Exhibit B

I hereby supplement this statement and attach hereto Exhibit B, Truck Side Guards and Skirts to Reduce Vulnerable Road User Fatalities: FInal Report on Net Benefits and Recommendations, referred to herein as the “final report,” in contrast to the “published report.” I was the project manager for the Federal Motor Carrier Safety Administration for this taxpayer-funded research. This attachment is the final report that I received from the Volpe Center, meeting all the requirements of the Statement of Work. Among other things, this final report found that it was cost effective to require tractor-trailers and single-unit trucks to be equipped with lifesaving side impact guards. The cost-benefit analysis and most of the rest of this final report were suppressed from the published report by U.S. DOT after I retired.

Quon Y. Kwan — 04/11/2024

Quon Kwan — Date

LISA BRENNER

4/11/2024

LISA BRENNER
Notary Public - State of Maryland
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My Commission Expires Aug 14, 2027

Truck Side Guards and Skirts to Reduce Vulnerable Road User Fatalities: Final Report on Net Benefits and Recommendations

U.S. Department of Transportation
Federal Motor Carrier Safety Administration

January 2019

FOREWORD

The authors wish to express their appreciation to Quon Kwan, Jeff Loftus, and Martin Walker of the Federal Motor Carrier Safety Administration for sponsorship of this report and to several individuals for their valuable input. The authors thank Coralie Cooper and Ryan Keefe at the U.S. DOT Volpe Center for advising the study team on data sources; John Knox White at the San Francisco Municipal Transportation Agency; Keith Kerman at the New York City Department of Administrative Services; Kristopher Karter at the City of Boston Mayor's Office of New Urban Mechanics for maintenance cost information; Eran Segev, Emily Lawless, and Emma Vinella Brusher for review, editing, and formatting; Ross Froat, Dan Horvath, and Bill Sullivan at the American Trucking Associations, Inc. for peer review, discussion, and feedback; and Volpe's Office of Communication and Knowledge Management for assistance with obtaining images.

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16. Abstract
This report summarizes a literature review of vulnerable road user (VRU) truck lateral protective device regulatory and technical standards, crash mitigation effectiveness, and U.S. implementation; an analysis of potential interactions between side guards and common truck parts—including aerodynamic skirts—and commercial vehicle safety inspections; and a benefit-cost analysis of deployment of side guards on the U.S. truck fleet.

The benefit-cost analysis relies on forecasts of vehicle miles traveled, fuel use, and vehicle registration to build a model of the U.S. truck fleet. Three scenarios of national side guard deployment are calculated, including sensitivity analysis for effectiveness of the technology, for the period 2020 to 2045. Two benefit categories are considered: (1) Safety benefits derived from reductions in crash costs for crashes between VRUs and trucks; (2) Aerodynamic benefits derived from fuel use reductions in vehicles that are side guard equipped. Results of the analysis indicate that side guard deployment on the U.S. truck fleet would produce net benefits. Improved aerodynamics provide a substantial portion of the total net benefits of side guards; however, consideration of aerodynamic skirts, which produce aerodynamic benefits but no assumed safety benefits, shows that side guards are still net beneficial at the incremental cost of reinforcing skirts to side guard strength. The report recommends and provides criteria for development of a new industry standard for side guards.

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TABLE OF CONTENTS

LIST OF FIGURES (AND FORMULAS) .... **V**

LIST OF TABLES .... **VIII**

LIST OF ACRONYMS, ABBREVIATIONS, AND SYMBOLS .... **X**

EXECUTIVE SUMMARY .... **XIII**

1. INTRODUCTION **1**

2. CURRENT SIDE GUARD REGULATIONS AND STANDARDS **5**

2.1 INTERNATIONAL REGULATIONS 5
2.2 REGUALTIONS IN FOREIGN COUNTRIES 7
2.3 DOMESTIC REGULATIONS 8
2.3.1 Federal 8
2.3.2 State and Local 8
2.4 INDUSTRY STANDARDS AND RECOMMENDED SPECIFICATIONS 10
2.4.1 Volpe Specification Adopters 11
2.5 EXISTING EXEMPTIONS 12
2.6 CONCLUSIONS 13

3. CRASH MITIGATION EFFECTIVENESS **15**

3.1 OVERVIEW OF STUDIES 15
3.2 EFFECTIVENESS AND EXPOSURE: SUMMARY OF FINDINGS 15
3.2.1 Summary of Tables 16
3.3 CONCLUSIONS 19

4. BENEFIT-COST ANALYSIS **21**

4.1 INTRODUCTION 21
4.2 METHODOLOGY 22
4.2.1 Benefit-Cost Analysis Overview 22
4.2.2 Side Guard Benefit-Cost Analysis Methodology 22
4.3 BENEFITS 25
4.3.1 Safety Benefits 25
4.3.2 Aerodynamic Benefits 28
4.4 COSTS 29
4.4.1 Global Cost Data 29

4.4.2 Domestic Cost Data 30
4.4.3 Interaction with Truck Parts and Inspections 31
4.4.4 Inputs to the Benefit-Cost Analysis 33
4.5 SCENARIOS AND RESULTS 34
4.5.1 Scenario 1: Full Deployment First Year 35
4.5.2 Scenario 2: Gradual Deployment 36
4.5.3 Scenario 3: Aero Skirts Fully Deployed 38
4.5.4 Benefit-Cost Conclusions 39
5. CONCLUSIONS 44
5.1 EXISTING SIDE GUARD REGULATIONS 44
5.2 EFFECTIVENESS AND EXPOSURE STUDIES 44
5.3 BENEFIT-COST ANALYSIS 45
6. RECOMMENDATIONS 47
REFERENCES 50

LIST OF APPENDICES

APPENDIX A – SIDE GUARD REGULATIONS AND STANDARDS 57
APPENDIX B – SYSTEMATIC REVIEW OF EFFECTIVENESS STUDIES 77
APPENDIX C: TRUCK PART AND INSPECTION INTERACTIONS 85
APPENDIX D: ADDITIONAL BENEFIT-COST ASSUMPTIONS AND PROJECTIONS 105

LIST OF FIGURES (AND FORMULAS)

Figure 1: A large truck (left) typically has an exposed space, represented by the vertical arrow and approximately 50 inches in height, between the axles. During a collision, vulnerable road users (VRUs) can fall into the exposed space and suffer fatal crushing injuries. Side guards (right) are designed to cover these exposed spaces. (Source: mechanic, Dan Barbalata/123rf.com) ... 2

Figure 2: Nonoccupants' share of U.S. traffic fatalities has increased over the last 15 years (left), and the fatality shares of pedalcyclists and pedestrians outpaced overall fatality increases in 2015 (right) (National Highway Traffic Safety Administration, 2016). ... 3

Figure 3: Images of UN Regulation 73 side guards in France (top), the Netherlands (middle), and Thailand (bottom) (Source: top and middle, Volpe; bottom, Nuttapong Wannavijid, 123rf.com) ... 6

Figure 4: Timeline of national regulations relative to the passage and expansion of UN Regulation 73. ... 7

Figure 5: Images of side guard-equipped trucks in Cambridge (top left), Boston (top right), New York City (middle left, middle right, and bottom left), and Chicago (bottom right) (Source for Chicago: Rosanne Ferrugia; Boston: Kristopher Carter; others: Volpe) ... 9

Figure 6: Photo of a Single-Unit Truck (SUT) with Rail Side Guard ... 24

Figure 7: Photo of a Combination Truck (CT) with Rail Side Guard ... 24

Figure 8: Photo of a Single-Unit Truck (SUT) with Aero Side Guard ... 24

Figure 9: Photo of a Combination Truck (CT) with Aero Side Guard ... 24

Figure 10: Clock Point Diagram (NHTSA, 2010) ... 26

Figure 11: Side Guard-Relevant Bicyclist Fatalities by Truck Category from 2005 to 2015 ... 27

Figure 12: Side Guard-Relevant Pedestrian Fatalities by Truck Category from 2005 to 2015 ... 27

Figure 13: Undiscounted Benefits and Costs Occurring Each Year (2020-2045) for the Full Deployment First Year Scenario ... 36

Figure 14: Discounted Benefits and Costs Occurring Each Year (2020-2045) for the Full Deployment First Year Scenario (7 percent) ... 36

Figure 15: Undiscounted Benefits and Costs Each Year (2020-2045) for the Gradual Deployment Scenario ... 37

Figure 16: Discounted Benefits and Costs Each Year (2020-2045) for the Gradual Deployment Scenario ... 38

Figure 17: Undiscounted Benefits and Costs Occurring Each Year (2020-2045) for the Aero skirt Fully Deployed Scenario ... 39

Figure 18: Discounted Benefits and Costs Occurring Each Year (2020-2045) for the Aero skirt Fully Deployed Scenario ... 39

Figure 19: Discounted Cumulative Net Benefits of Each Scenario by Year (Low Benefits) ... 41

Figure 20: Discounted Cumulative Net Benefits of Each Scenario by Year (High Benefits) ... 42

Figure 21: Schematic of the UN Regulation 73 side guard dimensional requirements (Source: UN Regulation 73). ... 59

Figure 22. Schematic of 2018 proposed amendment to UN Regulation 73. ... 60

Figure 23: Image showing a rail-style side guard on a truck in Japan (Source: Hirohito Takada, 123rf.com) 61
Figure 24: Technical specifications of the UK dimensional requirements for side guards on trailers (Adapted from Transports' Friend, n.d.) 61
Figure 25: Image showing abandoned Chinese dump trucks with side guards (Source: Novyy Urengov, 123rf.com) 62
Figure 26: Images of single-unit and combination tractor trailers equipped with side guards in Peru (Source: Volpe) 63
Figure 27: Technical specifications of the Peru standard (Ministerio de Transportes y Comunicaciones, 2003) 63
Figure 28: Image showing a side guard on a truck in Brazil (Source: Sergio Shumoff, 123rf.com) 64
Figure 29: Technical specifications of the Brazil standard (all figures are in millimeters) (National Traffic Council, 2009) 65
Figure 30: Specifications of the Mexico City standard (Salvaguardas para Camiones Urbanos, 2015) 67
Figure 31: Technical specifications of the ATA standard (Australian Trucking Association, 2012) 71
Figure 32: Technical criteria of the Volpe specification (Source: Volpe) 72
Figure 33: Private sector rail and panel style side guards in the Boston and New York City (NYC) metro areas (Source: Volpe) 73
Figure 34: Fatality and injury distribution of bicyclists in passing/overtaking side impacts with trucks 4-6 years before and 4-6 years after the mandatory introduction of side guards in the UK (74 crashes in 1980-82 and 66 crashes in 1990-92) (Volpe National Transportation Systems Center, 2014) 78
Figure 35: Decrease in fatality and serious injury rates for bicyclists in passing/overtaking crashes following side guard implementation in the UK (74 crashes in 1980-82 and 66 crashes in 1990-92) 78
Figure 36: Truck with underbody fuel tank. (Source: Volpe) 97
Figure 37: Truck trailer with bolsters (vertical posts). (Source: FMCSA) 97
Figure 38: Truck trailer with bunks (horizontal structure) and stakes (vertical structures). (Source: Taina Sohlman, 123rf.com) 98
Figure 39: Truck with wheels and tires. (Source: Rob Wilson, 123rf.com) 98
Figure 40: Diagram of truck trailer chassis and truck landing gear. (Source: NCHRP) 99
Figure 41: Truck with a crane and stabilizer leg. (Source: Volpe) 99
Figure 42: A truck with an underbody toolbox. (Source: FMCSA) 100
Figure 43: Truck with fire extinguisher behind side guard (Source: Nuttapong Wannavijid, 123rf.com) 100
Figure 44: Truck with side lamps. (Source: Sergio Shumoff, 123rf.com) 101
Figure 45: Truck with aerodynamic skirt. (Source: Vitpho, 123rf.com) 101
Figure 46: Truck with ladder. (Source: Сергей Сергеев, 123rf.com) 102
Figure 47: Truck with a stored spare tire. (Source: Volpe) 102
Figure 48: Truck with a lift axle. (Source: Volpe) 103

Figure 49: Images of Volvo side guard-equipped vehicles currently manufactured for non-U.S. markets (Source: Alf van Beem and Raymondo166, Wikimedia Commons) 111
Figure 50: Safety Benefits Each Year by Scenario and Vehicle Type (Low Effectiveness).......112
Figure 51: Aerodynamic Benefits Each Year by Scenario and Vehicle Type (Low Effectiveness) 112
Figure 52: Costs of Side Guards Each Year by Scenario and Vehicle Type (Low Effectiveness) 113
Figure 53: Undiscounted Cumulative Net Benefits of Each Scenario by Year (Low Effectiveness) 113

LIST OF TABLES

Table ES-1: Scenario Benefit Cost Ratio (BCR) and Net Benefits for 2020-2045 (Discounted at 7 percent/year) xv
Table 1: VRUs killed in all large truck crashes in 2013-2016 2
Table 2: Summary table of countries that may see widespread use of side guards (Source: Volpe) 5
Table 3: Summary table of domestic regulations and their specifications 10
Table 4: Summary table of other side guard standards in Australia, the United Kingdom, and the United States 11
Table 5: Jurisdictions and other entities that have adopted the Volpe specification 12
Table 6: Summary table of four UK studies comparing nationwide data from 1980 to 2008 16
Table 7: Summary table of two UK studies predicting preventable bicyclist fatalities based on detailed investigations of individual crashes 17
Table 8: Summary table of studies from Australia, the Netherlands, and the UK that show similar numbers for pedestrians and bicyclists (and, in the last case, motorcyclists) 18
Table 9: Relative influence and effectiveness of large truck safety countermeasures in preventing UK bicyclist-truck fatalities (Source: HVCIS fatal 1997-2006, via (Knight, et al., 2005)) 19
Table 10: Fuel Efficiency Improvement of Combination Trucks (CT) and Single-Unit Trucks (SUT) by VMT 28
Table 11. Reported cost of rigid side guards for large trucks and trailers 30
Table 12: Truck parts and associated implementation costs related to their compatibility with side guards. 32
Table 13: Cost of Side Guard Pre-Market Installation by Truck Category and Length 33
Table 14: Scenario Benefit-Cost Ratio (BCR) Results (Discounted at 7 percent) 40
Table 15: Scenario Benefit-Cost Ratio (BCR) Results (Discounted at 3 percent) 40
Table 16: Payback Period for Each Scenario and Discount Rate 41
Table 17: Summary table of national standards and their specifications (UN Regulation 73 included for comparison) 57
Table 18: List of the 44 parties that have approved Regulation 73 (43 countries and the European Union) 59
Table 19: Summary table of recommended specifications from studies conducted in Australia, the United Kingdom, and the United States 68
Table 20: Summary table of vehicle types exempted from side guard fitment under UN or UK regulations and technical justification based on published assessments 75
Table 21: 1990-1992 crash severity distribution in truck-bicycle passing/overtaking crashes in the UK when the truck was either exempt or not exempt from side guard installation (KSI = killed or seriously injured) (Knight, et al., 2005) 80
Table 22: 2006-2008 crash severity distribution in truck-bicycle passing/overtaking crashes in the UK when the truck was either exempt or not exempt from side guard installation. (KSI = killed or seriously injured) (Cookson & Knight, 2010) 80
Table 23: Top ten common truck types, common elements, and representative images 90

Table 24: Truck parts and their associated conflicts, compatibility, and costs.............................93
Table 25: KABCO Schedule of Injury Severity and Cost (in 2016 dollars) (U.S. DOT, 2017) .107
Table 26: Side Guard Effectiveness from Four UK Studies Comparing National Data 1980-2008 108
Table 27: Example North American side guard aftermarket suppliers identified by market research...109
Table 28: Example North American side guard retrofit reported costs 109
Table 29: ATRI Cost of Trucking Report Operating Expense per VMT (Hooper & Murray, 2017)...115

LIST OF ACRONYMS, ABBREVIATIONS, AND SYMBOLS

Acronym	Definition
ATRI	American Transportation Research Institute
BCA	benefit-cost analysis
BCR	benefit-cost ratio
BTS	Bureau of Transportation Statistics
CLOCS	Construction Logistics and Community Safety
CT	combination truck
EIA	Energy Information Agency
FARS	Fatality Analysis Reporting System database
FMCSA	Federal Motor Carrier Safety Administration
FMCSR	Federal Motor Carrier Safety Regulations
FMVSS	Federal Motor Vehicle Safety Standard
FTA	Freight Transport Association (United Kingdom)
GES	General Estimation Survey database
GVWR	gross vehicle weight rating
HVCIS	Heavy Vehicle Crash Injury Study
KABCO	fatality (K), disabling injury (A), non-incapacitating injury (B), possible injury (C), and no injury (O)
kN	kilonewton
KSI	killed or seriously injured
LPD	lateral protective device
lb(s).	pound(s)
MAIS	Maximum Abbreviated Injury Scale
Mph	miles per hour
NACFE	North American Council for Freight Efficiency

Acronym	Definition
NTSB	National Transportation Safety Board
OEM	original equipment manufacturer
OMB	Office of Management and Budget
SUT	single-unit truck
TIFA	Trucks in Fatal Accidents (database)
UK	United Kingdom
UN	United Nations
UNECE	United Nations Economic Commission for Europe
U.S.	United States
U.S. DOT	United States Department of Transportation
VIUS	Vehicle Inventory Use Survey
VMT	vehicle miles traveled
Volpe	John A. Volpe National Transportation Systems Center
VRU(s)	vulnerable road user(s)
VRUMT	Vulnerable road user miles traveled
VSL	Value of Statistical Life

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EXECUTIVE SUMMARY

While large trucks comprise 4 percent of the United States (U.S.) vehicle fleet, they are associated with approximately 7 percent of pedestrian and bicyclist fatalities. The collision of a large truck with a vulnerable road user (VRU) such as a pedestrian, bicyclist, or scooter operator is more likely to result in death or serious injury than the collision of a large truck with another motor vehicle. The asymmetric mass ratio and the geometric incompatibility of the two crash partners—the VRU victim is typically overrun by a truck rather than thrust over the vehicle—make these collisions less survivable. Mitigation of truck crashes involving VRUs, rather than other motor vehicles, is the focus of this report.

