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ESTIMATION OF SEATBELT AND FRONTAL-AIRBAG EFFECTIVENESS IN TRUCKS: U.S. AND CHINESE PERSPECTIVES

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16. Abstract

The objectives of this study were (1) to estimate the effectiveness of seatbelts and driver airbags for mitigating medium- and heavy-truck driver injuries, and (2) to discuss the implication of these estimates with respect to truck-driving conditions in the U.S. and China.

U.S. data showed that fatal or serious injuries of truck drivers are caused mainly by rollover, collision with a light vehicle or another truck, or collision with fixed objects. Rollover crashes account for most serious injuries, and pose the highest injury risk per crash. By controlling for the difference in crash-type distributions between trucks and light vehicles, seatbelts were estimated to be about 58% effective in reducing truck-driver injuries—comparable to the value for light vehicles. Airbags' effectiveness was calculated to be about 6% for unbelted truck drivers and 4% for belted truck drivers—lower than that for light vehicles, primarily because of the higher proportion of rollover injuries sustained by truck drivers.

The main relevant difference between truck-driving conditions in the U.S. and China is the seatbelt-use rate of truck drivers: greater than 70% in the U.S., but likely less than 10% in China. This difference would likely reduce the true effectiveness of seatbelts. Therefore, it is important to encourage Chinese truck drivers to wear seatbelts, because the effectiveness of seatbelts at high use rates is much greater than that for airbags. In addition, the lower truck traveling speeds in China would likely result in a lower percentage of truck rollover crashes than in the U.S. Consequently, the effectiveness of both seatbelts and airbags in reducing truck driver injuries may be slightly higher in China than in the U.S.

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Contents

Introduction

Occupant-restraint systems, including seatbelts and frontal airbags, are the most important safety devices in cars and light trucks for preventing fatalities and injuries in motor-vehicle crashes. However, the development of restraint systems in medium/heavy trucks is not comparable to those in passenger vehicles, because airbags generally not available in medium/heavy trucks. Crashes involving medium/heavy trucks result in considerable loss in terms of fatalities, injuries, and property damage (Krishnaswami & Blower, 2003). Although lighter vehicles involved in crashes usually suffer the most damage, the adverse effects to trucks and truck drivers are also significant. Each year, about 340,000 medium/heavy trucks are involved in traffic crashes in the U.S., which leads to approximately 600 fatalities and 20,000 injuries for truck drivers. Therefore it is of interest to estimate the effectiveness of seatbelts and airbags, if used in medium/heavy trucks, to better understand how to protect truck drivers in traffic crashes. Such estimates will not only provide an objective view of the potential benefits of different kinds of restraint devices in trucks, but also provide valuable educational material for truck drivers, which could positively affect their attitudes toward those devices and encourage greater usage.

The objectives of the present study are (1) to estimate the effectiveness of seatbelts and airbags for mitigating truck-driver injuries in general, and (2) to discuss the implication of these estimates with respect to truck-driving conditions in the U.S. and China. Methods for estimating seatbelt effectiveness in cars were used in the current study for medium/heavy trucks, and airbag effectiveness in cars was used as the reference to predict airbag effectiveness in medium/heavy trucks because airbags are generally not available for medium/heavy trucks. The difference in crash type and injury distributions between medium/heavy trucks and cars was taken into account in the current analyses.

The report starts with an analysis of crash patterns and injury risk for medium/heavy trucks based on data from the U.S. A literature review on the methods and estimates of seatbelt and airbag effectiveness for cars and light trucks follows. Effectiveness of seatbelts and airbags for medium/heavy trucks is then estimated for the U.S. and China. The report concludes with a discussion and recommendations. In the following sections of this report, the word *truck* refers to a medium or heavy truck with gross vehicle weight rating (GVWR) of 10,001 lbs. or more, unless otherwise specified.

Crash Pattern and Injury Risk for Trucks in the U.S.

Truck crash data in the U.S. are more detailed and comprehensive than crash data available from China, so the process of determining crash modes and injury mechanisms associated with truck-driver injuries was accomplished largely using U.S. data. In the U.S., census crash-data files are available for all fatal motor-vehicle crashes, and for a representative sample of motor-vehicle crashes of all severities, including nonfatal crashes. In China, the primary source is the *China Road Traffic Accidents Statistics* published by the Ministry of Public Security. This annual publication provides tables of descriptive crash statistics for different crash types and vehicle types, including frequencies of crashes, vehicles involved in crashes, crash injuries, and the monetary costs of crashes. The underlying crash information used to produce the tables of statistics for China are not available for independent analysis. Therefore, it was necessary to rely on published statistics that provide only general and common descriptive statistics on traffic crashes.

U.S. Data Sources

Two crash-data files were used primarily in this study to characterize truck-driver injuries in traffic crashes in the U.S. The Trucks Involved in Fatal Accidents (TIFA) file was used for crashes in which there was a fatality. The TIFA file is produced by UMTRI from a survey of all trucks involved in a fatal crash in the U.S. It is a census file, meaning that every fatal truck crash occurring in the U.S. is included in the file. Data on nonfatal truck crashes are taken from the General Estimates System (GES) file, which is part of NHTSA's National Automotive Sampling System (NASS). GES is a nationally representative sample of the estimated 6.4 million police-reported crashes that occur annually. GES covers all vehicles involved in a traffic accident, not just trucks. GES is the product of a sample survey with clustering, stratification, and weighting that allows calculation of national estimates. GES samples about 10,000 trucks included in crashes per year. These 10,000 sampled trucks equate to a national estimate of about 340,000 trucks involved in a police-reported crash annually.

TIFA is the standard source for information on fatal crashes. The GES file covers all crash severities and is the only nationally representative crash file that covers all crash severities. The combination of fatal crashes from TIFA and nonfatal crashes from GES provides the best available comprehensive source for information on truck-driver injury in traffic accidents. The analysis here combines five years of GES and TIFA data (2003-2007).

Truck Driver Injury

The initial step was to identify the primary crash types and crash modes that result in truck-driver injuries. Table 1 classifies truck crashes by the most harmful event to the truck driver that occurred in the crash (*Crash type* column). Crash involvements in which it is unknown if the driver was injured are excluded from the table. The specific categories are selected to identify crash types in which truck drivers tend to be injured as well as to match crash type classifications available from Chinese sources. In the top part of the table, the crashes are rollover, a fire in the truck, or some other noncollision event. (The more common other noncollision events include immersion [as in a river or lake] and fell or jumped from the vehicle.) The rest of the crash types are collisions, either with a motor vehicle (car, another truck, or motorcycle), a train, a nonmotorist such as a pedestrian or bicyclist, some other sort of nonfixed object such as a parked motor vehicle, or a fixed object, classified as soft or hard based on the probability of severe truck driver injury in collisions. Soft fixed objects include ground, impact attenuators, guardrails, and posts. Hard objects include buildings, bridge abutments, concrete traffic barriers, and embankments.

Considering fatal or serious injuries, the primary crash types in which truck drivers are injured, at least in terms of frequency of injury, are rollovers, followed by collisions with a car or pickup, another truck, or a hard fixed object. Rollovers account for 42.7% of fatal/serious truck driver injuries. Other major categories are collisions with a car or other light vehicle (19.0%), collisions with another truck account (12.2%), and collisions with hard objects (9.9%).

Table 1
Annual Average of Truck Driver Injury Severity by Crash Type, TIFA & GES, 2003-2007.

