variables	
Independent Variables	C-statistic
MODE_COLL AGE2 CENTER BOOSTERSEAT	0.395
AGE1 AGE2 CENTER BOOSTERSEAT	0.444
AGE1 MODE_COLL CENTER BOOSTERSEAT	0.471
MALE1 AGE2 CENTER BOOSTERSEAT	0.427
MALE1 MODE_COLL CENTER BOOSTERSEAT	0.417
MALE1 MODE_COLL AGE2 BOOSTERSEAT	0.412
MALE1 AGE1 CENTER BOOSTERSEAT	0.467
MALE1 AGE1 AGE2 BOOSTERSEAT	0.451

MALE1 AGE1 MODE_COLL BOOSTERSEAT	0.443
AGE1 MODE_COLL AGE2 BOOSTERSEAT	0.453
Logistic Regression Models with five Independent Variables	
Independent Variables	C-statistic
AGE1 MODE_COLL AGE2 CENTER BOOSTERSEAT	0.442
MALE1 MODE_COLL AGE2 CENTER BOOSTERSEAT	0.414
MALE1 AGE1 AGE2 CENTER BOOSTERSEAT	0.472
MALE1 AGE1 MODE_COLL CENTER BOOSTERSEAT	0.445
MALE1 AGE1 MODE_COLL AGE2 BOOSTERSEAT	0.454
Logistic Regression Models with six Independent Variables	
Independent Variables	C-statistic
MALE1 AGE1 MODE_COLL AGE2 CENTER BOOSTERSEAT	0.460

APPENDIX D

	Child Occupant Fatalities	Child Occupant Non-fatalities	Total
Non-Rollover Crash	590 9.89%	5,376 90.11%	5,966 100%
Rollover	169 15.34%	933 84.66%	1,102 100%

The percentage of child occupant fatalities in rollovers (15.34%) is greater than the percentage of child occupant fatalities in non-rollover crashes (9.89%).

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