Compared to VRU crashes with passenger vehicles, VRU crashes with trucks and trailers are also more likely to involve initial impact with the side of the vehicle. Lateral protective devices, or side guards, are vehicle-based safety devices intended to prevent pedestrians, bicyclists, and potentially motorcyclists from falling into the exposed space between the axles of trucks with high ground clearance[1] and being run over by the rear wheels. Side guards represent one of the available countermeasures intended to mitigate truck collisions with VRUs. However, side guards are distinct from most other available countermeasures in both their technological maturity and their passive operation, requiring no behavioral or operational changes, nor requiring the engagement or training of the vehicle operator.

The John A. Volpe National Transportation Systems Center (Volpe) has completed a review of the published literature on the usage and effectiveness of side guards on heavy-duty trucks throughout the United States (U.S.) and globally. The review included national and international standards for side guards applicable to heavy-duty trucks as well as studies of the effectiveness of side guards in reducing VRU fatalities and serious injuries. The review also included published costs associated with side guard installation and maintenance in various markets.

Regulations for side guards have existed since at least 1979, when Japan adopted *Safety Regulations for Road Vehicles: Pedestrian Protecting Side Guards* (Ministry of Land, Infrastructure, Transport, and Tourism, 1979).[2] An international side guard regulation, United Nations (UN) Regulation 73 (United Nations Economic Commission for Europe, 1995), covers 43 countries and the European Union, and has served as a model for other national and local regulations and standards alongside the specification from the United Kingdom (UK) Construction and Road Use Regulations of 1986 (The Parliament of the United Kingdom, 1986).[3] A number of published recommendations to improve or increase the stringency of these standards were identified. No national side guard regulations currently exist in the U.S.; however a side guard specification published by Volpe in 2016 has been implemented at the local level by city jurisdictions and private fleets, resulting in approximately 3,000 installations through mid-2018.

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[1] Defined as the height between the bottom of the vehicle body and the ground on a level surface.

[2] At least one secondary source references side guard designs from as early as 1912 (Walz, Strub, Baumann, & Marty, 1990).

[3] The UN Regulations were established by the UN Economic Commission for Europe but are referred to as "UN Regulations" due to the system's 1995 expansion beyond Europe.

Of over 50 publications reviewed for information on side guard effectiveness, 11 were found to contain quantitative data, a majority of which presented evidence that side guards are effective in mitigating crashes between heavy-duty vehicles and VRUs. Analysis of the effectiveness data in the context of exposure data (percent of all VRU crashes that are side guard-relevant) produced a generalized total mitigation potential expressed as a reduction in the percentage of fatal/serious injuries for all VRU crashes. This total mitigation potential ranged from 5-30 percent in studies specific to bicycle fatalities, <1-6 percent in studies specific to bicyclist serious injuries, 2-4 percent in studies specific to pedestrian fatalities, <1 percent in studies specific to pedestrian serious injuries, and as high as 20 percent for generic VRU fatalities and 25 percent for generic VRU serious injuries in studies that didn't specify the VRU category.

While side guards may offer benefits for mitigating other crash types, such as those involving motorcycles and light duty vehicles, those crashes are not the purpose of side guard technology considered in this study. Panel-type side guards (as opposed to rail-type side guards), however, can provide aerodynamic benefits that result in reductions in fuel use. The cost of side guard installation depends on whether the side guard is equipped pre-market, aftermarket, or as a strength reinforcement of aerodynamic underbody fairings, also known as aerodynamic skirts or aero skirts.

A model of the U.S. trucking fleet was developed for benefit-cost analysis, and three bounding scenarios of side guard deployment were analyzed using that model for 2020 through 2045:

1. **Full Deployment First Year** simulates a mandate to equip all large trucks with side guards by a given date.
2. **Gradual Deployment** tracks a linear path of deployment through the period of analysis, which is 2020–2045.
3. **Aero skirts Fully Deployed** similarly tracks a linear path of side guard deployment through the period of analysis, but assumes that all vehicles are equipped with aero skirts prior to side guard installation. Aero skirts are a comparable technology that provides the same aerodynamic benefits as panel-style side guards but not necessarily the safety benefits, and which can be reinforced to provide comparable safety benefits as side guards for a nominal cost. This scenario provides insight into the marginal impact of side guard safety benefits relative to aero skirts.

Two initial findings from the benefit-cost analysis are notable and perhaps counterintuitive. First, more combination trucks than single-unit trucks were involved in side-guard relevant VRU fatalities between 2005 and 2015. This challenges the perception that combination trucks have negligible exposure to VRUs (e.g., traveling only on limited access highways). Second, 40% of single-unit truck miles traveled were found to be highway miles, nearly equal to their 43% share of urban miles, as compared to 69% highway miles and 22% urban miles for combination trucks. This challenges the perception that single-unit trucks operate too slowly to accrue aerodynamic benefits from a panel-type side guard or a side skirt.

Sensitivity analysis was conducted on the effectiveness of side guards in achieving safety and aerodynamic benefits. A high-benefits scenario used the highest values of safety effectiveness in the literature and 100 percent of the fuel savings effectiveness, while a low-benefits scenario used the lowest safety effectiveness values in the literature and 80 percent of the aerodynamic effectiveness.

The analysis shows that side guard deployment provides significant net benefits under the full range of scenarios. Table ES-1 shows the benefit cost ratio (BCR) and the discounted net benefits for each scenario and for each assumption about safety effectiveness. Benefits and costs are discounted at 7 percent per year to their present value and aggregated to give net benefits. The majority of the benefits of side guards stem from their aerodynamic properties. However, side guards show positive net benefits even when considering only the incremental costs and benefits of reinforcing aero skirts into side guards.

Table ES-1: Scenario Benefit Cost Ratio (BCR) and Net Benefits for 2020-2045 (Discounted at 7 percent/year)

Scenarios	BCR (High Benefits)	BCR (Low Benefits)	Total Net Benefits (High Benefits)	Total Net Benefits (Low Benefits)
Full Deployment First Year	4.65	3.53	$61.6 billion	$42.2 billion
Gradual Deployment	3.05	2.33	$23.5 billion	$15.3 billion
Aero skirt Fully Deployed	2.28	1.19	$2.70 billion	$0.40 billion

The present analysis provides a baseline set of results for FMCSA to consider in developing potential future policies related to side guard standardization and deployment.

This report recommends **development of an industry side guard standard** through a standards development organization, with FMCSA supporting current efforts by certain truck manufacturers and major truck fleets.[4] A **new side guard industry standard** should address, at a minimum:

- Side guard installation on new trucks and new trailers exceeding 10,000 pound GVWR
- Dimensional requirements and performance-based mechanical requirements, including the flexibility to use non-side guard truck parts and accessories to meet these requirements
- Acceptable methods to demonstrate installation and maintenance compliance
- Retrofitting of side guards on existing trucks and trailers

As part of this standard development, particular attention and potentially further research is recommended to achieve industry consensus on:

- Appropriate maximum side guard ground clearance for providing full safety benefit as well as maximum flexibility for vehicle operations; and
- A best practice approach for reinforcing aerodynamic skirt products to provide side guard safety performance while minimizing incremental cost and impact on aerodynamic performance.

[4] Examples of SDOs include, but are not limited to, the American Trucking Associations Technology and Maintenance Council (TMC) and the American National Standards Institute (ANSI).

The new industry standard could potentially establish two tiers of compliance: a minimum set of requirements for international harmonization, e.g., aligned with the UN Regulation 73, as well as a more stringent set of recommended, best practice criteria.

Recognizing geographic differences in VRU exposure, the industry standard should be suited for the environment, e.g., side guards may be exempted for trucks operating exclusively in rural and remote environments. Flexibility should also be considered for side guard clearance on vehicles that cross unimproved, low clearance railroad grade crossings.

This report finally recommends FMCSA and researchers focus on the following further areas of inquiry:

- Determine the extent to which lateral underride technologies will be deployed in the absence of federal intervention.
- Additional potential safety benefits of side guard technology that were not addressed in the current study and incorporating them into the model.

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1. INTRODUCTION

In the coming decades, the need to transport increasing amounts of freight to large urban areas could increase conflicts between freight vehicles and other road users, in particular vulnerable road users (VRUs) such as pedestrians, bicyclists, and other non-occupants of vehicles. Current megatrends that may increase the number of conflicts between VRUs and large trucks include an urbanizing population, growing urban freight volume (due in part to e-commerce growth), and the growth of walking, biking, and other two-wheeled transportation as reported in the United States Department of Transportation (U.S. DOT) Beyond Traffic 2045 synthesis (United States Department of Transportation, 2017).[5] In 2015, over 4,000 people including 410 VRUs were killed and more than 111,000 people were injured in crashes involving large trucks (United States Department of Transportation, 2017).

Large trucks are overrepresented in VRU fatalities. While large trucks comprise 4 percent of the United States (U.S.) vehicle fleet (Bureau of Transportation Statistics, 2017), they are associated with approximately 7 percent of pedestrian and bicyclist fatalities (National Transportation Safety Board, 2013) (National Transportation Safety Board, 2014), approximately 450 annually (see Table 1:) (Federal Motor Carrier Safety Administration, 2017). In urban areas, the overrepresentation is significantly greater. For example, trucks in New York City comprise 3.6 percent of registered vehicles but accounted for an average of 12 percent of pedestrian fatalities from 2002 to 2006 (New York City Department of Transportation, 2010) and 32 percent of bicyclist fatalities from 1996 to 2003 (New York City Departments of Health and Mental Hygiene, Parks and Recreation, Transportation, and the New York City Police Department, 1996-2005). Furthermore, truck and bus crashes are between three and eight times more likely to result in a pedestrian fatality than crashes involving passenger vehicles (New York City Department of Transportation, 2010) (San Francisco Municipal Transportation Agency, 2015). A review of crashes in London found the incidence of death to be 78 times higher in collisions between large trucks and bicyclists than between cars and bicyclists (Quilty-Harper, Burn-Murdoch, & Palmer, 2012).

Compared to VRU crashes involving light-duty vehicles, VRU collisions with large trucks are more likely to involve an impact with the side of the truck. Accordingly, side guards, also referred to as lateral protective devices, are required to be installed on certain motor vehicles, trailers, and semi-trailers in at least 32 countries that the John A. Volpe National Transportation Systems Center (Volpe) identified. As shown in Figure 1, side guards are intended to mitigate side impact crashes by shielding pedestrians, bicycles, and other two-wheelers from the open space between the axle groups of large trucks. To date, a number of U.S. cities and one state have also mandated requirements for side guards, as has at least one U.S. commercial vehicle insurer.

[5] According to one market study, the U.S. is projected to be the second highest growth market for motorcycles, mopeds, and scooters through 2020: http://www.strategyr.com/Marketresearch/Motorcycles_Scooters_and_Mopeds_Market_Trends.asp

Figure 1: A large truck (left) typically has an exposed space, represented by the vertical arrow and approximately 50 inches in height, between the axles. During a collision, vulnerable road users (VRUs) can fall into the exposed space and suffer fatal crushing injuries. Side guards (right) are designed to cover these exposed spaces. (Source: mechanic, Dan Barbalata/123rf.com)

Current federal regulations require rear impact guards for trailers and semi-trailers to reduce the number of deaths and serious injuries that occur when passenger vehicles crash into the backs of these vehicles. However, there are currently no federal regulations concerning side guards to protect pedestrians and bicyclists from the risk of falling under the sides of trucks and being caught under the wheels. No prior federal research appears to have been performed or published on the topic of truck side guards to mitigate collisions with VRUs.

This study in part supports the critical role of the Federal Motor Carrier Safety Administration (FMCSA) in advancing Road to Zero, the U.S. DOT initiative to eliminate all traffic fatalities within 30 years (Federal Motor Carrier Safety Administration, 2016). The focus of this study recognizes that the non-occupant fraction of all road users killed in the U.S. has increased from 20 percent in 1996-2000 to 32 percent in 2012-2015, as shown in Figure 2 (National Highway Traffic Safety Administration, 2016).

Table 1: VRUs killed in all large truck crashes in 2013-2016

Non-motorist Type	2013	2014	2015	2016
Total Non-motorist Fatalities	441	393	410	468
Pedestrian	339	308	334	364
Pedalcyclist	79	61	54	87
Other/ Unknown Non-motorist	23	24	22	17
Total Fatalities	**3,964**	**3,903**	**4,067**	**4,317**
Percent Non-motorist Fatalities	**11%**	**10%**	**10%**	**11%**

Note: Reprinted from *Pocket Guide to Large Truck and Bus Statistics*, by the Federal Motor Carrier Safety Administration, retrieved from https://www.fmcsa.dot.gov/sites/fmcsa.dot.gov/files/docs/safety/data-and-statistics/413361/fmcsa-pocket-guide-2018-final-508-compliant.pdf by the United States Department of Transportation.

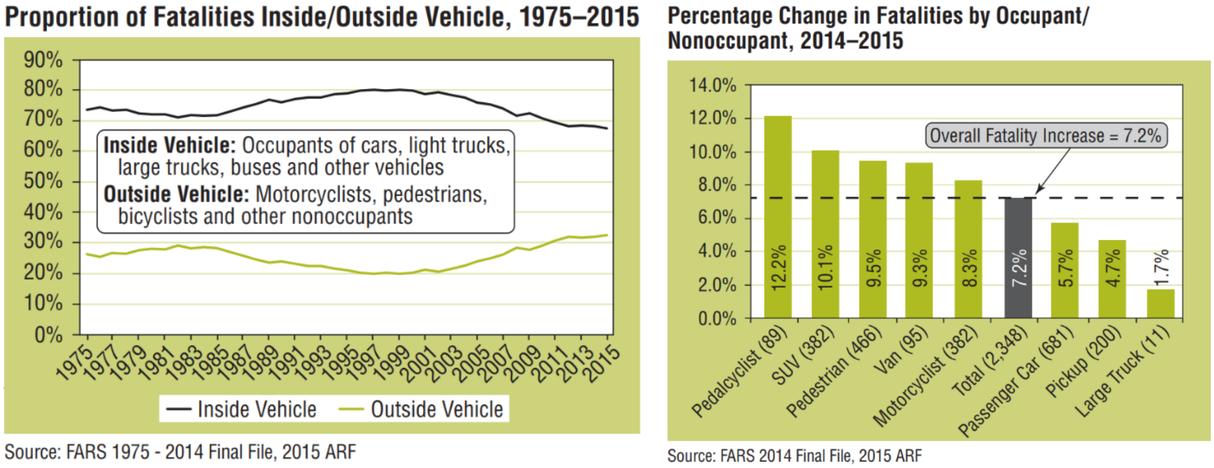

Figure 2: Nonoccupants' share of U.S. traffic fatalities has increased over the last 15 years (left), and the fatality shares of pedalcyclists and pedestrians outpaced overall fatality increases in 2015 (right) (National Highway Traffic Safety Administration, 2016).

It should be noted that **the focus of this study is on lightweight side guards (weighing tens of pounds) for protecting VRUs and not the significantly heavier (hundreds or thousands of pounds), more costly, and less widely commercialized side underride barriers that would be involved in protecting car occupants.** This study does not attempt to compare all crash avoidance and crash mitigation technologies for addressing truck-VRU fatalities and injuries. Lightweight side guards, the focus of this study, are a potentially cost-effective and near-term technology for protecting VRUs that is already mature and globally widespread and involves no behavioral modifications for truck drivers. The technology is also distinct from other potential alternatives in that it can offer both economic and environmental co-benefits if integrated as part of commercially available aerodynamic fairings, or integrated into industry-supported efforts such as the Department of Energy Vehicle Technologies Office 21st Century Truck Partnership.