Crash type	Truck driver injury						Total	
	Fatal/ serious injury		Minor injury		No injury			
	N	%	N	%	N	%	N	%
Rollover	4,810	42.7	1,953	22.2	6,244	2.1	13,008	4.1
Fire	217	1.9	40	0.5	1,067	0.4	1,325	0.4
Other noncollision	241	2.1	202	2.3	12,067	4.0	12,510	3.9
Collision with:								
Truck	1,371	12.2	1,200	13.6	23,322	7.8	25,892	8.1
Car/pickup	2,136	19.0	4,073	46.3	202,362	67.7	208,571	65.4
Unknown motor vehicle	477	4.2	410	4.7	10,067	3.4	10,954	3.4
Train	63	0.6	37	0.4	219	0.1	319	0.1
Pedestrian/bicycle	25	0.2	36	0.4	4,710	1.6	4,771	1.5
Other nonfixed object	267	2.4	63	0.7	15,230	5.1	15,560	4.9
Hard fixed object	1,118	9.9	405	4.6	6,362	2.1	7,884	2.5
Soft/other fixed object	518	4.6	377	4.3	16,151	5.4	17,045	5.3
Motorcycle	2	0.0	5	0.1	986	0.3	994	0.3
Unknown	12	0.1	1	0.0	160	0.1	173	0.1
Total	*11,255*	*100.0*	*8,802*	*100.0*	*298,949*	*100.0*	*319,006*	*100.0*

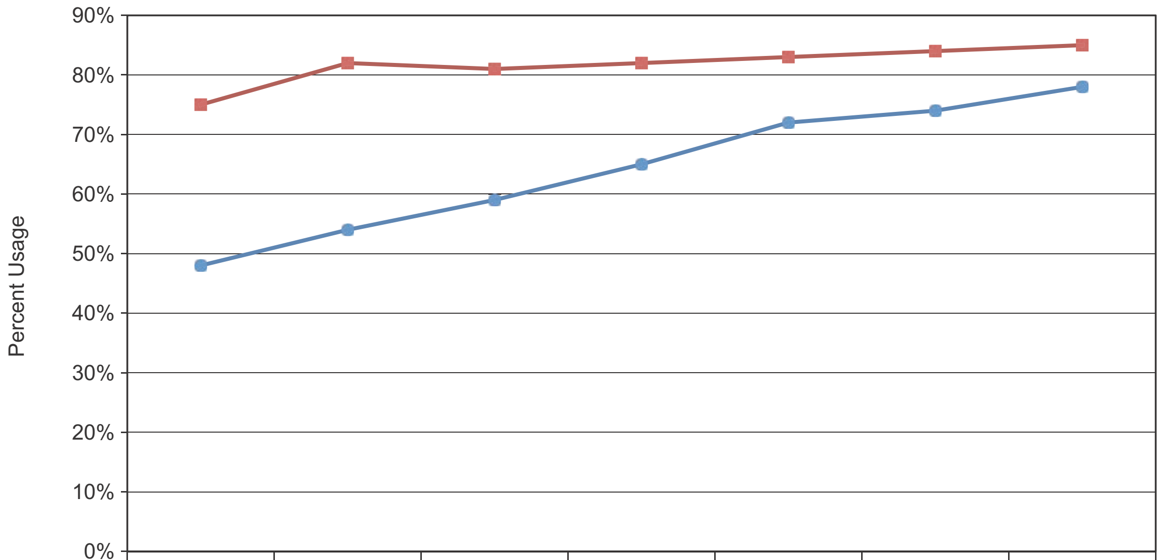
However, injury frequency does not capture the relative risk of different types of crashes. Collisions with a car account for 19.0% of fatal or serious injuries to truck drivers, but almost two-thirds of truck crashes are with cars or other light vehicles. On the other hand, rollover occurs in only about 4.1% of all truck crashes, but accounts for 42.7% of fatal or serious truck-driver injuries.

Table 2 shows the probability of injury for the different crash types, along with the normalized injury probability. Injury probability is computed as the proportion of crashes that result in either fatal or serious injuries or any injury to truck drivers. The normalized injury probability is the ratio of the injury probability for each crash type to the overall injury probability, given involvement in traffic crashes. Normalizing injury probabilities is an effective way to identify crash types that pose the most serious injury risks to truck drivers. From this table, it can be seen that rollovers are about 10 times more likely to result in a fatal or serious injury than crash involvement overall. The next most risky crash types are collisions with trains, truck fires, collisions with hard fixed objects, and collisions with other trucks. Collisions with light vehicles (cars or pickups) pose only 30% of the injury risk to truck drivers of crash involvement overall, and collisions with motorcycles, bicyclists, and pedestrians are the least likely to produce a truck-driver injury. Fire and collisions with trains are very serious when they occur, but they are rare events, accounting for only 0.4% and 0.1% of truck crashes and 1.9% and 0.6% of serious injuries, respectively. Consequently, the primary opportunities for reducing truck-driver injury in crashes are in rollovers and in collision impacts on trucks and off-road objects such as bridges and concrete posts.

Table 2
Probability of Truck Driver Injury by Crash Type.

Crash type	Injury probability		Normalized to all crash types	
	Fatal/serious injury	Any injury	Fatal/serious injury	Any injury
Rollover	0.37	0.52	10.5	8.3
Fire	0.16	0.19	4.6	3.1
Other noncollision	0.02	0.04	0.5	0.6
Collision with:				
Truck	0.05	0.10	1.5	1.6
Car/pickup	0.01	0.03	0.3	0.5
Unknown motor vehicle	0.04	0.08	1.2	1.3
Train	0.20	0.31	5.6	5.0
Pedestrian/bicycle	0.01	0.01	0.1	0.2
Other nonfixed object	0.02	0.02	0.5	0.3
Hard fixed object	0.14	0.19	4.0	3.1
Soft/other fixed object	0.03	0.05	0.9	0.8
Motorcycle	0.00	0.01	0.1	0.1
Unknown	0.07	0.07	1.9	1.1
Total	*0.04*	*0.06*	*1.0*	*1.0*

Seatbelts are the primary means of reducing truck-driver injuries in crashes. In recent years in the U.S., seatbelt-use rates among truck drivers have been increasing, though they remain below usage rates for light-vehicle drivers (Figure 1). Several factors probably contribute to the increase in seatbelt use by truck drivers. In many states, using seatbelts has been made a primary-enforcement violation, meaning that officers can pull drivers over and write a ticket just for failing to use seatbelts. In addition, many trucking companies require their drivers to use seatbelts.



	2002	2005	2006	2007	2008	2009	2010
Trucks	48%	54%	59%	65%	72%	74%	78%
Cars	75%	82%	81%	82%	83%	84%	85%

Figure 1. Observed Truck Driver Seatbelt Use Rates, U.S. (FMCSA, 2005, 2006, 2007, 2008, 2009, 2010; NHTSA, 2010)

The situation in China is probably significantly different. Observational studies on belt-use rates for truck drivers in China are not available. However, informal observations indicate that seatbelt usage in China is very low for truck drivers, maybe less than 10%. In this light, injuries for unbelted truck drivers in the U.S. are probably a better measure for comparison with China than the overall situation, which combines belted and unbelted drivers.

Table 3 shows truck-driver injury probability by crash type for belted and unbelted drivers in the U.S. Injury probabilities for fatal and serious injuries are shown separately from the probability of receiving any injury. Comparing the columns for belted and unbelted drivers shows that the probability of injury is much lower for belted than for unbelted drivers. This relationship holds for each crash type, with minor exceptions, as well as overall. In all crashes, belted truck drivers have a serious-injury probability of 0.03, compared with 0.16 for unbelted drivers, about five times greater.

Considering any injury severity, injury probability for unbelted drivers is 0.21, but only 0.06 for belted drivers. Injury risk is also significantly lower for belted drivers in each of the primary crash types identified as the most risky, including rollover, fire, and collisions with a truck or hard fixed object. The one exception is for the risk of fatal or serious injury in collisions with a train. That risk is about the same regardless of whether the driver is belted or not. However, the frequency of those crashes is so low that the differences between the belted and unbelted drivers are probably not reliably estimated. In addition, collisions with a train often may be so violent that belt use may not make much difference.

Table 3
Injury Probability by Crash Type for Belted and Unbelted Truck Drivers, TIFA & GES 2003-2007.