In addition to the potential benefit for VRU safety and the fuel-saving potential co-benefit, other longer-term benefits of side guards may be considered—for example, improved sensing of trucks and trailers and thus collision avoidance by advanced driver assistance systems, road spray reduction and associated crash avoidance, and trailer wind stability. These issues have also not previously been considered together. The findings of this study will lay a foundation to inform potential future regulatory actions as well as best practices that the industry may voluntarily adopt.

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2. CURRENT SIDE GUARD REGULATIONS AND STANDARDS

Side guards are a mature technology. Volpe identified references to side guard designs from as early as 1912, while the first legislative requirements appeared in the 1970s. Japan and the United Kingdom (UK) led in requiring the use of side guards on large vehicles (in 1979 and 1986, respectively), and the United Nations (UN) and China have both maintained side guard regulations since 1988 and 1989, respectively, in various climatic, roadway, and urban conditions. Volpe also identified two countries in South America—Peru and Brazil—with established national side guard regulations.

In this section, side guard regulations and regulatory trends are reviewed, compared for applicability to vehicle types, and synthesized. Volpe leveraged its Massachusetts Institute of Technology Library partnership in support of this regulatory review, which included international regulations, foreign regulations, U.S. regulations and standards, and industry standards and recommended specifications. The most prolific source of specifications and standards proved to be international and foreign regulations, particularly those of the UN and the UK, with additional precedents identified from Brazil, China, Japan, and Peru. A non-exhaustive review of these sources along with online image searches identified at least 65 countries with widespread use of side guards either through regulations or other adoption methods (Table 2).

Table 2: Summary table of countries that may see widespread use of side guards (Source: Volpe)

Source	Number of Total Countries
Abides by UN Regulation 73	43
Independent national regulation	5*
Subnational regulation	3
Industry standard or recommended specification	3
Image search	14

*Includes the European Union

2.1 INTERNATIONAL REGULATIONS

Following independent regulations passed in Japan and the UK, a process of international harmonization began in 1988, with a proposal from the Netherlands and the UK to the United Nations Economic Commission for Europe (UNECE) to require "lateral protection devices" on vehicle classes N_2, N_3, O_3, and O_4 (as defined in the UNECE Consolidated Resolution on the Construction of Vehicles, RE3).[6] The regulation was added as Regulation 73 to the 1958 "Agreement Concerning the Adoption of Uniform Technical Prescriptions for Wheeled Vehicles, Equipment and Parts which can be fitted and/or be used on Wheeled Vehicles and the Conditions

[6] Category N refers to motor vehicles with at least four wheels that are used for the carriage of goods (i.e., commercial trucks), and Category O refers to trailers.

for Reciprocal Recognition of Approvals Granted on the Basis of these Prescriptions" (commonly referred to as "the 1958 Agreement").

Originally applicable only to European countries, the type approval system established in the 1958 Agreement—which allows a motor vehicle product approved by any authority party to the agreement to be accepted by other authorities applying the regulation—was expanded beyond Europe in a 1995 revision (GlobalAutoRegs, 2017). To reflect the broader coverage, the regulations annexed to the agreement are now widely referred to as "UN regulations" rather than "UNECE regulations." At the time of publication, Volpe is aware of 43 countries that have approved this regulation, suggesting widespread adoption of truck side guards in their respective nations (UNECE Inland Transport Committee, 2017) (See Figure 3, Table 18, and Figure 21).

A proposal was advanced in 2018 to amend UN Regulation 73. It would reduce the maximum allowable ground clearance (the height from the ground to the bottom edge of the side guard) to between 350 and 450 mm, versus 550 mm at present. The proposal would also increase the quasi-static force test to 3 kN from the existing 1 kN, with the intent of increasing protection for motorcyclists. (Economic Commission for Europe, 2018)

Figure 3: Images of UN Regulation 73 side guards in France (top), the Netherlands (middle), and Thailand (bottom) (Source: top and middle, Volpe; bottom, Nuttapong Wannavijid, 123rf.com)

Finally, the International Standards Organization maintains a typology to categorize all standards around the world, and for side guards, the relevant International Classification of Standards number appears to be 43.040.60 (International Organization for Standardization, n.d.).

2.2 REGUALTIONS IN FOREIGN COUNTRIES

Outside of the international UN Regulation 73, seven countries have taken steps to standardize side guard usage. The earliest national standard that Volpe found was Japan's "Pedestrian Protecting Side Guards," which made side guards a requirement in 1979 (Pedestrian Protecting Side Guards, Article 18-2, 1979). The United Kingdom followed with a 1983 amendment to the Road Vehicles (Construction and Use) Regulations to require the fitment of side guards to some new goods vehicles and some existing semitrailers; this regulation would eventually serve as the model for UN Regulation 73 (The Parliament of the United Kingdom, 1986). Additionally, side guard regulation has been implemented at the national scale in China (1989), Peru (2003), and Brazil (2009) (see Figure 4).

Two nations outside of the U.S. have also seen side guard programs on a local level, with the implementation of a side guard requirement for large vehicles in Mexico City in 2015 (Salvaguardas para Camiones Urbanos, 2015) and the implementation of side guards on city fleet vehicles in two Canadian jurisdictions: Saint-Laurent (Montréal), Quebec, in 2013 (The Jessica Campaign, 2016), and St. John's, Newfoundland and Labrador, in 2017 (Macdonald, 2016). Table 17 in Appendix A details the specifications of each national standard. Schematics and narrative descriptions follow, including the subnational regulations passed in Mexico and Canada.

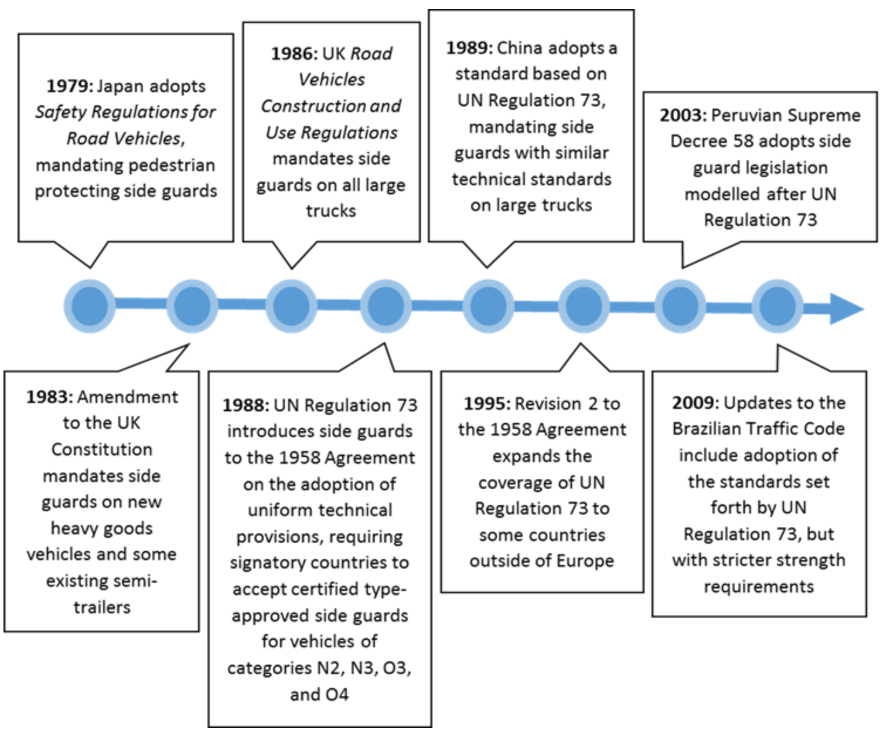

Figure 4: Timeline of national regulations relative to the passage and expansion of UN Regulation 73.

2.3 DOMESTIC REGULATIONS

2.3.1 Federal

Large truck design in the U.S. is regulated by Federal Motor Vehicle Safety Standards (FMVSS) and Federal Motor Carrier Safety Regulations (FMCSRs). FMVSS 223 applies to rear underride guards, which are intended to arrest light-duty vehicles that crash into the rear of a tractor trailer. No FMVSS or FMCSR currently requires or references side underride guards. The National Highway Traffic Safety Administration (NHTSA) rejected adding side underride guard requirements to the FMVSS in 1991. However, those requirements were proposed for a different purpose: protecting passenger car occupants rather than pedestrians and bicyclists (Padmanaban, 2013). Thus, the side guards considered at that time would have been significantly stronger, heavier, and costlier than the ones considered in this study, as they would have been designed to arrest or deflect a motor vehicle rather than a person. At the time of publication, no federal regulation or guidance focusing on VRU side underride mitigation appears to exist or to have been considered in past federal rulemakings.

2.3.2 State and Local

Although no national side guard regulations currently exist in the United States, there are at least seven municipal and state-level requirements that have either been implemented since 2008 or are pending. Washington, DC; New York, NY; the adjoining cities of Boston, Cambridge, and Somerville, MA; Seattle; San Francisco; Chicago; and Philadelphia have required side guards on a combination of municipal heavy-duty vehicles, city-regulated trucks (New York City, 2015), and all registered trucks in the District (Washington, DC, 2016). The Council of the District of Columbia passed a 2008 law requiring District-owned heavy duty vehicles to be equipped with side-underrun guards, but the law was not funded until 2014. Also in 2008, the City of Portland, OR, through a City Council resolution, implemented a pilot program on its municipal truck fleet, which resulted in about 12 vehicles being fitted with side guards (DePiero & Leader, 2012). In 2013, the City of Boston began retrofitting City vehicles with side guards, and in October 2014 it enacted the nation’s first ordinance requiring side guards on City-contracted trucks (City of Boston Mayor's Office, 2014), followed by similar ordinances in Somerville, MA and Chicago. In 2015, the New York City Council enacted a local law requiring side guards on 10,000 trucks by 2024, including the City-owned fleet and the City-regulated commercial refuse fleet. In 2016, the 2008 District of Columbia law was amended to apply to all District-registered large trucks effective 2019 (Council of the District of Columbia, 2016), potentially making it the broadest implementation of side guards. In 2019, Massachusetts legislation advanced impacting state-owned and state contracted large trucks (Massachusetts, 2019). Volpe estimates that approximately 3,000 trucks have been equipped through mid-2018 under these local laws.

As of late 2018; Cambridge, MA; Seattle, WA; Philadelphia, PA; Portland, OR; and the Commonwealth of Massachusetts were in various stages of considering procurement laws that would require side guards on fleet vehicles under government contract. Additionally, the Massachusetts 2018 Strategic Highway Safety Plan includes side guards as a “high-leverage policy to reduce the frequency and severity of roadway fatalities.” (Massachusetts DOT, 2018)

With the exception of Boston, these local laws have referenced and adopted the Volpe standard and are therefore generally consistent (see Figure 5 and Table 3). The City of Boston ordinance preceded the Volpe specification and was instead modeled on the UN Regulation 73 specifications. The Boston ordinance is expected to eventually be revised to align with the Volpe specification (Carter K. , 2017).

Figure 5: Images of side guard-equipped trucks in Cambridge (top left), Boston (top right), New York City (middle left, middle right, and bottom left), and Chicago (bottom right) (Source for Chicago: Rosanne Ferrugia; Boston: Kristopher Carter; others: Volpe)

Table 3: Summary table of domestic regulations and their specifications

<table>
<tr><th>City</th><th>Date Enacted</th><th>Vehicles Covered</th><th>Vehicles Exempted</th><th>Strength Rqmt.</th><th>Maximum Ground Clearance</th><th>Maximum Gap between Guard and Wheels</th></tr>
<tr><td>Boston, MA</td><td>2014</td><td rowspan="5">Vehicles of weight 10,000 lbs. or higher.</td><td>- Agricultural trailers,
- Fire engines, and
- Trucks used exclusively for snow removal.</td><td rowspan="5">2 kN (440 lbs.)</td><td>21.5 in.[7]</td><td rowspan="5">11.8 in.</td></tr>
<tr><td>New York, NY</td><td>2015</td><td>- Street sweepers,
- Fire engines,
- Car carriers, and
- Off-road construction vehicle types on which side guard installation is deemed impractical by the department.</td><td rowspan="4">350 mm (13.8 in.)</td></tr>
<tr><td>Washington, DC</td><td>2016</td><td>None</td></tr>
<tr><td>Somerville, MA [8]</td><td rowspan="2">2017</td><td rowspan="2">- Ambulance;
- Fire apparatus;
- Low-speed vehicle with maximum speed under 15 mph;
- Agricultural tractor.</td></tr>
<tr><td>Chicago, IL</td></tr>
</table>

2.4 INDUSTRY STANDARDS AND RECOMMENDED SPECIFICATIONS

Several organizations, including Volpe and the Office of the Assistant Secretary for Research and Technology (OST-R), have developed side guard standards or guidelines to assist fleet operators who wish to implement side guards voluntarily. In some cases, as with the Australian Trucking Association standard and with the Volpe specification, these assist fleet operators in countries where there is no national side guard regulation. The Construction Logistics and Community Safety (CLOCS) Standard and Fleet Operator Recognition Scheme (FORS) are different, in that they assist UK fleet operators in implementing a stricter standard than exists nationally. Among these standards, Volpe's is the most stringent, with a strength requirement of 2 kN and a maximum ground clearance of 350 mm. The Australian Trucking Association standard ("Side Under Run Protection Technical Advisory Procedure"), which the group recommends to its members, is the most lenient, with a strength requirement of 1 kN and a maximum ground clearance of 550 mm (Australian Trucking Association, 2012). The CLOCS, FORS, and ATA standards are largely adopted by industry members, while the Volpe specification has been adopted by a mix of private fleets and U.S. cities and states (see Table 4).

[7] As of September 2017, the City of Boston was expected to revise the maximum clearance to 13.8 inches to align with other U.S. cities.

[8] As of January 2019, Cambridge, MA, was also expected to develop a similar ordinance.

Table 4: Summary table of other side guard standards in Australia, the United Kingdom, and the United States

Standard	Year Published	Adopters	Vehicles Covered	Strength Rqmt.	Maximum Ground Clearance	Maximum Gap Between Wheels and Guard
Australian Trucking Association (ATA) Standard	2012	Melbourne Metro	Vehicles of categories N_2, N_3, O_3, and O_4.	1 kN (225 lbs.)	550 mm (21.7 in)	Maximum of 300 mm (11.8 in.) behind the front tire and 300 mm (11.8 in.) in front of the rear tire
Construction Logistics and Community Safety (CLOCS) Standard for Construction Logistics; Fleet Operator Recognition Scheme (FORS)—United Kingdom	2015	London fleet managers (CLOCS) and fleet operators (FORS)	All rigid mixer, tipper and waste type vehicles over 3.5 tonnes gross vehicle weight that are exempt under the mandated UK standard	2 kN	550 mm (21.7 in)	300 mm (11.8 in.) between the back of the front wheel and the front of the side guard, 300 mm (11.8 in.) between the back of the side guard and the back tire
Volpe Standard—United States	2016	Boston Chicago New York City Wash., D.C. Somerville, MA San Francisco Seattle State of MA	Vehicles of weight 10,000 lbs. or higher	2 kN [9]	350 mm (13.8 inch) clearance	Should not exceed 300 mm (11.8 inches)

Additionally, six sets of recommended specifications for either standard establishment or standard improvement were reviewed (see Table 19 in Appendix A).

2.4.1 Volpe Specification Adopters

Volpe identified a wide range of adopters of the Volpe specification at the local (and, to a more limited extent, state) level in the U.S. and Canada. Additionally, Mexico City's 2015 side guard regulation is based on the Volpe specification. Table 5 summarizes known adoption of the Volpe specification among North American jurisdictions, insurers, and institutions. It does not include voluntary adoption by a growing range of private fleets in the freight and construction sectors.

[9] The Volpe specification is published in Imperial units, however it is summarized here in metric units for consistency with the other standards.

Table 5: Jurisdictions and other entities that have adopted the Volpe specification

Adopting Entity	Year of Adoption
Portland, OR *	2008
Montréal, QC *	2012
Boston, MA **	2014
Newton, MA *	2014
Fort Lauderdale, FL *	2015
Mexico City, Mexico	2015
New York, NY	2015
Orlando, FL *	2015
University of Washington	2015
San Francisco, CA	2016
Seattle, WA	2016
Washington, DC	2016
Cambridge, MA	2017
Chicago, IL	2017
Energi Insurance	2017
Greenville, NC	2017
Halifax, NS	2017
Harvard University	2017
Somerville, MA	2017
CEMEX	2018
Philadelphia, PA	2018
State of Massachusetts	2018
Madison, WI	2018
Acadia Insurance Group	2018

* Not known whether Volpe specification used.