Crash type	Belted truck drivers		Unbelted truck drivers	
	Fatal/serious injury	Any injury	Fatal/serious injury	Any injury
Rollover	0.34	0.49	0.67	0.83
Fire	0.13	0.16	0.91	0.92
Other noncollision	0.02	0.03	0.06	0.23
Collision with:				
Truck	0.05	0.10	0.18	0.24
Car/pickup	0.01	0.03	0.04	0.07
Unknown motor vehicle	0.04	0.08	0.14	0.18
Train	0.29	0.31	0.26	0.84
Pedestrian/bicycle	0.01	0.01	0.02	0.03
Other nonfixed object	0.02	0.02	0.02	0.02
Hard fixed object	0.12	0.17	0.63	0.69
Soft/other fixed object	0.03	0.05	0.16	0.20
Motorcycle	0.00	0.01	0.01	0.01
Unknown	0.08	0.08	1.00	1.00
Total	*0.03*	*0.06*	*0.16*	*0.21*

The result for fire is noteworthy because some truck drivers believe that the use of belt restraints increases the risk of becoming entrapped in a fire and unable to escape. However, the result here strongly indicates that, in case of a fire, belt use reduces the risk of serious, or indeed of any, injury. The explanation is likely that the use of seatbelts protects drivers sufficiently in crashes that they are able to escape if a fire starts.

Unbelted drivers may be so injured by other crash events that they cannot escape from an ensuing fire. There is no evidence here that entrapment is a risk with respect to truck fires.

Table 4 shows the distributions of fatal or serious injuries and of all injuries by impact location on the trucks. The distribution of all collision impacts is also shown for comparison. In crashes in which the primary injury-causing mechanism is a collision with a vehicle or object, frontal impacts account for a majority (53.1%) of fatal or serious truck driver injuries. By comparison, only 28.8% of the most harmful impacts are to truck fronts. Also, frontal impacts are somewhat more likely to result in fatal or serious injuries than any injury, with fewer than half (48.6%) of all truck-driver injuries occurring in frontal impacts. In looking for opportunities to protect truck drivers in collisions, the primary injury source is an impact to the front of the truck. Side impacts account for about a quarter of the fatal or serious injuries, evenly divided between driver-side and passenger-side impacts.

Table 4
Truck Driver Injury by Impact Location, Collision Events Only, TIFA & GES 2003-2007.

Impact location	Truck driver injury				All crashes (includes no injury)	
	Fatal/serious injury		Any injury			
	N	%	N	%	N	%
Front	3,173	53.1	6,113	48.6	84,031	28.8
Right side	725	12.1	1,555	12.4	71,818	24.6
Left side	760	12.7	1,683	13.4	57,297	19.6
Back	616	10.3	2,114	16.8	48,821	16.7
Other	702	11.7	1,116	8.9	30,025	10.3
Total	*5,976*	*100.0*	*12,581*	*100.0*	*291,991*	*100.0*

It should be noted that only a simple classification of impacts by the side of the truck that was struck is possible in the data used here. Information is not available on the angle of impact, nor is there any more detail on the point of the truck where the impact occurred. For example, whether the impact was offset to the right or left on the truck front is not identified.

Table 4 includes both belted and unbelted drivers, but belt use is known to affect the probability of injury as well as the severity of the injury. Moreover, the experience of unbelted drivers is of interest because it is likely that relatively few truck drivers in China use seatbelts. Table 5 tabulates the probabilities of fatal or serious injuries and of any injury for belted and unbelted drivers by the point of impact. Overall, the probability of a fatal or serious injury in a crash where the most harmful event is a collision is 0.019 (1.9%) for a belted driver, but 0.088 (8.8%) for an unbelted driver. Frontal impacts are the most serious for both belted and unbelted, but serious injury probability is 0.196 for unbelted drivers, compared with only 0.034 for belted drivers. Left-side (the driver's side) impacts have a slightly higher probability of injury compared with right-side (passenger side), as might be expected. However, while the probability of serious injury in frontal impacts is about three times greater than in an impact to either side for belted truck drivers, the increased injury risk of frontal impact for unbelted drivers is four to almost six times higher.

Table 5
Driver Injury Probability by Impact Location, Belted and Unbelted Drivers Collision Events Only, TIFA & GES 2003-2007.

Impact location	Belted drivers		Unbelted drivers	
	Fatal or serious injury	Any injury	Fatal or serious injury	Any injury
Front	0.034	0.070	0.196	0.258
Right side	0.010	0.022	0.036	0.048
Left side	0.013	0.030	0.050	0.063
Back	0.012	0.042	0.031	0.062
Other	0.020	0.033	0.094	0.144
Total	*0.019*	*0.042*	*0.088*	*0.123*

Because rollover is the primary injury mechanism for truck drivers, Table 6 shows the extent to which rollover accounts for truck-driver injury. Almost 52% of truck-driver fatal injuries occur in crashes where trucks rolled over. However, rollover also accounts for a large share of each of the other injury severities. Almost 56% of A-injuries and 45.1% of B-injuries occur in rollovers. Almost a quarter of the least serious injuries occur in truck rollovers. Overall, of the total of 20,057 injuries of all severities to truck drivers, 7,651 (38.1%) occurred in rollover crashes. Taking just the most serious injuries (fatal, A-, and B-injuries), 48.7% occur when the trucks rolled over.

Table 6
Truck Driver Injury Severity by Rollover,
TIFA & GES, 2003-2007.

Driver injury severity	No roll	Rollover	Total
Fatal	361	383	744
A-injury	1,519	1,905	3,424
B-injury	3,890	3,197	7,087
C-injury	6,637	2,165	8,802
None	292,143	6,806	298,949
Unknown	19,619	177	19,796
Total	*324,169*	*14,634*	*338,803*
Row percentages			
Fatal	48.5	51.5	100.0
A-injury	44.4	55.6	100.0
B-injury	54.9	45.1	100.0
C-injury	75.4	24.6	100.0
None	97.7	2.3	100.0
Unknown	99.1	0.9	100.0
Total	*95.7*	*4.3*	*100.0*

In some rollovers, the rollover itself is the first event in the crash. However, in others, there was an initial impact, either with another vehicle or an object, followed by rollover. Table 7 classifies rollovers as either first event or as subsequent to an impact. The impacts are discriminated as frontal impact, right side, left side, or rear. In 69.8% of rollovers, the trucks rolled over without a prior collision. Of those where there was a collision, the most frequent impact location was a frontal impact (13.9%). A side impact preceded the rollover in 15.7%, with slightly more on the right side than the left. In a small number of cases (0.6%), the truck was struck in the rear and then rolled over.

Table 7
Truck Rollover Mechanism
TIFA & GES, 2003-2007.

All rollovers	N	%
Roll only	10,212	69.8
Front impact then roll	2,033	13.9
Right side impact then roll	1,381	9.4
Left side impact then roll	918	6.3
Rear impact then roll	90	0.6
Total	*14,634*	*100.0*

In rollovers, the number of quarters a vehicle rolls is a measure of the energy involved: the more times the vehicle rolls, the higher the energy. This is of interest in considering countermeasures to protect truck drivers and reduce injuries. The primary crash-data files used for this analysis do not include information on how many times the trucks turned over when they rolled, but this information is available in another crash dataset. The Large Truck Crash Causation Study (LTCCS) data are assembled from in-depth investigations of 963 truck crashes with serious injuries (K-, A-, or B-injuries). In these data, the amount of rollover is captured as the number of quarter turns of roll. A truck rolling onto its side has experienced one quarter turn. Two quarter turns means the truck rolled onto its top, and so on.

As shown in Table 8, most rollovers involved only one quarter turn of roll. About 6.8% rolled onto their tops, and fewer than 10% of rollovers involved three or more quarter turns. Rollovers onto the top and beyond can result in cab crush and deformation, but in most rollovers the truck simply rolls onto its side. However, these also present considerable risk of injury, particularly for unbelted drivers.

Table 8
Number of Quarter Turns of Roll,
LTCCS 2001-2003.

Number of quarter turns	N	%
1	200	80.0
2	17	6.8
3	18	7.2
4	5	2.0
9	1	0.4
Unknown	9	3.6
Total	*250*	*100.0*

Ejection also clearly presents injury risk to truck drivers, though the risk of ejection is almost completely eliminated for truck drivers who use seatbelts. Table 9 shows truck-driver ejection by seatbelt use for all crash severities. About 3% of unbelted drivers are either completely or partially ejected in truck crashes, but only 115 of 269,627 (0.04%) of belted drivers are ejected. One explanation for an ejected belted driver is that the cab may have been completely destroyed. In practical terms, the use of seatbelts eliminates ejection.