** Not consistent with Volpe specification but revision expected to align.

2.5 EXISTING EXEMPTIONS

In contrast to light-duty vehicles, medium- and heavy-duty vehicles involve diverse body styles, dimensions, and uses. Certain truck types are more challenging to equip with side guards or may require side guard modifications. Volpe researched the existing vehicle exemptions in UN Regulation 73 and the UK Road Vehicles (Construction and Use) Regulations, and reviewed published assessments from a detailed 2004 TRL report (Smith & Knight, 2004) on the technical justifiability of the UK side guard exemptions—i.e., whether a unique physical configuration, unique operational requirements, or minimal exposure to pedestrians and bicyclists support exempting the vehicle. The UN and UK exemptions and Volpe's synthesis of the assessments of whether these existing exemptions are technically justified are summarized in Table 20 in Appendix A.

2.6 CONCLUSIONS

This review of national and local side guard regulations, research-based standards, and recommended specifications demonstrates both a global precedent for side guard adoption and a growing trend of subnational efforts in countries such as the U.S. where national adoption and standardization have not occurred.

A comparison of the key attributes of each confirmed national standard and the multinational UN Regulation 73 produces several findings. First, the UK standard applies to trucks of a lower gross vehicle weight (GVWR) rating than the Japan standard (3,500 kg or 7,716 lbs. compared to 8 tons or 16,000 lbs.), but it also exempts more vehicle types and has a higher ground clearance (550 mm or 21.7 in. compared to 450 mm or 17.7 in.). Compared to the Japan and UK regulations, the UN regulation maintains the more lenient minimum ground clearance of 550 mm (21.7 in.) used by the UK, and a lower minimum strength requirement of 1 kN versus 2 kN. China, Peru, and Brazil have each adopted the maximum ground clearance and wheel gap requirements of UN Regulation 73, and the first two have also adopted the same 1 kN strength requirement. The Brazil regulation, which is intended to address motorcyclist collision injuries and fatalities, has the highest strength requirement of any identified regulation, requiring side guards to withstand forces of 5 kN (Ministerio de Transportes y Comunicaciones, 2003).

Side guard regulations passed by municipalities tend to be modeled on UN Regulation 73 (e.g., in Canada) or on standards adopted by peer municipalities (e.g., Mexico City enacted a law based on one passed in New York City, which was based on the Volpe specification). Academic analyses of available side guard standards, meanwhile, have produced recommendations for more stringent specifications, i.e., higher strength requirements and lower ground clearances, and for fewer vehicle type exemptions.

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3. CRASH MITIGATION EFFECTIVENESS

Overall, about 50 publications were accessed and reviewed for this analysis. Section 3.1 describes the nature of the eleven publications that contained data specifically on the safety effectiveness of side guards for VRUs. Section 3.2 summarizes the data that these studies provide on VRU exposure to side guard relevant crashes, as well as the effectiveness that the side guards can have in such crashes.

3.1 OVERVIEW OF STUDIES

The majority of the studies on side guards present quantitative and/or qualitative evidence that side guards are effective at mitigating crashes with VRUs. A few of the findings were inconclusive, but no studies disproved side guard effectiveness. Most studies articulate that the type of side guards in common use (i.e., with ground clearance as high as 550 mm) are primarily effective for passing and overtaking maneuvers, in which the heavy vehicle travels roughly parallel with the VRU, with VRU impact on the passenger side of the vehicle ("nearside," in UK terminology). A number of studies present evidence supporting this. It appears that side guards—in particular more stringently designed side guards with lower ground clearance—can also be effective in crashes where the vehicle makes a turn to the passenger side, though the evidence to support this is less conclusive.

The studies summarized in this section fall into three categories: (1) field evaluation studies, which analyzed real-world crash data; (2) experimental studies, which conducted physical tests to assess side guard performance; and (3) simulation studies, which used computer models to simulate crash circumstances and outcomes. Some publications had multiple study components, and are thus cited in more than one section. A systematic review of the published findings is provided in Appendix B. The following is a summary of this review.

3.2 EFFECTIVENESS AND EXPOSURE: SUMMARY OF FINDINGS

While side guard effectiveness is the capacity to mitigate crash outcomes, exposure is the number of relevant crashes that side guards could mitigate. The overall benefit of side guard deployment—the number of fatalities and serious injuries mitigated—is a product of effectiveness and exposure. This section summarizes the available literature on the fraction of all crashes between trucks and VRUs that are likely to be side guard-relevant. The primary focus here is on exposure data for which there are corresponding effectiveness data.

The introduction of side guards globally over the past three decades was intended to prevent bicyclists and pedestrians from falling into the space between the axles of a passing large truck and being run over by the wheels. A definition of side guard-relevant crashes must at least involve an initial point of impact on the side. However, relevance likely also depends on the relative maneuvers of the truck and VRU during the collision. Glancing collisions while traveling in roughly parallel lines are most confidently side guard relevant. Turning collisions where a truck turns across the path of a bicyclist or pedestrian appear side guard relevant as well, though the effectiveness is of lower confidence based on the studies Volpe reviewed, and their effectiveness may be more sensitive to side guard design, e.g., smooth panel versus rail construction, inboard distance from the side of the truck body, and ground clearance.

In the U.S., according to an NTSB analysis using Trucks in Fatal Accidents (TIFA) data from 2005-2009, **initial side-impact crashes represent 25-29 percent of pedestrian fatalities involving trucks and 44-55 percent of bicyclist fatalities involving trucks** (National Transportation Safety Board, 2013). These reported data do not provide the same degree of specificity as other studies on exposure, since they do not distinguish between various types of maneuvers.

3.2.1 Summary of Tables

Overall, there was much more information available for bicyclist fatalities than for any other category of VRU safety impact (bicyclist serious injuries, pedestrian fatalities, and pedestrian serious injuries).

Table 6 summarizes four UK studies that relied on "before and after" comparisons of national data to infer side guard benefit (Knight, 2005), (Smith, 2005), (Cookson, 2010), (Robinson, 2014). For ***bicycles***, across the three observation periods from 1980 to 2008, **the side guard-relevant crashes ranged from 10 to 22 percent of all crashes, and from 11 to 29 percent of serious crashes where the VRU was killed or seriously injured (KSI).** This only focuses on ***passenger side*** impacts with glancing type collisions, which the studies assume are the most relevant. **It is possible but less likely that glancing type collisions on the driver side may also be side guard-relevant, which would bring the total percentage of side guard relevant crashes up to as much as 45 percent of all crashes**. However, the studies do not provide exposure data for driver side bicycle crashes. In terms of pedestrians, the UK data show that "going ahead other" passenger side crashes in the first two observation periods (1980-1992) were **19-20 percent of all crashes and about 10-14 percent of all fatal crashes.** Broadening the focus to look at all passenger side crashes brings the total to **28-30 percent of all crashes and 17-23 percent of all fatal crashes.** Table 6 summarizes the key information from these studies in more detail.

Table 6: Summary table of four UK studies comparing nationwide data from 1980 to 2008

Safety impact	Exposure range (side guard relevant crashes as a percentage of all crashes)	Effectiveness range (reduction in fatality or serious injury as a proportion of all injuries)	Exposure × effectiveness (theoretical mitigation potential expressed in terms of all crashes)
Bicyclist fatalities	9-23%	55-75%	5-17%
Bicyclist serious injuries	12-35%	3-17%	<1-6%
Pedestrian fatalities	10-14%	20-27%	2-4%
Pedestrian serious injuries	19%	<1%	<1%

Table 7 shows data from two UK studies that took a different approach. These studies conducted detailed investigations of individual fatal crashes and assessed whether they could have been prevented by side guards. Finally, Table 8 summarizes other studies from Australia and the

Netherlands that show similar numbers for pedestrians and bicyclists (former) or do not differentiate (latter). The table also includes a UK study that provides a single combined effectiveness estimate for motorcycles, bicyclists, and pedestrians.

Table 7: Summary table of two UK studies predicting preventable bicyclist fatalities based on detailed investigations of individual crashes

Study	Guard implementation	Crash set	Exposure (side guard relevant crashes as a percentage of all crashes)	Effectiveness (reduction in fatality or serious injury as a proportion of all injuries)	Exposure times effectiveness (theoretical mitigation potential expressed in terms of all crashes)
Keigan09	UK regulatory requirement	Heavy vehicle changing lanes or turning left	24.2%	93.8%	22.7%
Keigan09	UK regulatory requirement	Cyclist lost control alongside vehicle	16.7%	45.5%	7.6%
Keigan09	UK regulatory requirement	Total of the two above	40.9%	74.1%	30.3%
Talbot14	UK regulatory requirement	Side crashes	100.0%	11.5%	11.5%
Talbot14	More stringent side guard dimensions to close gaps	Side crashes	100.0%	26.9%	26.9%

Another noteworthy resource is the UK's HVCIS fatal crash database. In this national database, available countermeasures are matched to each fatal crash along with an estimated probability that each countermeasure would have prevented the fatality. The probability estimation is based on review of evidence in the police crash report files as well as on published guidance about the efficacy of the various countermeasures (Cookson & Knight, 2010). Since side guards are already required in the UK, the estimated benefits related to side guard countermeasures in the HVCIS solely reflect incremental benefits associated with enhancing the existing requirement. Table 9 shows side guards along with some other possible countermeasures, for reference.

Table 8: Summary table of studies from Australia, the Netherlands, and the UK that show similar numbers for pedestrians and bicyclists (and, in the last case, motorcyclists)

Publication	Guard implementation	Crash set	Exposure (side guard relevant crashes as a percentage of all crashes)	Effectiveness (reduction in fatality or serious injury as a proportion of all injuries)	Exposure times effectiveness (theoretical mitigation potential expressed in terms of all crashes)
Rechnitzer93	Not specified	All fatal crashes	100.0%	20.0%	20.0%
Rechnitzer93	Not specified	All serious injury crashes	100.0%	25.0%	25.0%
VanKampen99	Bus as proxy for low-clearance guard condition	All passenger side turning maneuvers (rail-style side guard)	Not specified	25.0%	Not specified
VanKampen99	Bus as proxy for low-clearance guard condition	All passenger side turning maneuvers (smooth-style side guard)	Not specified	35.0%	Not specified
Riley81	Not specified	Side impacts for motorcyclists, bicyclists, and pedestrians	66.0%	24.0%	15.0%

This review of effectiveness studies relies heavily on references from the UK, in part due to the relative ease of accessing and reviewing publications in English. There are likely other effectiveness studies that this effort has not yet obtained, due to language limitations and other challenges associated with international research. The reviewed literature consistently shows that side guards are effective at mitigating fatalities and serious injuries for VRUs. Most studies focused on bicyclist fatalities, although there are several studies that address safety effectiveness for pedestrians and motorcyclists. According to the literature, side guards appear to be relevant for a significant fraction of crashes (9-40 percent of bicyclist crashes and 10-19 percent of pedestrian crashes) and effective in a significant proportion of these crashes.

Table 9: Relative influence and effectiveness of large truck safety countermeasures in preventing UK bicyclist-truck fatalities (Source: HVCIS fatal 1997-2006, via (Knight, et al., 2005))

Countermeasure	Total estimated lives that would have been saved by countermeasure (1997-2006)
Improve forward vision	8
Improve side vision	21
Install stronger and lower side guards*	13.25
Install aerodynamic side guards*	21
Provide bicycle lane	34.25
Other	9.75

*This is the **additional** projected benefit of **improved** side guards, not the overall benefit from side guards, since they are already required in the UK.

Multiplying effectiveness by exposure produces a generalized total mitigation potential expressed in terms of a reduction in the percentage of fatal/serious injuries for all crashes (not just side guard relevant ones).

- **Fatalities:** Looking across the studies specific to bicycle fatalities, this total mitigation potential ranged from 5 – 30 percent. For studies specific to pedestrian fatalities, the total mitigation potential ranged from 2 – 4 percent. For studies that presented generic estimates of effectiveness (not differentiating among VRU category), the total mitigation potential for fatalities ranged as high as 20 percent.
- **Serious injuries:** For the studies with data specific to bicycle serious injuries, the estimate of total mitigation potential ranged from <1 – 6 percent and for the one study with specific data on pedestrian serious injuries the estimate was <1 percent. For other studies that presented generic estimates of effectiveness (not differentiating among VRU category), the total mitigation potential for serious injuries ranged as high as 25 percent.

3.3 CONCLUSIONS

A variety of sources provide data on the safety effectiveness of side guards for VRUs, including field evaluation studies, which use real-world crash data; empirical studies, which involve physical tests to assess performance; and simulation-based studies, which use computer modeling to assess performance. Volpe reviewed over 50 publications for information on side guard effectiveness, 11 of which contained quantitative data on safety effectiveness for VRUs. The majority of these studies on side guards present quantitative and/or qualitative evidence that side guards are effective at mitigating crashes with VRUs. A few of the findings were inconclusive, but no studies disproved side guard effectiveness. Most studies articulate that the type of side guards in common use, with ground clearance up to and exceeding 550 mm, are primarily effective for passing/overtaking maneuvers, in which the heavy vehicle travels roughly parallel with the VRU, with VRU impact on the passenger side of the vehicle (“nearside,” in UK terminology). A number of studies present evidence supporting this. Evidence was also identified indicating that side guards—in particular more stringently designed variants with decreased height between the bottom edge and the roadway—can be effective for crashes in which the vehicle turns toward the passenger side, though the evidence is less conclusive.

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4. BENEFIT-COST ANALYSIS

4.1 INTRODUCTION

Trucking plays a central role in freight and logistics and is an essential component of the U.S. economy. At the same time, crashes involving trucks and VRUs accounted for 468 fatalities in 2016, with societal costs of $4.5 billion,[10] a value that does not include the costs of non-fatal injuries. Truck side guards are an existing technology that has been widely deployed internationally for reducing fatal VRU crashes.

Separately, volatile fuel costs and environmental concerns have focused attention on fuel efficiency in the trucking sector. According to estimates from the Energy Information Administration (EIA), the trucking industry's total fuel expenses were $5.88 billion in 2015,[11] a value that does not include the societal costs of emissions from this consumed fuel. Both aerodynamic truck and trailer skirts and certain side guards that are designed to reduce aerodynamic drag have been developed as one way of producing fuel savings.

This section analyzes the benefits and costs of side guard deployment scenarios from a societal perspective. The goal is to understand whether the costs of side guard installation are justified by the potential safety and fuel efficiency benefits. The present analysis does not compare the net benefits of all the technologies that could potentially be used to produce similar benefits, but instead assesses the net benefits (or total societal benefit) of truck side guards as an available and technically mature countermeasure to reduce crash costs between heavy trucks and VRUs and to reduce fuel use in operation. The results of this report can, however, be used in future comparisons of the total net benefits of side guard deployment relative to alternative technologies that could address the same issues.

The analysis considers a technology closely related to side guards: aerodynamic truck and trailer skirts (aero skirts), which are installed in a way that makes them incompatible with also installing side guards.[12] Aero skirts provide similar fuel reduction benefits as certain side guards, but some may not be structurally reinforced to withstand crashes with VRUs and thus may not provide equivalent crash safety benefits. Aero skirts are already deployed on a significant portion of van and refrigerated trailers in the U.S. and are increasingly being deployed on new trucks and trailers or retrofitted onto older models. According to the North American Council for Freight Efficiency (NACFE) 2018 Annual Fleet Fuel Study, almost nine out of 10 recently purchased box-type trailers within the 20 participating fleets were equipped with aero skirts (Berg, 2018). Rapid aero skirt adoption has been driven in part by a 2010 California Air Resources Board

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[10] Crash costs here represent the total cost to society rather than the cost to carriers alone. This was calculated using U.S. Department of Transportation (DOT) Value of Statistical Life (VSL) for 2016 of $9.6 million, and 468 fatalities occurred in crashes involving trucks and VRUs in 2016.

[11] Estimate built from American Transportation Research Institute (ATRI) estimate of fuel cost per mile ($0.21) and FHWA estimate of heavy-duty truck vehicle miles traveled (roughly 280 billion miles).

[12] Aero skirts can be structurally reinforced to garner the same safety benefits as side guards.

requirement as well as by EPA Greenhouse Gas Phase 2 Regulations for Medium- and Heavy-Duty Vehicles (Agency, 2018).

4.2 METHODOLOGY

4.2.1 Benefit-Cost Analysis Overview

Benefit-cost analysis (BCA) is an evaluation method that allows decision makers to compare alternative options by reframing the impacts of those options into commensurable terms, such as dollars. BCA considers the widest possible scope of who is impacted by a choice, yielding a full accounting of societal impacts. These impacts are broadly categorized into costs and benefits, and are further categorized by their cause or impact, e.g., benefits such as safety and costs such as installation. Impacts are determined for the present and for all relevant future years as determined by the lifecycle of the asset or program considered.

Impacts are converted from impact quantities (e.g., number of fatal crashes) into dollar values (e.g., a DOT-supplied cost of $9.2 million per fatality) for comparison. Impacts often occur over many years, and to account for the greater value of the present impacts versus those further in the future, the future impacts are discounted so that the values of all years are treated as present values.

Total benefits and costs from all years are summed, resulting in total net benefit, interpreted as the value of the option. Total net benefit may be positive or negative. Additionally, a benefit-cost ratio (BCR) can be calculated (total benefits divided by total costs) and used to categorize the option as being net beneficial (BCR>1), net neutral (BCR=1), or net negative (BCR<1). These two analysis outputs, net benefits and BCR, are used for comparative purposes.

The primary alternative of comparison is the case where no action is taken. Similarly, net benefits and BCR could be used in a comparison of all relevant alternatives (including the do-nothing case) to determine the most cost-effective option.

A net positive BCA is not a decisive reason for pursuing an option, as other considerations may make the option untenable, such as monetary or legal constraints.

4.2.2 Side Guard Benefit-Cost Analysis Methodology

This section provides an overview of the methodology for this side guard benefit-cost analysis. The impact categories considered are those for which the side guard is expected to deliver benefits or costs. Safety benefits are calculated as crash cost reductions in crashes between VRUs and side guard-equipped trucks. Fuel savings benefits (aerodynamic) are calculated from reductions in fuel use by side guard-equipped trucks. The costs considered are all costs associated with deploying side guards, which includes installation and maintenance.[13] The period

[13] Details about the method and cost of side guard maintenance can be found in Appendix D.

of analysis is from 2020 through 2045. Future values of each impact are discounted at 7 percent, consistent with the Office of Management and Budget's BCA guidelines (OMB, 2017).

A model of the trucking fleet was developed for the BCA analysis, and three alternative scenarios of deployment were considered to provide insight into the potential range of net benefits; all scenarios assume side guards achieve full deployment by 2045. These bounding scenarios were considered to account for the uncertainty of future regulatory and voluntary industry action.

4.2.2.1 Truck Assumptions

This analysis considers the full population of commercial trucks over 10,000 lbs., including the two categories of single unit trucks and combination trucks. Single-unit trucks are vehicles over 10,000 pounds that have a single frame, often with two axles, while combination trucks include a power unit (or tractor unit) that tows one or more trailer(s).

These two truck categories are further broken down by cargo body types (e.g., dump truck, flatbed, or van). The characteristics of cargo body types (such as truck length) were determined from the Vehicle Inventory and Use Survey (VIUS), part of the 2002 Economic Census. The VIUS dataset is considered the most reliable data on the U.S. truck fleet available at this time.

Estimates of the total size of the U.S. fleet by truck category are derived from the Bureau of Transportation Statistics' (BTS) vehicle registration data, which provide annual State-level registration data for all motor vehicles including heavy trucks. The proportion of cargo body types in each truck category is obtained from the VIUS dataset.

Side guards are directly deployed on single-unit trucks (SUT), but are indirectly deployed on combination trucks (CT) (tractor trailers) because they are deployed on the trailers and not the tractor. Trailers can be pulled by different truck tractors depending on operational needs or availability. Estimates of the number of trailers in the U.S. are provided in the Americas Commercial Transportation (ACT) Research Co.'s U.S. trailer factory shipment data (ACT Research Co., 2014), and annual sales growth of 1 percent was assumed.

To avoid excess complexity, the model presented here does not account for differences in fuel efficiency between tractor trailer engines and further does not associate the estimated vehicle miles traveled (VMT) with tractor types.

The remainder of this report does not distinguish between truck tractors and trailers, and uses "trucks" or "vehicles" to refer to all single-unit trucks and combination trucks (tractors with trailers).

Attempts were made to break out BCA-relevant information by cargo body type, but ultimately the most important distinction for calculating benefits and costs was between truck category (SUT or CT).

The trucking fleet model assumes that truck owners/operators of trucks with different body types are equally likely to deploy side guards, meaning that owners/operators of an SUT dump truck are equally likely as owner/operators of other SUTs to deploy side guards. This assumption could be adjusted in the model if data about the likelihood of deployment by cargo body type were available.

4.2.2.2 Side Guard Assumptions

Three kinds of lateral underride protective equipment are relevant to this report:

1. **Aero skirts**, discussed above, are essentially un-reinforced side guards that provide aerodynamic benefits but not necessarily safety benefits.
2. **Rail side guards** are reinforced bars that provide safety but not aerodynamic benefits.
3. **Aero side guards** are essentially aero skirts that have been reinforced to prevent unintentional entry under the side of a truck and therefore provide both safety and aerodynamic benefits.

Both aerodynamic and safety benefits increase when the panel-style side guard maintains lower ground clearance. The photos shown in Figure 6 through Figure 9 illustrate SUT and CT trucks equipped with aero (panel-style) and rail-style side guards.

Figure 6: Photo of a Single-Unit Truck (SUT) with Rail Side Guard

Figure 7: Photo of a Combination Truck (CT) with Rail Side Guard

Figure 8: Photo of a Single-Unit Truck (SUT) with Aero Side Guard

Figure 9: Photo of a Combination Truck (CT) with Aero Side Guard

4.3 BENEFITS

4.3.1 Safety Benefits

4.3.1.1 Reductions in Crash Fatalities, Injuries, and Associated Costs

The key feature of side guards compared to other lateral devices on heavy trucks is their ability to withstand low force collisions,[14] preventing impacting objects from passing under the truck and incurring significantly more harm. Side guards provide this function when the object contacting the side guard collides with low force and is stopped from underriding. Compared to motor vehicles, VRUs have low mass and do not travel at high speeds, and therefore have lower acceleration on impact.

Side guards may also reduce truck crash costs involving motorcycles (also a VRU, but not for the purposes of this report) and other vehicles (passenger cars) if the acceleration of these vehicles on impact with a side guard-equipped truck is low enough.[15] This report does not calculate these potential benefits from truck-involved motorcycle or passenger vehicle crashes.

Safety benefits, or reductions in crash costs, can be produced by two means:

1. The crash event is avoided entirely so that the costs of the crash are avoided entirely
2. The crash severity is mitigated so that the severity of the injury is lessened, which reduces the costs

A crash's severity is defined by the injuries to a VRU's body or the damage sustained by trucks in the crash. Side guards are not intended to prevent crashes, but rather to reduce the severity of bodily injury in a crash. This reduction in severity primarily occurs because the side guard prevents VRUs from passing under the truck where they could be struck by the undercarriage or run over by the wheels. According to the HVCIS, aero side guards would mitigate a larger number of fatalities compared to rail side guards; however, the present analysis assumes equal crash severity reduction for rail and aero side guards (Knight, et al., 2005)).

Annual crash costs were calculated based on historical frequencies of crashes by truck category, type of VRU involved, severity of bodily injury, and the crash costs by severity (bodily injury). The resulting annual crash costs represent total annual safety benefits that could be realized from side guard deployment. Reductions in total annual crash costs are based on proportion of trucks side guards equipped in a given year. This methodology assumes that all trucks have an equal chance of being involved in a VRU crash.[16]

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[14] The guiding principle is that force equals mass times acceleration. Low-force collisions therefore can be low mass, low acceleration, or both low mass and low acceleration.

[15] The assumption here is about 20 mph for a car, 10 mph for a motorcycle due to the fact that motorcycle occupants are less protected than passenger vehicle occupants and would only see reductions in injuries in crashes at lower speeds.

[16] As previously, it also assumes that each vehicle type within SUT and CT is equally likely to deploy side guards.

No consideration was made for the effect of other technologies, such as automated or connected trucks on VMT, except those made by EIA in its fuel use forecasts or those made by the Federal Highway Administration (FHWA) in its VMT forecasts.

4.3.1.2 Relevant Crashes and Forecasts of Crashes

The projected frequency of side guard-relevant crashes can be broken down by truck category, VRU type (pedestrian or bicyclist), and bodily injury type. This report uses crash data to determine the number of side guard-relevant U.S. crashes, i.e., those which could have been mitigated by side guards based on the features of the crash.

Data on VRU- and truck-involved crashes are obtained from three sources: the General Estimates System (GES), the Fatality Analysis Reporting System (FARS), and Truck in Fatal Accidents (TIFA), which is a more detailed subset of the FARS database. These databases provide information about the first point of contact between the VRU and the truck in truck-VRU crashes.

The crashes included in this analysis were limited to those whose crash cost could conceivably be reduced if a side guard had been deployed on the truck. The FARS, GES, and TIFA databases used two methods of coding contact points: clock points and relative direction.

The majority of crashes were coded using the clock point system shown in Figure 10. Clock point 12 is the front of the truck, clock point 6 is the rear, and the hour hands in between mark the angle and point at which the truck encountered the VRU. Clock points 12 (front of truck) and 6 (rear of truck) were dropped from this analysis, as they could not conceivably be mitigated by side guards.

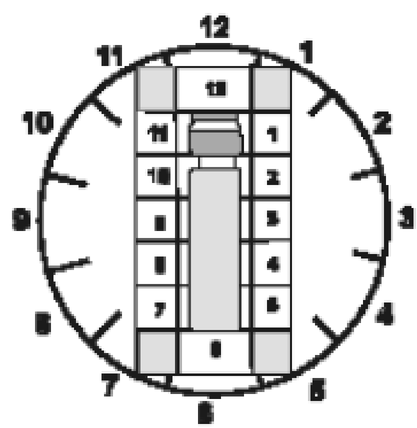

Figure 10: Clock Point Diagram (NHTSA, 2010)

Crashes were assigned a relative direction of impact as follows: left, left-front side, left-back side, right, right-front side, and right-back side. Crashes were dropped from the analysis if the first contact point was coded as a non-collision, an impact with the top of the truck, an impact with cargo/truck parts set in-motion, other objects set-in-motion, or an unreported or unknown impact area.

Figure 11 and Figure 12 depict the side guard-relevant truck-involved crashes with bicyclists and pedestrians, respectively, from 2005 to 2015 by truck category. The graphs show stability across time in the number of crashes for both pedestrian- and bicycle-involved crashes with either SUTs or CTs.

The primary components of crash risk are the total vehicle miles traveled (VMT) by trucks and the total miles traveled by pedestrians and bicyclists (VRUMT). The expectation is that both of these measures increase over time. VMT for trucks has increased steadily over the 2005-2015 period. No measure of VRUMT exists, but a Census Bureau report on mode of commute shows marginal change in the number of workers who walk or bicycle (Mckenzie, 2015). The fraction of bicycling work commuters rose from 0.5 percent in 2006 to 0.6 in 2013, and the fraction of walking work commuters fell from 2.9 percent in 2006 to 2.8 in 2013. The number of commuters is an imperfect measure of VRUMT because it is not a measure of distance, which more closely approximates exposure, and because it does not account for non-commute and recreational trips.

The assumption of this report is that the change in crash rate in the past is a reasonable indication of the change in crash rate in the future without side guard deployment.

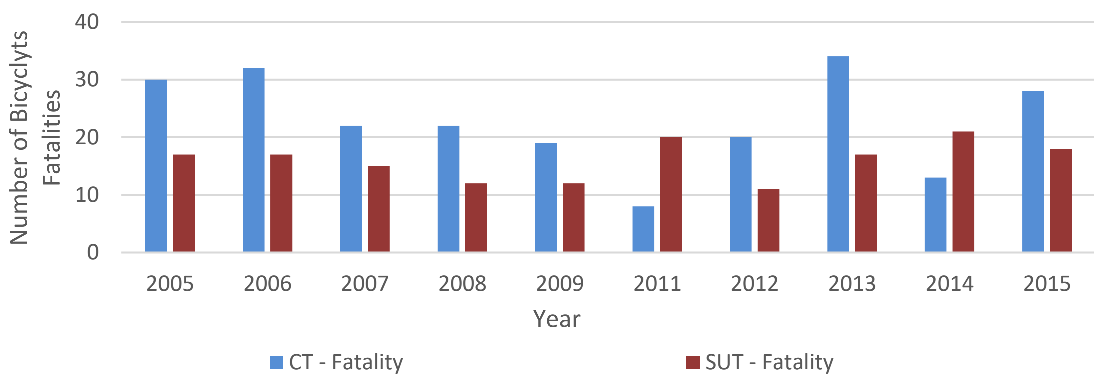

Figure 11: Side Guard-Relevant Bicyclist Fatalities by Truck Category from 2005 to 2015

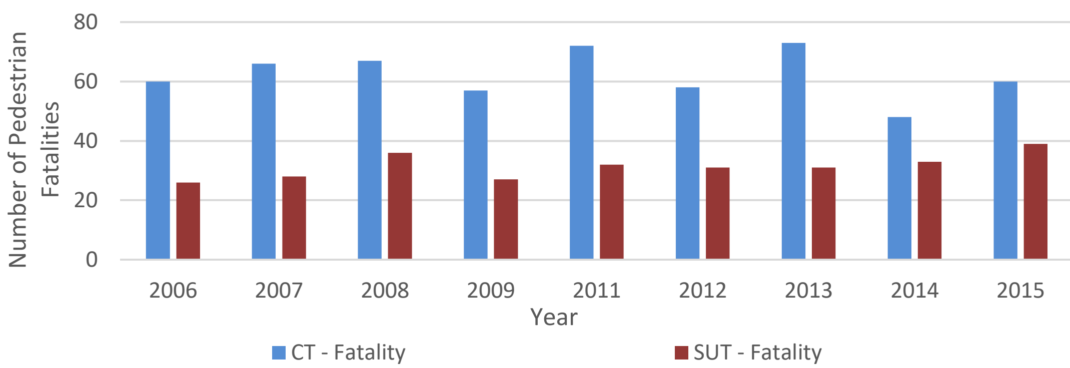

Figure 12: Side Guard-Relevant Pedestrian Fatalities by Truck Category from 2005 to 2015

4.3.2 Aerodynamic Benefits

The second principal benefit of side guards addressed in this report is aerodynamics improvement. Side guards can reduce wind drag experienced by the vehicle at higher speeds, resulting in increased fuel efficiency. More fuel efficient vehicles use less fuel, and this reduction in fuel use is considered a reduction in real cost and, therefore, a benefit.

Fuel use in gallons was estimated using FHWA's forecasts of VMT multiplied by the EIA's forecast of gallons per mile (GPM) for new trucks. Aerodynamic benefits accrue from reductions in total fuel used by the proportion of side guard-equipped trucks and the fuel efficiency gained for an assumed speed on each functional class of VMT.

The aerodynamic benefit of aero skirts has been shown to be dependent on speed and on the vehicle category. A fuel efficiency improvement) by speed schedule was developed from this research for both SUTs and CTs (Cooper, 2003). For instance, approximately 20 percent of the fuel savings benefit achieved by CTs at 55 mph is still achieved at 20 mph; and, correspondingly, about 16.5 percent of the benefit achieved by SUTs at 55 mph is still achieved at 20 mph.

Table 10 shows the assumed speed on each functional class, percent of single-unit truck and combination truck VMT driven on each functional class, and the final VMT-weighted fuel efficiency percent gains from side guard use- by single-unit truck and combination truck vehicles for each functional class.[17] The fuel efficiency improvement values were summed by vehicle type and applied to the total annual combination truck and single-unit truck VMT values.

Table 10: Fuel Efficiency Improvement of Combination Trucks (CT) and Single-Unit Trucks (SUT) by VMT

Truck Type	Category	Interstate Rural	Interstate Urban	Other Arterial Rural	Other Rural	Other Urban
SUT and CT	Assumed Speed (MPH)	55	55	40	25	25
CT	Percent of VMT Driven	30%	21%	18%	9%	22%
	Fuel Efficiency (GPM) Percent Increase with Side Guard Deployed	1.4%	1.0%	0.7%	0.1%	0.3%
SUT	Percent of VMT Driven	10%	13%	17%	17%	43%
	Fuel Efficiency (GPM) Percent Increase with Side Guard Deployed	0.4%	0.6%	0.5%	0.2%	0.5%

The fuel efficiency percent gains meet expectations given the roadway type and the vehicle type characteristics. Side guard-equipped CTs travelling on Rural Interstates (30 percent of total CT VMT) show the largest gain in fuel efficiency. Side guard-equipped SUTs driven on Other Urban roads (43 percent of SUT VMT) show a much smaller gain in fuel efficiency commensurate with the lower speeds on those roadways compared to interstate speeds and with the reduced impact of side guards on SUT fuel efficiency compared to CTs.

[17] An assumption was made that the bodies of trucks, tractors, and trailers are in fairly good condition, with no major dents.

Given the light weight of side guards relative to the weight of the rest of the vehicle (between approximately 0.05 and 0.5 percent of the weight of the vehicle), there is no concern about reduced fuel efficiency from the added side guards' weight. However, if there were fuel efficiency reductions from weight, side guard testing for fuel efficiency would incorporate the impact of the weight of the side guards.