Table 9
Restraint Use and Ejection, All Truck Drivers in Crashes, TIFA & GES, 2003-2007.

Restraints	Not ejected	Partial	Complete	Total
None	10,230	72	242	10,544
Belts	269,512	34	81	269,627
Unknown	55,873	6	33	55,912
Total	*335,614*	*113*	*355*	*336,083*
Row percentages				
None	97.0	0.7	2.3	100.0
Belts	100.0	0.0	0.0	100.0
Unknown	99.9	0.0	0.1	100.0
Total	*99.9*	*0.0*	*0.1*	*100.0*

Among more seriously injured unbelted truck drivers, ejection is a significant causal mechanism. Table 10 shows that 20.8% of unbelted drivers with either fatal or serious injuries were partially or completely ejected. Among seriously injured belted drivers, the percentage is only 0.8%, and in many of these cases the cab structure may have been effectively destroyed around the driver.

Table 10
Restraint Use and Ejection, Driver with KAB Injury, TIFA & GES, 2003-2007.

Restraints	Not ejected	Partial	Complete	Total
None	1,172	72	236	1,479
Belts	7,201	34	28	7,263
Unknown	649	6	33	688
Total	*9,022*	*112*	*296*	*9,430*
Row percentages				
None	79.2	4.9	15.9	100.0
Belts	99.2	0.5	0.4	100.0
Unknown	94.4	0.9	4.7	100.0
Total	*95.7*	*1.2*	*3.1*	*100.0*

Information on the ejection path is available for fatal crashes only. These crashes are not necessarily fatal to the truck driver, but there was at least one person in the crash who was killed. Nevertheless, since ejection is so highly correlated with fatal and serious injuries, fatal crashes are a pertinent subset. Table 11 uses data from crash years 1999 through 2007 to increase sample size. Only ejections are included; there were 618 truck drivers ejected in fatal crashes over that period. The ejection path is almost evenly divided between the side door, side window, and windshield. However, 61.7% of all ejections occurred out the sides of trucks (either through the door or the window), compared with 29.8% out of the front of the vehicle (through the windshield) and only 2.3% out the rear window. The frequency of door or side-window ejections is likely related to the fact that ejection frequently occurs in rollover. Almost 55% of ejections happened in rollovers (based on TIFA and GES data, 2003-2007). In this light, the elevated percentage of side-window ejections among partial ejections could be drivers, even belted drivers, whose head and upper torso suffered excursion out the window during a rollover due to rotational forces. Seatbelt use may not address this injury mechanism, though side-curtain airbags may be effective.

Table 11
Ejection Path for Ejected Drivers, TIFA 1999-2007.

Ejection path	Totally Ejected	Partial Eject	Total
Side door	126	39	165
Side window	118	98	216
Windshield	130	54	184
Back window	5	9	14
Other path	37	2	39
Total	*416*	*202*	*618*
Row percentages			
Side door	30.3	19.3	26.7
Side window	28.4	48.5	35.0
Windshield	31.3	26.7	29.8
Back window	1.2	4.5	2.3
Other path	8.9	1.0	6.3
Total	*100.0*	*100.0*	*100.0*

Cab Style

Most trucks in the U.S. in recent years have conventional cabs. A conventional cab is one in which the engine is mounted forward of the passenger compartment, so that the truck has a hood out in front of the driver. The hood length can vary from 2 or 3 feet to as much as 12 feet. The engine and frame out in front of the driver obviously can serve to protect the driver in crashes.

The other primary types of truck cabs are the cab-over-engine (or cabover) and cab-forward. As the name implies, in a cabover, the cab is placed over the engine, with the driver essentially on top of the engine compartment. In a cab forward, the cab is forward of the engine compartment. In both of these cab types, the driver sits at the front of the truck, without a hood in front. Cab forwards are more often used for medium-duty straight-truck applications, while cabovers used to be more common for truck-tractors.

Changes in the way truck lengths are regulated in the mid-80s caused a shift from cabovers to conventional cabs. In the mid-80s, about 40% of trucks were of the cabover design, with the percentage higher for truck-tractors. However, when length laws changed from regulating overall length to regulating trailer length, there was a rapid and sustained transition to conventional cabs in the U.S. As a result, fewer than 5% of trucks involved in fatal crashes are cabovers. Among truck-tractors, the proportion is even lower.

Overall, it appears that injury rates are higher in cabovers than in conventional cabs. A 1991 study (Campbell & Sullivan, 1991) calculated fatal-injury rates for truck drivers by cab style. The authors found that fatal-injury rates per mile were about 1.54 times higher for cabovers than for conventional cabs. Seatbelt-use rates were much lower for the data years used in the study (1980-1988), ranging from about 6.1% in 1980 to 43.2% in 1988. Table 12, reproduced from Campbell and Sullivan (1991), illustrates the effect of cab style on injury probability, controlling for seatbelt use. Injury probabilities for serious and fatal injuries are higher in cabovers than in conventional cabs, both where drivers were coded as using seatbelts and where they were not. More recent crash data (TIFA and GES, 2003-2007) has significantly less information for cabovers than for conventional cabs, but the relationships observed in the older crash data remain unchanged.

Table 12
Injury Severity by Truck Cab Style for Restrained and Unrestrained Drivers

Injury severity	Unbelted				Belted			
	Conventional		Cabover		Conventional		Cabover	
	N	%	N	%	N	%	N	%
Fatal Injury	1,877	16.1	3,084	22.6	109	3.8	161	5.3
A Injury	626	5.4	1,010	7.4	104	3.6	223	7.4
B Injury	1,120	9.6	1,452	10.6	307	10.7	396	13.1
C Injury	1,171	10.0	1,212	8.9	385	13.4	348	11.5
Not Injured	6,861	58.9	6,883	50.5	1,970	68.5	1,903	62.8
Total	*11,655*	*100.0*	*13,641*	*100.0*	*2,875*	*100.0*	*3,031*	*100.0*

Cab Survival Space in Crashes

Maintaining the integrity of the driver's cab space is one of the prerequisites for protecting truck drivers in crashes. A 1991 study (Campbell & Sullivan, 1991) included an estimate of driver survival space in a set of 131 tractor crashes that were fatal to the truck driver. The researchers reviewed photographs and other materials to estimate survival space for the truck driver. Insufficient survival space was recorded if the left one-third of the occupant compartment was reduced by 50% or more. In addition, the researchers made a judgment as to whether countermeasures such as seat belts, prevention of fire, and stronger cab structures could have prevented the fatality. Fifty-one (42%) of the 131 fatal crashes were judged not survivable. Of the remaining 70 crashes, in 28 it was judged that there was not sufficient survival space for the driver, and in 42, sufficient survival space was preserved. Thus, in 65% of this sample of truck-driver fatal crashes, the crash was either not survivable by the countermeasures considered or insufficient survival space was preserved.

No more recent work has been found on truck-cab survival space. However, information on the larger topic of the maintenance of cab integrity in crashes can be gleaned from available crash data. Extrication may be regarded as a partial surrogate for cab-crush or intrusion. Extrication is coded when it is necessary to use mechanical means or other force to free a driver. When drivers have to be extricated, there is some cab deformation or intrusion enough to trap the drivers. Clearly, there can be cab deformation without extrication, as when the deformation is not severe enough or possibly on the passenger's side and not the driver's side. But when extrication is necessary, there is very likely some cab deformation. Accordingly, the proportion of extrication likely provides the lower-bound estimate of the true amount of cab deformation in truck crashes.

Data on extrication is available only for fatal crashes. In all fatal crashes involving a truck, about 5% of truck drivers require extrication (TIFA, 2003-2007). Extrication is clearly related to truck-driver injury. About 16.1% of seriously injured drivers are extricated, and 27.0% of fatally injured drivers are extricated. Using extrication as a surrogate for cab deformation implies that at least 5% of trucks in fatal crashes (fatal to someone in the crash, not necessarily a truck occupant) experience cab deformation sufficient to require extrication to remove the driver. In fatal-to-the-truck-driver crashes, at least 27.0% experience cab crush.

However, whether extrication is required is related to seatbelt use. Unbelted drivers require extrication at a much higher rate than belted drivers. This implies that unbelted drivers move within the cab during crashes and get into areas where they become entrapped and require extrication. In fatal crashes, 11.9% of unbelted drivers require extrication, compared with 3.3% of belted drivers (TIFA 2003-2007). Unbelted drivers are injured at a higher rate than drivers who use seatbelts, suggesting that one of the injury mechanisms could be that the lack of belts allows the truck driver to be thrown around during the crash and injured by cab crush.

Effectiveness of Seatbelts and Frontal Airbags in Cars and Light Trucks

Given the fact that frontal airbags are not generally installed in trucks and seatbelt effectiveness has not been investigated extensively for trucks, the performance of seatbelts and airbags in cars and light trucks provide the best insights for estimating their effectiveness in trucks. Therefore, in this section, we report on a literature review that was conducted on the effectiveness of seatbelts and frontal airbags in cars and light trucks. The methods and results reported here were further used to estimate their effectiveness in trucks.

Seatbelt Effectiveness

Seatbelts provide two major components of occupant protection: reduction in rates of ejection, and mitigation of occupant-to-interior impact energy (Viano, 1995). As a result, seatbelts are generally most effective in rollover crashes, where ejection risks are the greatest for passengers of cars and light trucks. In contrast, seatbelts are the least effective in side impacts, where side door intrusion is the major injury mechanism.

In the 1970s, field-data analyses of seatbelt effectiveness found estimates varying from 7.5% to 85.6% based on limited sample sizes (Robertson, 2002). However, in the 1980s, the double-pair comparison method was introduced by Evans (1986, 1988) to isolate the effectiveness of seatbelts from other confounding factors. Because this method analyzes the fatality risk for crashes with at least two occupants in the vehicle, it controls for many confounding factors that could affect the fatality risk, such as vehicle size, year, and crashworthiness, impact direction, and crash severity. Since its introduction, the double-pair comparison method has been adopted by many researchers to investigate the effectiveness of seatbelts in reducing fatalities and injuries in motor-vehicle crashes. Studies using crash data from the Fatality Analysis Reporting System (FARS) before 1985 consistently indicated seatbelt effectiveness of 40 to 50%, and 45% was and still remains as the official estimate by the National Highway Transportation Safety Administration (NHTSA). In contrast to the 40 to 50% effectiveness estimate in data before 1985, seatbelts were found to be 60 to 65% effective in data from 1986 and subsequent years using the same double-pair comparison method. NHTSA quickly discovered that the jump in these estimates was biased by the self-reported seatbelt use from survivors mainly due to seatbelt laws. When survivors who were actually unbelted are misclassified as belted, it lowers the fatality risks in the belted group, raises the risks in the unbelted group, and inflates the effectiveness estimate. To solve this problem, NHTSA has used the Universal Exaggeration Factor (UEF) to correct overestimated seatbelt effectiveness (Kahane, 2000). It was found that a UEF of 1.369 is fairly robust across crash modes, driver demographics, and driver behaviors, and will adjust the 60 to 65% seatbelt effectiveness back to 40 to 50%. Table 13 shows the estimated effectiveness of 3-point seatbelts for cars and light trucks by crash mode (Kahane, 2000). Seatbelts are approximately equally effective for cars and light trucks in frontal crashes. The biggest difference is in side impacts, especially near-side impacts, in which the effectiveness of seatbelts in cars is substantially lower than in light trucks. The reason for this finding is that the injury mechanism in near-side impacts often involves door intrusion. Cars are often more vulnerable to intrusion than light trucks, in which seatbelts can prevent ejection and mitigate impact energy with interior components. Seatbelts are highly effective in rollover crashes, where the majority of fatalities are due to ejections. Although it may seem odd to have a high seatbelt effectiveness in rear impacts and other crashes, the fatality reduction by seatbelts in those conditions generally involve ejections, and multiple or oblique impacts, where seatbelts can be useful. These estimates of the effectiveness of seatbelts in different crash modes, as well as accounting for the difference in effectiveness between cars and light trucks, can provide insights for estimating the effectiveness of seatbelts in trucks.

Table 13
Fatality Reduction with and without Ejection of 3-Point Seatbelt and Ejection Rate by Direction of Impact (Kahane, 2000).

Crash type	Fatality Reduction		Fatality Reduction without Ejection*		Ejection rate in Fatalities	
	Cars	Light Trucks	Cars	Light Trucks	Cars	Light Trucks
Frontal impacts	50	53	36	31	21	33
Side impacts	21	48				
Near side	10	41	-4	15	21	39
Far side	39	58	21	28	26	45
Rollover	74	80	28	27	69	78
Rear impacts & Others	56	81	31	46	37	52
Overall	*45*	*60*	*26*	*28*	*28*	*48*

* Fatality reduction without ejection was calculated by assuming a 74% fatality rate of ejectees and a 91% effectiveness rate of seatbelts in preventing ejections in fatal crashes in cars and light trucks.

Frontal Airbag Effectiveness

In the following sections the term *airbag* will refer to frontal airbags.

Unlike seatbelts, airbags do not prevent ejection; they only provide protection in occupant-to-interior impacts. However, because airbags deploy automatically, they do not require occupant action beforehand; therefore they have 100% use rate when installed.

The earliest estimation of the effectiveness of airbags was conducted by NHTSA in 1974, in which a fatality reduction of 57% was estimated for airbags in frontal crashes and 20% in side impacts. However, more recent estimates of airbag effectiveness in cars have dropped significantly to about 30% in frontal crashes, close to 0% in side impacts, and 12 to 14% in all crashes (NHTSA, 1999, 2001). Table 14 provides a summary of airbag effectiveness estimated by different studies in the literature. Although variations exist across studies, the majority of the findings are consistent. Because of their design, airbags are most effective in pure frontal crashes (12 o'clock), somewhat effective in near-frontal crashes (11 and 1 o'clock), but not effective in side impacts and other crash types. As a result, airbags reduce fatalities in pure frontal crashes by about 30%, but for all crashes their effectiveness in fatality reduction is only about 10 to 15%. However, based on limited studies by NHTSA, airbags seem to be about 20% more effective in reducing MAIS3+ injuries than fatalities. Furthermore, airbags are generally about 1.5 times more effective for unbelted than belted occupants.

Table 14
Driver Airbag Effectiveness Estimated across Studies in the Literature
Reported by Fatality Reduction (MAIS3+ injury reduction).

Literature	Pure frontal (12 o'clock)			Overall		
	Belted	Unbelted	Total	Belted	Unbelted	Total
NHTSA (1984)						20-40%
Evans (1991)						18%
Edwards (1994)			29%			22%
Lund and Ferguson (1995)			35%			16%
Viano (1995)						21%
Kahane (1996)	21%	34%	30.5%	9%	13%	11%
NHTSA (1999)	21%	34%	31% (50%)	9%	14%	11% (42%)
Martin (2000)			30%			
NHTSA (2001)	21%	36%	29% (49%)	11%	14%	12% (30%)
Cummings (2002)			22%	7%	9%	8%
McGwin (2003)						2%
Newgard (2008)			20%			13%
Median Value	*21%*	*34%*	*29%*	*9%*	*14%*	*12%*

Seatbelt use and airbag effectiveness

Historically, seatbelts have been designed to be used as the primary restraint system and airbags as the supplementary restraint system. Therefore airbags are generally designed to ensure that belted occupants receive the best protection. Several NHTSA reports (Kahane, 1996; NHTSA, 1999, 2001) have shown that even though seatbelts and airbags are both effective when used alone, seatbelts alone are much more effective than airbags alone in reducing fatalities. In particular, seatbelts can reduce fatalities by about 45%, while airbags used without seatbelts reduce fatalities by only about 12%. Seatbelts and airbags, when used together, have an estimated 51% fatality-reducing effectiveness, which is only 6% higher than using seatbelts alone. Field data also showed that airbag effectiveness is dependent on seatbelt use. As shown in Table 14, airbag effectiveness is generally higher for unbelted than belted occupants, especially in pure frontal crashes, which is what airbags are designed for. This finding has a major influence on whether airbags should be installed in a given type of a vehicle and in a given region, considering the seatbelt-use rate for the given type of a vehicle and in the given region, because the safety benefit provided by airbags decreases as the seatbelt-use rate increases. A study by Viano (1995) has demonstrated that the safety benefit from an increased seatbelt-use rate is about two times the benefit achieved by a similar increase in airbag penetration into the fleet. For instance, a 5% increase in seatbelt use would provide a safety benefit similar to that of a 10% increase in airbag installation.