4.4 COSTS

To determine the cost of side guards, Volpe reviewed available literature, performed market research, and drew on data generated from prior engagement with the cities of New York, Boston, San Francisco, Chicago, and Cambridge in identifying side guard suppliers.

4.4.1 Global Cost Data

A 2006 Australian study quantified the unit costs of side guards based on data from two European manufacturers based in Sweden and also estimated the costs of equipping these European side guards on Australian vehicle types (Australian Government Department of Infrastructure, Transport, Regional Development and Local Government, 2009). The unit cost of the side guard device for each meter of vehicle length was reported to be $45.88 AD in 2005, including an assumed shipping cost to Australia equal to 20 percent of the cost of the product. Volpe excluded this Australian shipping cost to isolate the cost of the side guard device, and since the original values were reported in 2005 Euros and Australian dollars, Volpe converted unit and per-vehicle costs to 2017 U.S. dollars.[18] Volpe computed the side guard cost per vehicle meter length to be $36.27 in 2017 U.S. dollars.

When multiplied by the vehicle lengths for each Australian vehicle type, the per-vehicle costs of adding a side guard to both the left and right sides of the vehicle are as shown in Table 11 (Standards and International Vehicle Safety Branch, 2006). The cost of equipping a vehicle with side guards is found to be $453 for a single-unit truck, $689 for a semi-trailer, and between $907 and $1,941 for longer combination vehicles. Based on the reported distribution of truck and trailer types in Australia, the fleet-weighted average cost of side guards is $669 per vehicle. As noted, this estimate is for the product alone, as shipping cost can vary widely. Given the similarity between the Australian and U.S. truck fleet (Blower, 2012), this may be a generally transferable cost estimate for the U.S. context.

[18] The currency and inflation calculation for this table were performed using the following historical currency conversion and inflation calculators: http://www.xe.com/currencytables/; http://www.saving.org/inflation/

Table 11. Reported cost of rigid side guards for large trucks and trailers

Vehicle Type	Vehicle Length (m)	Cost (2017 USD)
3 axle semi-trailer	19	$689
5 axle semi-trailer	19	$689
6 axle semi-trailer	19	$689
7 axle B-Double	25	$907
8 axle B-Double	25	$907
9 axle B-Double	25	$907
Double Road Train	36.5	$1,324
Triple Road Train	53.5	$1,941
2 axle rigid commercial vehicle	12.5	$453
3 axle rigid commercial vehicle	12.5	$453
4 axle Twin-Steer rigid commercial vehicle	12.5	$453
2 axle rigid commercial vehicle with 2 axle dog trailer	19	$689
3 axle rigid commercial vehicle with 3 axle dog trailer	19	$689
Fleet average		**$669**

Volpe's review of a number of European side guard vendors corroborates that the typical cost of side guards in that mature market is in the hundreds of dollars per vehicle for rail-style side guards. On the low end, a pair of twin-rail 10-foot side guard kits from UK suppliers, including mounting hardware, can be purchased for about $300 plus shipping costs (Commercial Body Sideguard Systems, n.d.). These knock-down side guard kits can be mounted to the truck cargo bed on van or flatbed type bodies (Sideguard Legs- Pre-Assembled (Galvanized), n.d.) or bolted to the frame rail on tankers, cement mixers, etc.

4.4.2 Domestic Cost Data

The total cost of a side guard includes materials and installation labor, both of which decrease along a production curve. Since side guards are less widely available in the U.S. than in countries with side guard regulations, U.S. costs are currently higher. In 2013, Volpe was aware of only one manufacturer of side guards in North America. In 2018 there were at least nine side guard suppliers, including trailer skirt manufacturers, truck body builders, and part suppliers, as shown in Table 27 (Appendix). Several of these suppliers are also listed on the New York City Hunts Point Clean Truck Program side guard vendor list, which is periodically updated (Vendor Network- Side Guard Vendors, 2017).

More recent data obtained by Volpe from North American suppliers and fleets show per-vehicle prices as of 2017, following a number of local side guard pilot programs and laws, ranging approximately from $700 to $1,800 for rail-style designs and approximately from $1000 to

$2700 for panel style designs.[19] Variation in costs is attributable to costs of different designs, the quantity of product needed to fit different size vehicles, and the labor required for different types of installation. Increased side guard installation under a number of Vision Zero programs may be stimulating manufacturer interest, attracting new entrants, and reducing costs closer to the ranges documented in Europe.

4.4.3 Interaction with Truck Parts and Inspections

Volpe performed an analysis, detailed in Appendix C, of potential side guard interactions with common truck parts that could increase or reduce the cost of side guard implementation, as well as potential interactions of side guards with commercial vehicle safety inspections that could pose barriers or added costs.

Volpe identified typical parts and accessories present on the ten most common truck types in the U.S. truck fleet with a gross vehicle weight rating greater than 10,000 lbs. and assessed their potential interactions with side guards. These interactions vary in compatibility, which Volpe's analysis (described in Appendix C) designated as *synergistic*, *adaptation*, or *incompatible*. Certain truck parts were found to require pre-market or aftermarket adaptations to accommodate side guards, whereas several truck parts appear to be synergistic with side guards, i.e., these parts can serve as part of the side guard device. Table 12 summarizes potential added costs or cost savings associated with combining side guards and these truck parts and accessories on a vehicle. "Synergistic" truck parts present potential cost savings related to side guard implementation; "synergistic or adaptation" truck parts present minimal cost, no cost, or minimal cost savings; "adaptation" truck parts present low cost; incompatible truck parts present high cost. No "incompatible" truck parts were identified.

Aftermarket installation can incur costs related to relocating or replacing existing common truck parts and accessories that a manufacturer currently installs without consideration for side guard placement. However, if truck and trailer manufacturers were to install side guards pre-market, the coordinated placement of truck parts and accessories together with side guards could eliminate the costs of component repositioning and adaptation.

[19] Based on data provided by Airflow, Takler, Transtex, Allied Body, and Laydon/WABCO; NYC Department of Citywide Administrative Services Fleet and Boston Mayor's Office; and City of Cambridge side guard 2016 request for proposal bid results.

Table 12: Truck parts and associated implementation costs related to their compatibility with side guards.

Related Implementation Cost	Synergistic *(Potential Cost Savings)*	Synergistic or Adaptation *(Minimal Cost or Potential Cost Savings)*	Adaptation *(Low Cost)*	Incompatible *(High Cost)*
Aftermarket	• Wheels • Frame or chassis • Underbody toolbox • Side marker lamps • Air reservoir • Stairs • Stored spare tire • Tires • Lift axle	• Underbody fuel tank • Aerodynamic truck skirt • Ladder • Stabilizer leg	• Fire extinguishers	• None
Pre-market	• Wheels • Frame or chassis • Underbody toolbox • Fire extinguisher • Side marker lamps • Air reservoir • Stairs • Stored spare tire • Tires • Lift axle	• Underbody fuel tank • Aerodynamic truck skirt • Ladder • Stabilizer leg	• None	• None

Volpe's interview with the FMCSA Field Operations Office Director confirmed that the Level 1 inspection is preferable whenever possible. Level 1 inspections include the driver and his/her credentials, a vehicle walk-around, and the inspector physically entering underneath the vehicle. The interview also identified five available solutions for continuing to perform Level 1 inspections on commercial vehicles equipped with side guards:

- **Partial Level 1 inspections**: These inspections will check brakes without the inspector going underneath the vehicle;
- **Improved inspection facilities**: Inspection facilities with pits and ramps for Level 1 inspections;
- **Movable side guards**: Removable or hinged side guards that permit easy access;
- **Improved inspection techniques**: Inspectors perform Level 1 inspections with a "creeper" (a low-profile rolling cart) from the truck rear; and
- **Improved technology in inspections**: Anticipated transition to roadside wireless inspections in the future.

In summary, Volpe's analysis did not find that any of the required or common truck parts would be incompatible with side guards. While some truck parts may require pre-market or aftermarket adaptation, several parts are synergistic in that they can already act as a partial side guard, which can yield cost savings compared to installation of a larger, purpose-built side guard. Commercial vehicle safety inspections of trucks with side guards can be addressed in five ways, some of which are currently common practice. Both findings indicate minimal additional vehicle adaptation costs incurred beyond the purchase, installation, and maintenance of side guards--as discussed in the following section—particularly if implemented as a factory-installed device.

4.4.4 Inputs to the Benefit-Cost Analysis

4.4.4.1 Installation

The principal cost of side guard deployment is the cost of purchasing and installing the equipment on the truck.

This analysis considers side guard installation cost factors that could be captured in the vehicle data available and that are relevant to installation costs. The primary installation cost factors are the method and timing of installation and the length of the truck. The categories of installation based on these factors are as follows:

- An aftermarket product on trucks without an aero skirt
- An aftermarket product on trucks with an aero skirt, through reinforcement of the aero skirt with bracing
- A factory-installed, pre-market product

The installation costs applied to pre-market installations are the average installation costs weighted by the share of vehicles of a given length. The percent of trucks by length were determined from the VIUS 2002 dataset. Pre-market rail and panel side guards are treated as having the same installation cost. Table 13 shows the cost of pre-market installation of side guards by cargo body type and length and the share of the vehicles of a given length by body type.

Table 13: Cost of Side Guard Pre-Market Installation by Truck Category and Length

Category	12.5 m	19 m	25 m	36.5 m	53.5 m	Total
SUT, Percent of Trucks	93.4%	6.5%	-	-	-	100%
SUT, Cost of Installation	$423	$689	-	-	-	$440
CT, Percentage of Trucks	-	95.7%	4.0%	0.17%	0.11%	100%
CT, Cost of Installation	-	$689	$907	$1,324	$1,941	$700

Aftermarket installation can increase upfitting costs related to relocating or replacing existing common truck parts and accessories, which most U.S. truck manufacturers currently install without consideration for side guard placement. As noted above, the cost of retrofitting a truck with side guards ranges in installation cost irrespective of vehicle size from $700-$1,800 for rail design and $1,000-$2,700 for full panel designs. The analysis used the median of these figures for each installation type: $1,250 for rail retrofit and $1,850 for panel.

Annual total cost of installation is the product of the number of vehicles deploying side guards of each deployment type each year and the cost of installation by deployment type.

4.4.4.2 Maintenance

Installation of new equipment is expected to produce recurring maintenance costs incurred by truck operators to maintain proper functioning of or reduce deterioration of the side guard.[20]

The per truck per year cost of maintenance of $7.27 used in this report is constructed from an estimate of time required to conduct maintenance on a side guard unit, and the mean hourly wage for bus and truck mechanics. The time required for side guard maintenance comes from interviews with jurisdictions that have installed side guards on some publicly owned and operated trucks (See Appendix D).

4.5 SCENARIOS AND RESULTS

This section provides context for the benefit-cost analysis scenarios that were computed, describes the purpose of each scenario, details the assumptions of each scenario, and discusses the results and findings of the analyses.

This report recognizes that there are many scenarios that could be selected. How deployment may progress in the real world is an open question, and at the present time many different scenarios are possible. Given the evidence of value from the benefit and cost components as discussed in sections 4.3 and 4.4, the business case for deployment of side guards by truck owners or operators appears relatively strong.

The intent of this report is to provide an understanding of the impacts of national-scale deployment of side guards, and it is still unclear what the entire fleet will actually experience. Owners have potentially many alternatives for capital investments to increase safety or reduce fuel costs. All three analyses assume full side guard deployment by 2045 or earlier.

While the scenarios are not necessarily realistic, and while they are not intended to predict how implementation would actually occur, they were chosen to bound the range of plausible results.

The fact that the timing and extent of deployment can significantly impact the costs and benefits accrued over the analysis period, as well as direct competition that side guards face from aero skirts for fuel efficiency improvements, are incorporated into these scenarios.

The scenarios were calculated with two different levels of side guard effectiveness: a low effectiveness, reported in each scenario section that follows and in the conclusion, and a high effectiveness, reported in the conclusion. The low-effectiveness assumption uses the lowest values of safety effectiveness found in the literature and only 80 percent effectiveness for the

[20] No additional maintenance costs to other parts of the trucks equipped with side guards were found.

fuel reduction benefits. The high-effectiveness scenario sets side guard safety effectiveness at the highest values in the range found in the literature, and sets fuel savings at literature values.

4.5.1 Scenario 1: Full Deployment First Year

The Full Deployment First Year scenario assumes that starting in 2020, all existing trucks without side guards will be retrofitted with side guards, and all new trucks in 2020 and thereafter will install side guards pre-market. The scenario assumes that 30 percent of existing single-unit trucks and combination trucks in the fleet have aero skirts deployed. Finally, the scenario assumes that all trucks will install full-panel or aero side guards and not rail side guards, and will therefore accrue all aerodynamics benefits. Evidence about whether rail or full-panel deployment is more likely to be deployed was not available.[21]

This deployment scenario is intended to mimic a mandatory deployment policy. It estimates the maximum benefits that could potentially accrue over the analysis period because all trucks accrue benefits for all years.

Figure 13 shows the annual costs and benefits for the analysis period 2020-2045 for the Full Deployment First Year scenario.[22] In 2020, all existing trucks are equipped with side guards, and the total cost of installation is near $12 billion. Total costs are marginal in the following years relative to 2020, as only new vehicles are equipped and maintenance costs are incurred. Safety benefits are marginally smaller than costs after 2020 and reach roughly one-quarter billion dollars in 2045. The aerodynamic benefits are substantial and rise from $3 billion in 2020 to more than $6 billion in 2045.

Figure 14 shows the same forecast of these same benefits discounted at 7 percent to their present values. Discounting overcomes the fuel use growth, leading to a decline in annual aerodynamic benefits.

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[21] Regarding this assumption, it is worth noting that the ratio of deployed rail side guards to deployed panel aero side guards would have to be approximately 17 to 1 (for CTs) and 3 to 1 (for SUTs) before fuel savings benefits would no longer exceed the cost of deployment in a given year.

[22] This is not a summation of benefits.

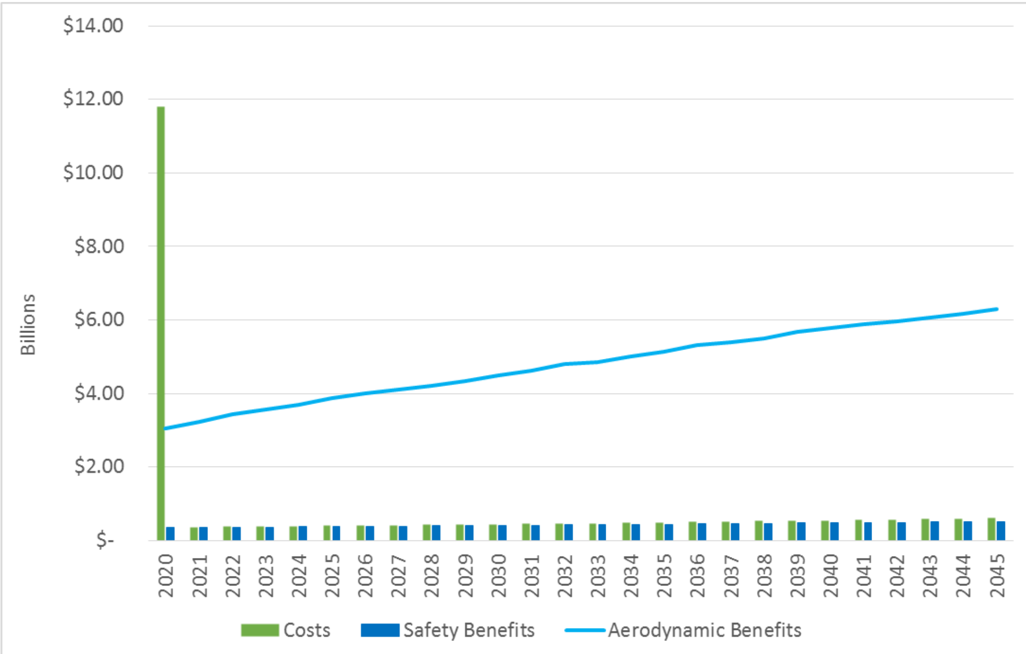

Figure 13: Undiscounted Benefits and Costs Occurring Each Year (2020-2045) for the Full Deployment First Year Scenario

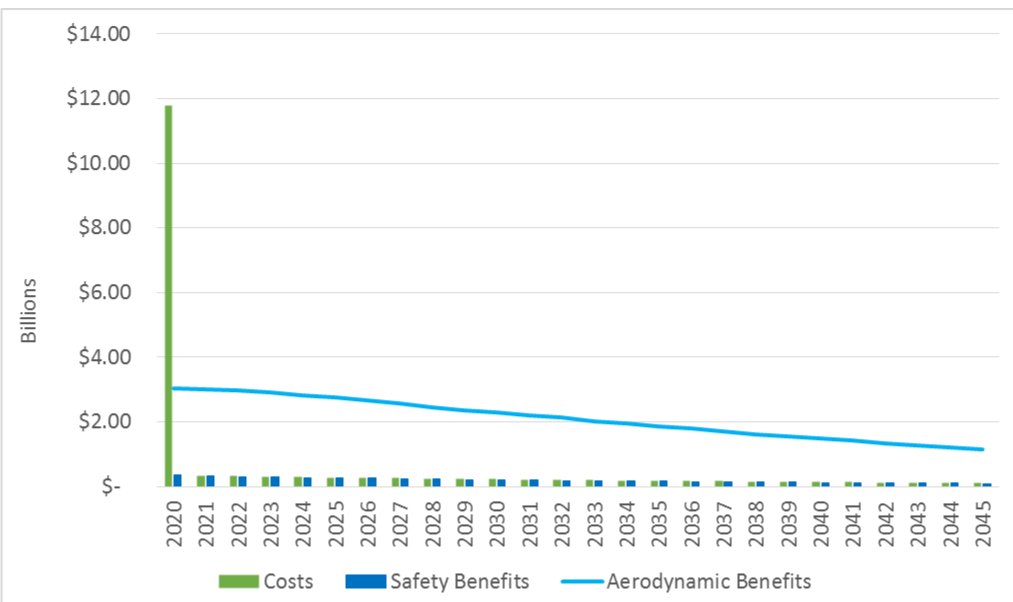

Figure 14: Discounted Benefits and Costs Occurring Each Year (2020-2045) for the Full Deployment First Year Scenario (7 percent)

4.5.2 Scenario 2: Gradual Deployment

The Gradual Deployment scenario assumes that 5 percent of existing trucks without side guards will be retrofitted with side guards each year until all existing trucks have been retrofitted with side guards. New vehicles in a given year that are equipped with a side guard are considered existing in following years. For new trucks, the scenario assumes that 5 percent will deploy pre-market side guards in 2020, and that the percent of new trucks deploying side guards will increase by 5 percent each year until all new trucks deploy pre-market side guards in 2039. Aero skirts are estimated to be deployed on 15 percent of existing single-unit trucks (SUT) and combination trucks (CT) and 30 percent of new SUTs and CTs, which are retrofitted in later years. The scenario assumes that 5 percent of SUTs will be equipped with rail panel side guard and not rail side guards, and will therefore not accrue aerodynamic benefits.[23]

This scenario attempts to provide a more realistic rate of adoption among new and existing trucks by gradually rolling out deployment throughout the period of analysis. The realism of this gradual deployment depends on how quickly non-mandated deployment would reflect other adoption patterns, such as an S-curve where adoption rates gradual increase until half of all potential deployers have deployed, after which deployment rates slow.

Figure 15 shows the annual costs and benefits for the analysis period 2020-2045 for the Gradual Deployment scenario.[24] The annual cost of side guards rises from roughly $0.75 billion in year 2020 to roughly $1.5 billion in 2041, after which it drops to roughly $0.5 billion because all existing trucks have been equipped with side guards and only new trucks are installing side guards. Aerodynamic benefits rise from near marginal in 2020 to just under $5 billion in 2041, after which the rate of growth slows as only some portion of new vehicles are deploying side guards leading to a final annual benefit of $5.4 billion in 2045. The values of aerodynamic benefits in this scenario do not match the value in the previous scenario because not all vehicles with aero skirts deploy side guards. Figure 16 shows the same forecast of these same benefits discounted at 7 percent to their present value.

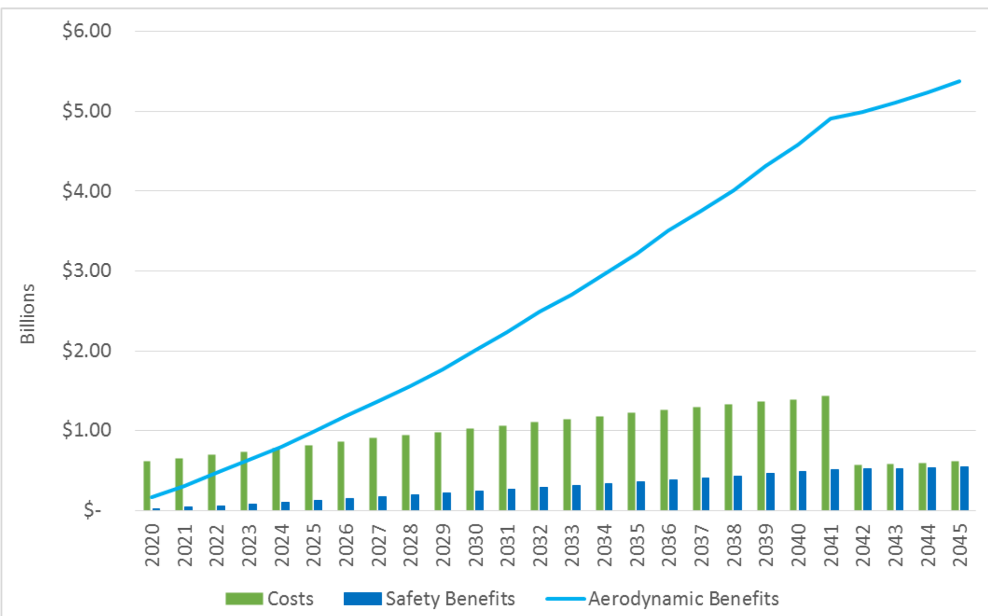

Figure 15: Undiscounted Benefits and Costs Each Year (2020-2045) for the Gradual Deployment Scenario

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[23] Given the strong aerodynamic benefits for CTs, it seems unlikely that CT owners/operators would choose rail over panel side guards.

[24] This is not a summation of benefits.

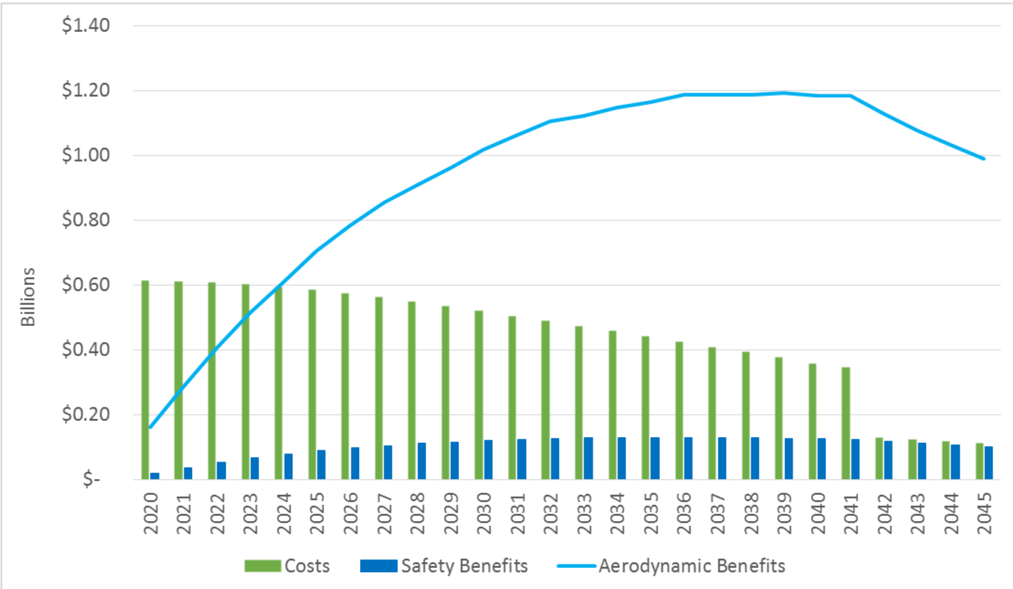

Figure 16: Discounted Benefits and Costs Each Year (2020-2045) for the Gradual Deployment Scenario

4.5.3 Scenario 3: Aero Skirts Fully Deployed

The Aero Skirts Fully Deployed scenario assumes that all trucks are equipped with aero skirts in 2020 and that all new trucks are pre-market equipped with aero skirts. Any side guard installed in this scenario is an adaptation of an aero skirt, which has a lower cost than a side guard retrofit install with no aerodynamic panel.[25] This scenario establishes the net benefits of only the safety benefits of side guards, by reinforcing aero skirts to be strong enough to produce safety benefits (i.e., strong enough to prevent VRUs from entering under the vehicle). This scenario assumes no fuel cost benefits ever accrue because fuel savings have already been achieved by the aero skirts.

Side guard deployment follows the same pattern in this scenario as in the gradual deployment scenario: 5 percent of existing trucks without side guards will be retrofitted with side guards each year until all existing trucks have been retrofitted with side guards. The maintenance costs are attributed to the side guards rather than the aero skirts. Further, the scenario assumes that 15 percent of new trucks do not upgrade aero skirts to side guards and thus do not attain the associated safety benefits.

Figure 17 shows the annual costs and benefits for the analysis period 2020-2045 for the aero skirt fully deployed scenario.[26] Aerodynamic benefits are zero in each year by construction because the scenario assumes that all vehicles have deployed aero skirts to which the aerodynamic benefits should accrue. Costs rise similarly to the gradual deployment scenario to a peak in 2040, when all existing vehicles have been retrofitted from aero skirts to side guards. Finally, the safety benefits rise from marginal in 2020 to more than $0.5 billion in 2045. Figure 18 shows the same forecast of these same benefits discounted at 7 percent to their present value. Figure 18 shows

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[25] Maintenance costs are attributed to side guards and not to aeroskirts in this scenario. This is an accounting choice that may overestimate this cost.

[26] This is not a summation of benefits.

that discounting does not overcome safety benefit growth completely, leading to marginally increasing annual safety benefits.

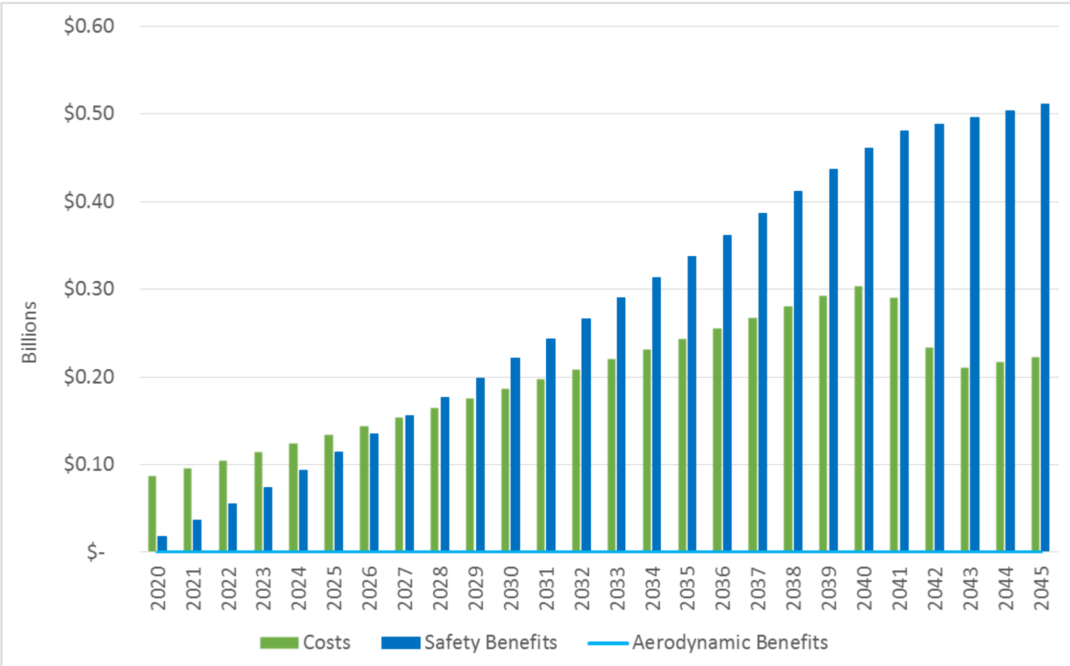

Figure 17: Undiscounted Benefits and Costs Occurring Each Year (2020-2045) for the Aero skirt Fully Deployed Scenario

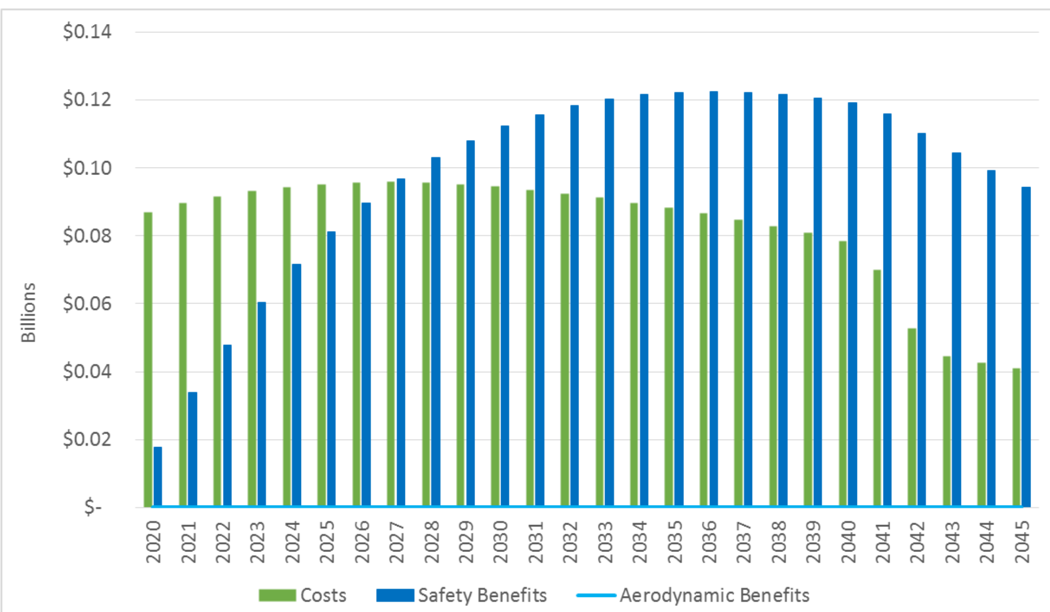

Figure 18: Discounted Benefits and Costs Occurring Each Year (2020-2045) for the Aero skirt Fully Deployed Scenario

4.5.4 Benefit-Cost Conclusions

Each scenario of side guard deployment shows that the technology provides positive net benefits. Aerodynamic benefits represent a greater overall share of the total benefits than do safety benefits, as aerodynamic benefits accrue whenever the vehicle is driven at medium or high speeds. In Scenario 3, however, where no additional aerodynamic benefits are accrued, the safety benefits alone still produce positive net benefits.

Given the relative share of fuel benefits and the lack of conflicting technologies to aero skirts and side guards, the deployments of full-panel side guards or aero skirts appears more likely than not for any given vehicle. The marginal safety benefit of reinforcing an aero skirt to a side guard is potentially high enough to cover the cost of retrofitting within a few years.

Table 14 shows the benefit-cost ratios (BCR) and net benefits for each scenario and each side guard effectiveness assumption. The low-effectiveness assumption uses the lowest values of safety effectiveness found in the literature and only 80 percent effectiveness for the fuel reduction benefits. The high-benefits scenario sets side guard safety effectiveness at the highest values in range found in the literature, and sets fuel savings at literature values.

Table 14: Scenario Benefit-Cost Ratio (BCR) Results (Discounted at 7 percent)

Scenarios	BCR (High Benefits)	BCR (Low Benefits)	Total Net Benefits (High Benefits)	Total Net Benefits (Low Benefits)
Full Deployment First Year	4.65	3.53	$61.6 billion	$42.2 billion
Gradual Deployment (5 Percent Annual Retrofit)	3.05	2.33	$23.5 billion	$15.3 billion
Aero skirt Fully Deployed	2.28	1.19	$2.70 billion	$0.40 billion

Table 15: Scenario Benefit-Cost Ratio (BCR) Results (Discounted at 3 percent)

Scenarios	BCR (High Benefits)	BCR (Low Benefits)	Total Net Benefits (High Benefits)	Total Net Benefits (Low Benefits)
Full Deployment First Year	6.12	4.65	$101 billion	$72 billion
Gradual Deployment (5 Percent Annual Retrofit)	3.59	2.76	$45.2 billion	$30.5 billion
Aero skirt Fully Deployed	2.52	1.31	$5.2 billion	$1.1 billion

The benefit-cost ratio provides some indication of the cost effectiveness of a particular side guard deployment scenario for achieving social benefit. The BCR is unitless and is useful for comparing alternative choices, but it does not provide the complete picture.