Vehicle type, crash type, and crash severity

The size and type of vehicles may affect airbag effectiveness, but these effects have not yet been quantified thoroughly in the literature. NHTSA studies (Kahane, 1996; NHTSA, 1999, 2001) did not show significant differences in the effectiveness of airbags between cars and light trucks, nor between cars with different weights, though heavy cars showed a slightly lower effectiveness than light cars. Although vehicle type has little effect on airbag effectiveness overall, different types of vehicles tend to be involved in different types of crashes, which may affect airbag effectiveness. For example, light trucks are generally more likely to be involved in rollover crashes, but airbags can only reduce fatalities and injuries in frontal crashes. Therefore, airbag effectiveness for light trucks should theoretically be lower than that for cars. However, light trucks are usually larger and heavier than cars, which would provide larger survival space and less intrusion. As a result, the effectiveness of airbags in frontal crashes is likely to be higher for light trucks than for cars. Because airbags are effective only in frontal or near-frontal crashes, differences in the distributions of crash types for cars and trucks must be considered when airbag effectiveness in cars is used to estimate effectiveness in trucks.

Crash severity also plays an important role in airbag effectiveness. Although airbags are designed to reduce fatalities and serious injuries, they might also cause some injuries, which tend to be minor injuries to the upper extremities. Using the NASS-CDS database, Segui-Gomez (2000) found that airbag deployment in frontal or near-frontal crashes decreases fatal and severe injuries (AIS4+), while it increases AIS 1 to 3 injuries in low-severity crashes. Therefore, it is important to deploy airbags only when they are needed, and not to deploy them in low-severity crashes. Consequently, additional research is needed to determine a proper deployment threshold that can maximize the benefit of airbags. Unfortunately, due to the complexity of crash scenarios and various airbag designs in different automotive companies, no widely accepted airbag-deployment threshold is available. In the literature, it was commonly suggested that a higher deployment threshold should be beneficial, because many airbag-induced minor injuries can be avoided in low-severity crashes if the airbag is not deployed. However, adverse consequences of increasing the threshold of airbag deployment may occur, such as a delayed airbag deployment in severe crashes. As a result, the benefit of airbags in those crashes would be diminished. New airbag sensing mechanisms are needed to ensure an earlier airbag deployment when the threshold is set high.

Occupant factors — age, gender, size, and obesity

Age effects in the effectiveness of airbags appear to be complex. For example, Evans (Evans, 1991) did not find significant effects of age on airbag effectiveness, while Lund and Ferguson (1995) found that the fatality reduction by airbags is 31% for young adults (under 30) and 20% for older adults (over 30). More recently, Cummings et al. (2002) found that the age effect on airbag effectiveness is nonlinear, and middle-aged adults experience the highest effectiveness. Recent NHTSA studies (NHTSA, 1999, 2001) did not find significant age effects in pure frontal crashes until over age 70, where the airbag effectiveness dropped from 30% to 20%. This drop may be related to the reduced injury tolerance of the older population, for whom seatbelts alone can generate loadings that are too large for them to cope with, consequently reducing the airbag effectiveness.

Studies also found that the effectiveness of airbags is different for women and men, although this gender effect is highly correlated with body size. In general, shorter occupants seem to be overrepresented in fatality cases. However, the stature effect has rarely been quantified. A recent study using NASS-CDS data by Newgard and McConnell (2008) did not find evidence that occupant height or weight influenced airbag effectiveness for all crashes combined. However, among crashes with airbag deployments, the effect of deployment on injuries differs by occupant height, with the lowest odds of serious injuries among mid-size occupants and increased injury odds for smaller or larger occupants (Newgard & McConnell, 2008). This finding indicates that current airbag systems may be optimized to best protect mid-size occupants, resulting in decreased airbag effectiveness for smaller or larger occupants. Using similar data, Segui-Gomez (2000) also found that the level of crash severity at which airbags are protective is higher for female than for male drivers. This result suggests that airbags may cause more adverse effects for females in low-severity crashes than males.

Obesity would likely change the injury distributions to the occupants due to the increased mass (D.C. Viano, Parenteau, & Edwards, 2008; Zhu et al., 2006) and poor belt fit (Reed, Ebert-Hamilton, & Rupp, 2012). In particular, obese individuals tend to sustain more lower-extremity and thorax injuries compared with nonobese occupants. However, the obesity effect on airbag effectiveness has not yet been quantified. Intuitively, because airbags are designed to reduce mainly head and thorax injuries, one could conclude that obesity may not affect the overall effectiveness of airbags much. However, because airbags can potentially increase lower-extremity injuries, the obesity effects on airbag effectiveness may be very complex and are likely to change the injury pattern significantly.

Estimation of Seatbelt and Frontal Airbag Effectiveness in Trucks

Effectiveness of Seatbelts in Reducing Injuries

In this report, seatbelt effectiveness in reducing injuries of truck drivers (see Table 15) was estimated by the reduction ratio of injury risk from unbelted to belted truck drivers based on the truck injury data reported in the previous section. To consider the injury-risk differences among different crash types, seatbelt effectiveness was calculated for each crash type first, and a weighted average was then calculated based on the number of truck drivers involved in each crash type. To account for the bias generated by the self-reported seatbelt use, a UEF of 1.369 was used to adjust the seatbelt effectiveness. Note that there are two limitations in using this UEF value. First, this value is based on data from cars and light trucks. Second, this value is validated against fatality-risk reduction, but not injury-risk reduction. For crashes involving trucks, truck drivers may tend to misclassify themselves as belted more often than car drivers due to certain company policies about seatbelt usage. Therefore, the true UEF value for truck drivers could be higher than the current value. Nonetheless, using a UEF of 1.369 already significantly reduces the overestimation of seatbelt effectiveness from the misclassification of seatbelt use for truck drivers.

As shown in Table 15, the overall seatbelt effectiveness in reducing truck-driver injuries is 58.4%, which is higher than the 40 to 50% estimated for cars and light trucks. Two reasons may account for this difference. First, in this study, the severity of crashes is not controlled by the pair-comparison method. Consequently, it is possible that unbelted truck drivers were involved in more severe crashes than belted truck drivers due to their tendency to take more risks. Second, in truck crashes, the trucks generally sustain limited intrusion, unless the crash is with another truck, hard fixed object, train, or if the truck rolled over. Less intrusion and more survival space in truck cabs would likely increase the effectiveness of seatbelts in reducing fatalities and injuries.

Also of interest is the finding that seatbelt effectiveness is only 30.8% for truck drivers in rollover crashes as compared with over 70% effectiveness in rollovers for cars and light trucks (Table 13). This result may be explained by the difference of vehicle kinematics between trucks and cars in rollover crashes. Compared with cars, trucks tend to sustain fewer quarter turns in rollover crashes and a lower ejection rate. As a result, the effectiveness of seatbelts for reducing ejections is significantly lower for trucks than cars. As shown in Table 14, seatbelt effectiveness is less than 30% for cars in rollover crashes, if ejection reduction is excluded. Therefore, the 30.8% seatbelt effectiveness for trucks in rollovers is consistent with what has been found in cars and light trucks.

Table 15
Estimate of Seatbelt Effectiveness for Reducing Injuries for Truck Drivers.

Crash type	Unbelted		Belted		Seatbelt Effectiveness	
	Injured	Total	Injured	Total	Original	Adjusted*
Roll	847	1,271	3,643	10,803	49.4%	30.8%
Fire	19	21	157	1,257	86.2%	81.1%
Other noncollision	20	322	168	10,106	72.9%	62.9%
Truck	177	963	1,117	22,585	73.2%	63.2%
Car/pickup	231	5,777	1,755	177,948	75.4%	66.3%
Unknown MV	34	251	412	9,710	68.9%	57.5%
Train	14	56	41	142	-12.2%	-53.6%
Pedestrian/bike/animal	2	116	21	3,891	66.5%	54.2%
Other nonfixed object	15	890	247	12,291	-19.8%	-64.0%
Hard fixed object	228	364	799	6,599	80.7%	73.6%
Soft/other fixed object	105	656	365	14,386	84.1%	78.2%
Motorcycle	1	66	1	856	84.5%	78.7%
Unknown	0	0	11	152	92.5%	89.7%
Total	*1,694*	*10,753*	*8,738*	*270,727*	*69.6%*	*58.4%*

*UEF of 1.369 was used to adjust the original effectiveness estimates.

Frontal Airbag Effectiveness

Because airbags are installed in very few trucks, their effectiveness for trucks has rarely been investigated in the literature. To the best of our knowledge, the only study that estimated airbag effectiveness in trucks was conducted by Volvo (Volvo, n.d.). In that study, 94 in-depth crash investigations involving Volvo trucks were performed. The injury-reducing effect was assessed for every case based on accident sequences, type of accelerations, directions of forces, deformation, and driver injuries. It was estimated that airbags would provide an injury-reducing effect of 21% for belted drivers and 8% for unbelted drivers. Overall, these estimates are within the range of those from cars (Table 14). However, the obtained difference in airbag effectiveness for belted versus unbelted occupants in Volvo trucks seems opposite to the effectiveness for occupants of cars, for whom airbag effectiveness is generally greater for unbelted than belted occupants. This is likely due to using a sample of convenience with small sample size in the Volvo study, as well as the subjective evaluation of airbag effectiveness in each case. Nonetheless, the Volvo study provided an important reference point for estimating the airbag effectiveness for reducing the truck driver injuries. Note that Volvo also estimated that seatbelts alone are 60% effective in reducing truck-driver injuries, making it difficult for airbags to be more effective for belted than unbelted occupants.

In the current study, truck airbags were assumed to be effective only in frontal or near-frontal crashes, which accounted for 53% of the truck-driver injuries based on Table 4. In crashes with other trucks or hard fixed objects, the airbag-effectiveness values for belted and unbelted truck drivers were assumed to be 21% and 34%, respectively, based on values reported for cars in pure frontal crashes (Table 15). In crashes with other motor vehicles and soft fixed objects, the airbag-effectiveness values for belted and unbelted truck drivers were assumed to be 10.5% and 17%, respectively, which are half of those for cars. The reason for these lower effectiveness values is that trucks generally have substantial advantages over other vehicles in crashes, thus the airbag effectiveness is likely reduced in crashes with lower severity.

Table 16 shows the estimated injury reductions in different crash types and the estimated overall airbag effectiveness for belted and unbelted truck drivers. The results show an overall effectiveness of airbags in reducing injuries to be 4.1% for belted truck drivers and 6.3% for unbelted truck drivers. Compared with effectiveness values for cars, the values for trucks are lower, primarily because rollover crashes (in which airbags are essentially not effective at all) cause a higher percentage of total injuries for truck drivers than for occupants of cars.

Table 16
Estimate of airbag effectiveness for reducing fatalities in trucks

Crash type	Unbelted			Belted		
	Estimated Effectiveness	Injury Reduction*	Total Injury	Estimated Effectiveness	Injury Reduction*	Total Injury
Roll	0.0%	0	847	0.0%	0	3,643
Fire	0.0%	0	19	0.0%	0	157
Other noncollision	0.0%	0	20	0.0%	0	168
Truck	34.0%	32	177	21.0%	124	1,117
Car/pickup	17.0%	21	231	10.5%	98	1,755
Unknown MV	17.0%	3	34	10.5%	23	412
Train	0.0%	0	14	0.0%	0	41
Pedestrian/bike/animal	0.0%	0	2	0.0%	0	21
Other nonfixed object	0.0%	0	15	0.0%	0	247
Hard fixed object	34.0%	41	228	21.0%	89	799
Soft/other fixed object	17.0%	9	105	10.5%	20	365
Motorcycle	0.0%	0	1	0.0%	0	1
Unknown	0.0%	0	0	0.0%	0	11
Total injury		106	1,694		354	8,738
Weighted Average	*6.3%*			*4.1%*		

* Injury reduction = Total Injury × estimated effectiveness × 53%

It should be mentioned that the current estimates did not incorporate the effects of occupant factors (such as age, gender, stature, and obesity) on the effectiveness of airbags for truck drivers, because quantitative measures of such effects are generally not available. However, truck drivers are usually young-to-middle-aged males who have a relatively large stature and tend to be overweight. All of these characteristics, except obesity, would increase the effectiveness of airbags, based on the findings for passenger-car occupants. Therefore, it is likely that the true airbag effectiveness will be somewhat higher than the current estimate. Obese occupants tend to sustain more lower-extremity injuries, and airbags can also increase lower-extremity injuries, although they can significantly reduce head and chest injuries. Therefore, if airbags were to be installed in trucks, lower-extremity injury risks may rise, making additional protection necessary.

Seatbelt Use and Restraint Effectiveness

The above results clearly show a large benefit of seatbelts alone in reducing truck-driver injuries (58.4% effectiveness), compared with a relatively modest benefit from airbags (4.4% effectiveness for belted truck drivers and 6.3% effectiveness for unbelted truck drivers). However, a restraint system is only effective when it is used, therefore the seatbelt-use rate is critical in determining the true effectiveness of seatbelts in reducing injuries.

Figure 2 shows the estimated seatbelt, airbag, and combined seatbelt-plus-airbag effectiveness in trucks by seatbelt-use rate, in which a linear relationship is assumed between the seatbelt use rate and the effectiveness values. The airbag effectiveness is 6.3% at 0% seatbelt use rate, and decreases linearly to 4.4% at a 100% seatbelt-use rate. Opposite to the airbag effectiveness, seatbelts are 0% effective at a 0% seatbelt-use rate, and that effectiveness increases linearly to 58.4% at a 100% seatbelt-use rate. The total seatbelt-airbag effectiveness is calculated by combining the seatbelt and airbag effectiveness estimates together based on the seatbelt-use rate. For example, the seatbelt- and airbag-effectiveness values at 60% seatbelt-use rate are 58.4% * 0.6 = 35.04% and 6.3% - (6.3% -4.3%) * 0.6 = 5.1%, respectively. The total seatbelt-airbag effectiveness at a 60% seatbelt-use rate is calculated by 35.04% + (1 - 35.04%) * 5.1% = 38.4%. It is clear that seatbelts dominate the overall effectiveness of these restraint systems in reducing truck-driver injuries. Only if the seatbelt-use rate is low (<11%) will the effectiveness of airbags be higher than the effectiveness provided by seatbelts.

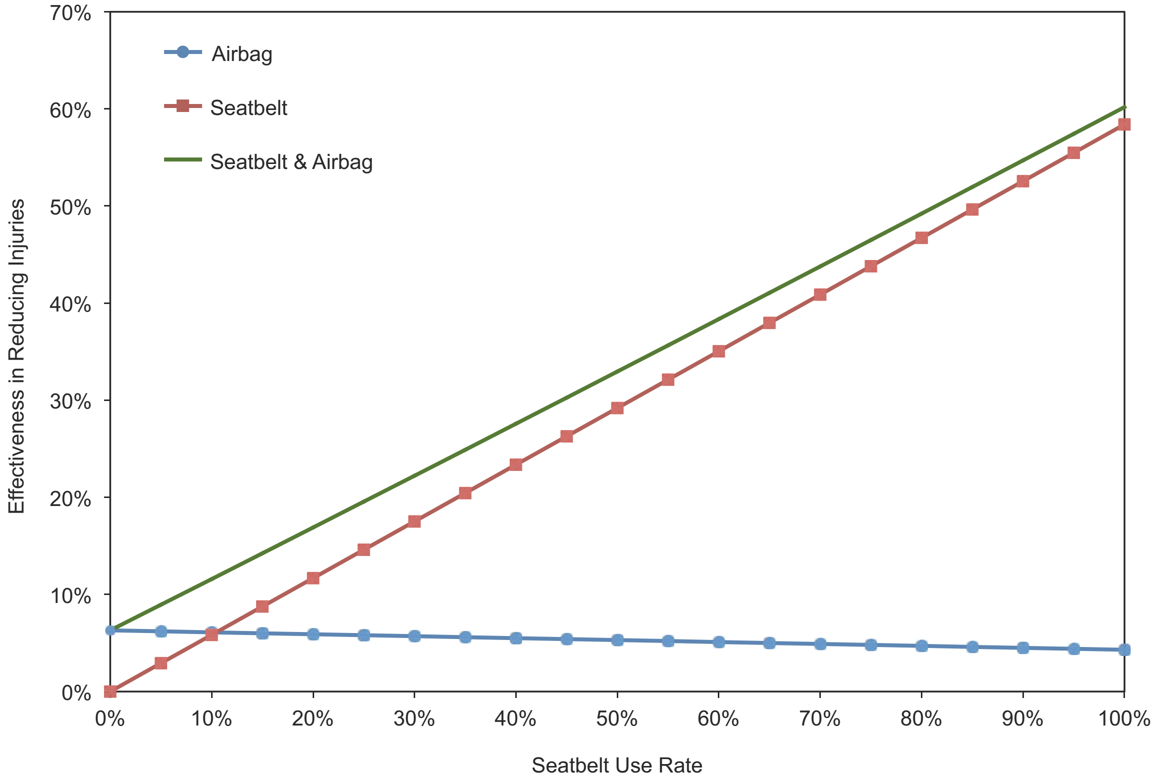


Figure 2. Estimated seatbelt and airbag effectiveness in trucks by seatbelt-use rate.

Implications for the U.S. and China

Applying the crash-injury experience in the U.S. to the Chinese conditions depends on several assumptions and adjustments. For example, we assume that the structures of trucks are reasonably comparable between the two countries. We assume that truck cabs in the U.S. are not significantly stronger or weaker than truck cabs in China with the same cab style. As a result, when crashing with another truck, other motor vehicles, or a fixed object, a truck in China should sustain a similar injury risk for the driver to that in the U.S. Similarly, when a truck rolls over, the risk to the driver is probably about the same regardless of where it occurs, whether in the U.S. or China. Consequently, whether the truck driver is properly restrained and the number of quarter turns would have more influence on injury outcomes than the country where the rollover occurs. Overall, given involvement in the same crash type, the injury probability to a U.S. truck driver should approximate the injury probability to a Chinese driver.

However, certain other factors that affect truck-driver-injury risks can be quite different between China and the U.S. Seatbelt-use rate is one such important factor to account for, because unbelted drivers have a much greater chance of injury if involved in a crash than belted drivers. The seatbelt-use rate among U.S. drivers is much higher than that in China. In recent years, observational studies have estimated seat belt use of around 75% for U.S. truck drivers. There are no comparable studies in China, but recent observational studies on driver seatbelt use in China varied significantly from 5 to 50% among different cities (Fleiter, Gao, Qiu, & Shi, 2009; Hu, 2011; Routley et al., 2008). Based on U.S. experience, truck drivers tend to have lower seatbelt-use rates than drivers of passenger vehicles due to the perception that trucks are safer than cars. In addition, Chinese truck drivers often wear seatbelts only when enforcement is strong. Because truck-driver injuries occur more often in rural areas where seatbelt enforcement is generally low, it is very likely that the seatbelt-use rate among truck drivers in China is less than 10%. This may significantly reduce the true effectiveness of seatbelts in China.

The radically different composition of the traffic stream must also be accounted for when applying the U.S. experience to the Chinese conditions. The traffic stream in China includes a much higher proportion of motorcycles, pedalcycles, and pedestrians than in the U.S. However, these changes do not necessarily affect the injury probabilities for truck drivers. On the other hand, due to the more complicated traffic stream, the driving speed of trucks in China may be lower than it is in the U.S. Consequently, the proportion of truck rollover crashes would be reduced. This difference would likely increase the overall seatbelt and airbag effectiveness for trucks, because U.S. data shows that in truck rollover crashes, seatbelt effectiveness is low and airbags are not effective at all.

Another relevant difference between the U.S. and China is the truck cab style. U.S. data shows that upwards of 95% of trucks in crashes have conventional cabs, while in China the cabover is still the most common cab style for trucks. Although based on the U.S data, injury risks in cabovers are significantly higher than in conventional cabs, it is unclear whether different cab styles would change the effectiveness values of seatbelts and airbags. Intuitively, a less crashworthy truck cab may reduce the restraint system effectiveness, suggesting that the effectiveness of seatbelts and airbags would be lower in cabovers than in conventional cabs. However, this conclusion needs further validation.

Conclusions

U.S. data show the following:

• Fatal or serious injuries to truck drivers are caused primarily by rollover, collision with a light vehicle, another truck, or a fixed object.

• Rollover crashes account for more than 40% of truck-driver injuries, and involve the highest injury risk among all crash types, although the majority (80%) of all truck rollovers involve only one quarter turn.

• Frontal crashes account for more than half of the truck-driver injuries in collision events.

• Belted drivers sustain much lower injury risks than unbelted drivers in almost every crash type, and seatbelts can virtually eliminate ejections.

• The seatbelt-use rate for truck drivers has continued to increase in the U.S. in recent years, but it is still lower than that for drivers of light vehicles.

Estimating the effectiveness of seatbelts and airbags in cars and light trucks provides valuable insights for estimating their effectiveness in trucks. Literature shows that the seatbelt-effectiveness values for reducing fatalities are about 45% and 60% for cars and light trucks, respectively. The median values of airbag effectiveness in light vehicles in pure frontal crashes are 21% and 34% for belted and unbelted drivers, respectively. Airbags are not effective in reducing injuries in crashes other than frontal or near-frontal crashes. A significant increase in seatbelt effectiveness was found soon after seatbelt laws were enacted, but these early estimates were inflated because some drivers claimed to have been belted when they were not. Consequently, an adjustment was developed to correct these biased results, which has led to consistent, but lower seatbelt-effectiveness values. On the other hand, estimates of airbag effectiveness vary substantially because of the uncontrolled effects of confounding complex factors, including seatbelt use, vehicle type, crash type and severity, occupant age, gender, stature, and obesity level.

U.S. truck-injury data reveal that seatbelts are about 58% effective in reducing truck-driver injuries overall (after adjusting for potential seatbelt-use misclassification). Seatbelt effectiveness in truck rollover crashes is relatively low (about 31%), likely due to the low ejection rate compared with light vehicles. By assuming that airbags are only effective in frontal and near-frontal truck crashes, airbag effectiveness was estimated at about 4% and 6% for belted and unbelted truck drivers, respectively. These results account for the large differences in the distributions of crash types between trucks and light vehicles, but do not incorporate the effects of occupant parameters, such as age, gender, size, and obesity level, due to the lack of quantitative measures in the literature. Airbag effectiveness would likely be lower than the current estimates except for the fact that the truck-driver population is mainly young-to-middle-aged males with medium-to-large stature—both of which may increase airbag effectiveness.

Two major differences exist between China and the U.S. for estimating restraint effectiveness for truck drivers. First, the seatbelt-use rate in China is significantly lower than that in the U.S., which will significantly reduce the true seatbelt effectiveness in preventing injuries. Second, the crash pattern of trucks in the U.S. may be different from that in China, where lower traveling speed may lead to a smaller proportion of rollover crashes. Interestingly, if truck rollover crashes account for a lower percentage of injuries in China than in the U.S., both seatbelt and airbag effectiveness would increase. Further investigations are needed to accurately quantify truck-crash patterns in China.

Overall, seatbelts can provide much greater benefits for reducing truck-driver injuries than airbags regardless of the crash type, occupant factors, and country. Increasing the seatbelt-use rate for truck drivers would be the most efficient and effective way to reduce truck-driver injuries. The question of whether airbags should be installed in trucks may need more detailed cost-benefit analysis, but our study did not show a significant safety benefit from airbags relative to seatbelts.

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