The overall level of net benefit is an important consideration as well**. For the low-benefits scenarios and discounted at 7 percent over the full period of analysis, the total net benefits are $42.2 billion, $15.3 billion, and $0.4 billion, respectively.** Given the strong impact on fuel efficiency, any given vehicle is able to recover the cost of side guard deployment within one to two years, depending on use, though the payback period for the fleet depends on when deployment occurs.

Table 16 lists the payback period for each deployment scenario and discount rate.

Table 16: Payback Period for Each Scenario and Discount Rate

	7 Percent Discount		**3 Percent Discount**	
Scenarios	***High Benefits***	***Low Benefits***	***High Benefits***	***Low Benefits***
Full Deployment First Year	3 years	4 years	3 years	4 years
Gradual Deployment	6 years	8 years	6 years	8 years
Aero skirt Fully Deployed	6 years	18 years	6 years	16 years

Figure 19 and Figure 20 show the cumulative benefits by year for the low- and high-benefits scenarios, respectively, discounted at 7 percent.

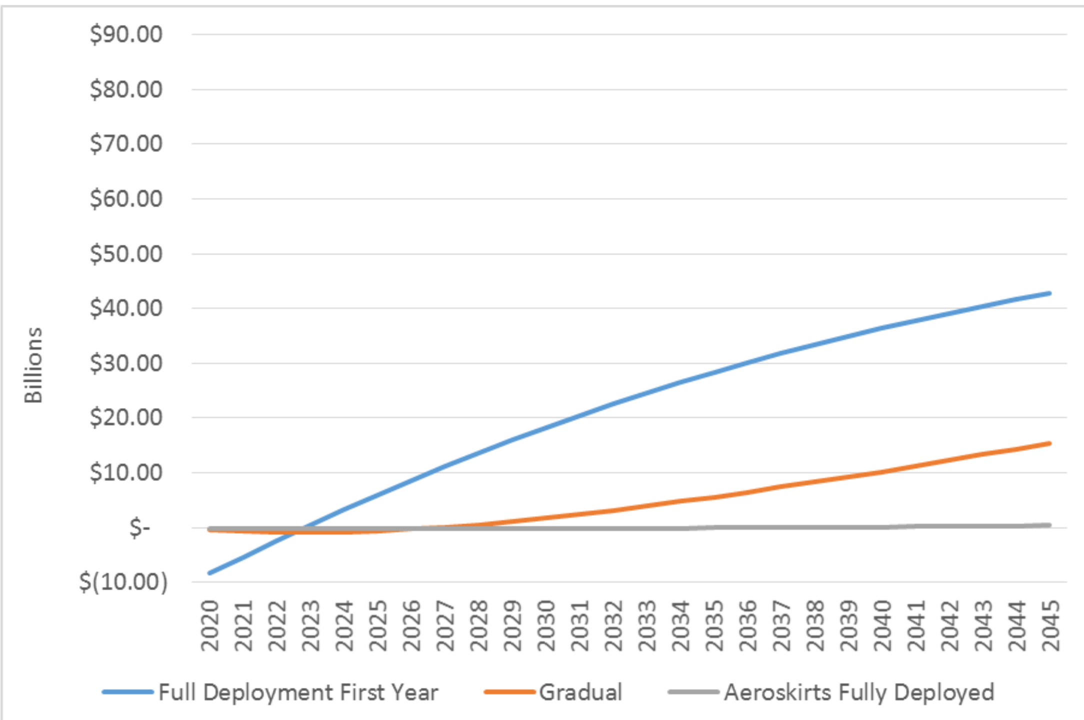

Figure 19: Discounted Cumulative Net Benefits of Each Scenario by Year (Low Benefits)

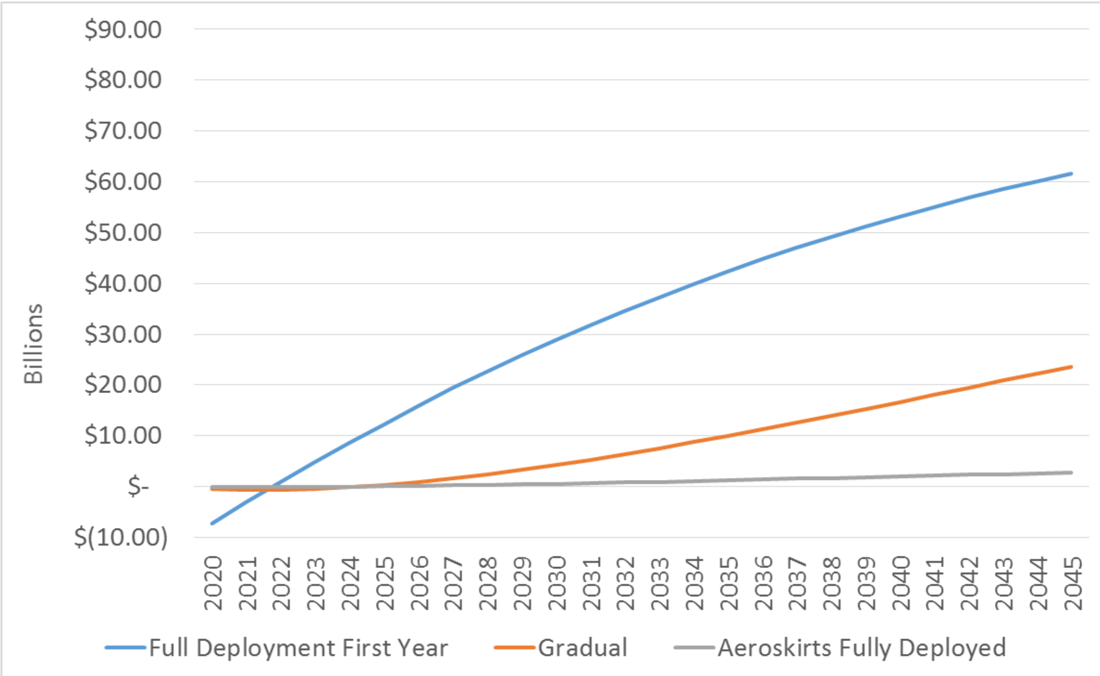

Figure 20: Discounted Cumulative Net Benefits of Each Scenario by Year (High Benefits)

With any analysis, it is important to understand how various assumptions have impacted the net benefits of the scenarios. The following is a partial listing of the assumptions highlighted in the report that are likely to overestimate or underestimate the net benefits:

- **Net Benefits Overestimated**
    - Dynamics between fuel savings and VMT. Increased VMT has many consequences that can be traced to some degree or another. The impact of increased truck VMT from reduced fuel use is beyond the scope of this study.
    - The analysis does not properly include scrappage of trucks and new sales. New sales are considered the difference in the total trucks from one year to another (data on truck sales is scarce), and this means that the model does not account for the retirement of trucks with side guards. It underestimates the number of trucks that will install side guards. This is a reduction in the total cost and therefore an overestimation of the net benefits.
- **Net Benefits Underestimated**
    - Maintenance costs may have been overstated as some side guard deployers reported having no additional maintenance costs for deploying side guards.
    - The analysis does not account for the potential ability of side guards to reduce crash costs for non-VRU truck-involved crashes, such as with motorcyclists, moped operators, and vehicle occupants.

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5. CONCLUSIONS

5.1 EXISTING SIDE GUARD REGULATIONS

There is global precedent for VRU-protecting side guard or lateral protective device adoption, as demonstrated by overseas national regulations spanning the previous 40 years, a multinational United Nations regulation for side guard type approval that has been adopted by 43 countries and the European Union, and the development of standards and local regulations in Australia and North America that appear to be catalyzing further adoption in comparable jurisdictions.

Specifications vary among the regulations and standards reviewed, but the approximate geometry and strength requirements remain relatively consistent. Most side guard standards require the guards to withstand 1-2 kN of quasi-static lateral force with limited deformation, enough to deflect a non-motorized VRU such as a pedestrian or a bicyclist in a collision. The Brazil standard, however, is also intended to protect motorcyclists and therefore has a greater strength requirement of 5 kN, and a 2018 proposal seeks to increase the UN regulation to 3 kN. (Economic Commission for Europe, 2018) Maximum ground clearances range from 350 mm (13.8 in.) to 550 mm (21.7 in.); a majority of regulations opt for the higher ground clearance, but academic studies and non-regulated standards (such as the specification developed by Volpe) recommend lower ground clearances, as does the 2018 proposed UN regulation amendment.

In contrast to the VRU-protecting side guards analyzed in the current study, side underride protection systems designed to arrest a passenger vehicle would require substantially heavier, stronger, and more costly construction. To avoid confusion between these two technologies and use cases, it is important to define clearly which population the side guard technology aims to protect, and to apply the proper context in any potential future U.S. standards or regulations.

5.2 EFFECTIVENESS AND EXPOSURE STUDIES

Volpe reviewed over 50 publications for information on side guard effectiveness and found 11 that contained quantitative data. A majority of the studies presented quantitative and/or qualitative evidence that side guards are effective at mitigating crashes with VRUs. Most studies focused on bicyclists as the crash target and demonstrated that side guards as currently designed (i.e., with ground clearance up to and exceeding 550 mm[27] or 21.7 in.) are effective for mitigating collisions between a VRU and a passing or overtaking truck. A smaller body of evidence is currently available to support the effectiveness of side guards in collisions between VRUs and a truck making a turn to the passenger side (i.e., right turns in the U.S. and left turns in the UK). A limited number of studies address and indicate that side guards further provide a level of effectiveness for crashes with pedestrians and motorcyclists.

[27] Maximum ground clearance of trailer side guards actually exceeds 550 mm once the trailer is attached.

Multiplying effectiveness (reduction in fatalities or serious injuries as a proportion of all side guard-relevant VRU crashes) by exposure (percent of all VRU crashes that are side guard-relevant) produces a generalized total mitigation potential expressed in terms of a reduction in the percentage of all fatal/serious injuries for all VRU crashes, not just side guard relevant crashes. This total mitigation potential ranges from 5 to 30 percent in studies specific to bicycle fatalities, <1-6 percent in studies specific to bicyclist serious injuries, 2-4 percent in studies specific to pedestrian fatalities, <1 percent in studies specific to pedestrian serious injuries, and as high as 20 percent for all VRU fatalities and 25 percent for all VRU serious injuries in studies that did not distinguish the VRU category.

5.3 BENEFIT-COST ANALYSIS

This report presents a broad benefit-cost analysis of deployment of side guards in the U.S. trucking fleet under various assumptions of deployment and effectiveness. The results under these scenarios show that side guard deployment would be an effective technology for generating net societal benefits in wide-scale U.S. deployment. Aerodynamics comprise a larger share of total benefits than safety benefits in the analysis,[28] but when isolated under one of the scenarios, safety benefits alone still produce net positive benefits.

As no consideration in this report has been made on the impact that other technologies may have on the benefits of side guard deployment, it is important for policy makers to further investigate how technologies may interact with one another in the field. Generally, technologies for aerodynamic benefits do not conflict, as they do not reduce the effectiveness of other fuel efficiency technologies. Technologies intended to produce safety benefits are sometimes not compounding in effect, i.e., they may not produce the same additional benefits when deployed together as when deployed separately. For example, automated vehicle technology is one technology that could reduce the number of truck-involved VRU crashes in the U.S. With fewer crashes to mitigate, the benefit of alternative safety mitigations such as side guards could, in principle, be reduced. However, the timeline and magnitude of any such reductions is unknown and challenging to predict. Moreover, as long as large trucks and VRUs continue to share street space, even sophisticated truck automation may offer limited benefit in side-impact crashes in which the VRU unexpectedly loses control.

[28] Compare Figure 50 and Figure 51 in Appendix A, which show the annual benefits by scenario and vehicle type for safety and aerodynamic benefits, respectively.

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6. RECOMMENDATIONS

The present analysis provides a baseline set of results for FMCSA to consider in developing potential future policies related to side guard standardization and deployment.

This report recommends **development of an industry side guard standard** through a standards development organization (SDO), with FMCSA supporting current efforts by certain truck manufacturers and major truck fleets.[29] A **new side guard industry standard** should address, at a minimum:

- Side guard installation on new trucks and new trailers exceeding 10,000 pound GVWR
- Dimensional requirements and performance-based mechanical requirements, including the flexibility to use non-side guard truck parts and accessories to meet these requirements
- Acceptable methods to demonstrate installation and maintenance compliance
- Retrofitting of side guards on existing trucks and trailers

As part of this standard development, particular attention and potentially further research is recommended to achieve industry consensus on:

- Appropriate maximum side guard ground clearance for providing full safety benefit as well as maximum flexibility for vehicle operations; and
- A best practice approach for reinforcing aerodynamic skirt products to provide side guard safety performance while minimizing incremental cost and impact on aerodynamic performance.

The new industry standard could potentially establish two tiers of compliance: a minimum set of requirements for international harmonization, e.g., aligned with the UN Regulation 73, as well as a more stringent set of recommended, best practice criteria.

Recognizing geographic differences in VRU exposure, the industry standard should be suited for the environment, e.g., side guards may be exempted for trucks operating exclusively in rural and remote environments. Flexibility should also be considered for side guard clearance on vehicles that cross unimproved, low clearance railroad grade crossings.

This report recommends FMCSA and researchers focus on the following further areas of inquiry:

- Determine the extent to which lateral underride technologies will be deployed in the absence of federal intervention. This may involve development of a more in-depth business case for owners that considers the payback period of equipping side guards given the vintage and use of the truck.

[29] Examples of SDOs include, but are not limited to, the American Trucking Associations Technology and Maintenance Council (TMC) and the American National Standards Institute (ANSI).

- For particular policy considerations, the model developed in this report should be expanded to incorporate dynamics of fuel use reductions on VMT and vehicle retirement.
- Additional potential safety benefits of side guard technology that were not addressed in the current study and incorporating them into the model (e.g., truck-involved crashes with automobiles at low speeds or equipped with ADAS and automation systems).

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APPENDIX A – SIDE GUARD REGULATIONS AND STANDARDS

Table 17: Summary table of national standards and their specifications (UN Regulation 73 included for comparison)

Country	Year Passed	Vehicles Covered	Vehicles Exempted	Strength	Maximum Ground Clearance	Maximum Gap Between Wheels and Guard
Japan [a]	1979	Ordinary-sized motor vehicles used for the transport of goods or ordinary-sized motor vehicle with a gross vehicle weight of 8 tons or more.	Motor vehicles with a passenger capacity of 11 persons or more and motor vehicles having a shape similar to the motor vehicles with a passenger capacity of 11 persons or more.[30]	Not available	450 mm (17.7 in.)[31]	Not available
United Kingdom	1983; expanded 1986	- A motor vehicle first used on or after April 1, 1984, with a weight that exceeds 3,500 kg (7,716 lbs.); - A trailer manufactured on or after May 1, 1983, with an unladen weight that exceeds 1,020 kg (2,249 lbs.); and, - A semi-trailer manufactured before May 1, 1983, that has a gross weight exceeding 26,000 kg (57,320 lbs.) and that forms a vehicle with a relevant train weight exceeding 32,520 kg (71,694 lbs.).	- A motor vehicle that has a maximum speed not exceeding 15 mph; - An agricultural trailer; - Engineering plant; - A fire engine; - Tipping trucks; - Military vehicles; - A vehicle without bodywork on its way to be checked/ fitted; - A refuse vehicle; - A specially designed vehicle carrier; - A motor car that forms part of an articulated vehicle; - A trailer with a load platform [with restrictions]; and - A trailer not from Great Britain.	2 kilonewtons (kN) (450 lbs.)	550 mm (21.7 in.)	300mm (11.8 in.)
United Nations [b]	1988; updated in 2007,	Vehicles of categories N_2, N_3, O_3, and O_4.[32]	- Tractors for semi-trailers, and - Vehicles designed and constructed for special purposes where it is not possible, for	1 kN (225 lbs.)	550 mm (21.7 in.)	300 mm (11.8 in.)

[30] This definition typically exempts buses.

[31] In practice, this clearance is typically only 380 to 400 mm (15-15.75 in.) on the largest articulated vehicles (Riley, Penoyre, & Bates, Protecting Car Occupants, Pedestrians, and Cyclists in Accidents Involving Heavy Goods Vehicles by Using Front Underrun Bumpers and Sideguards, 1985).

[32] N_2, N_3, O_3, and O_4 are vehicle categories defined in UNECE Consolidated Resolution on the Construction of Vehicles (R.E.3). Category N refers to motor vehicles with at least four wheels that are used for the carriage of goods (i.e., commercial trucks); Category O refers to trailers.

	2010, and 2016		practical reasons, to fit such lateral protection.			
China [a]	1989; updated in 1994, 2001	Vehicles of categories N_2, N_3, O_3, and O_4.	- Tractors; - Special purpose vehicles specially designed and manufactured for handling long goods that cannot be segmented, such as vehicles that transport timber, steel bars and other goods; and - Vehicles designed and manufactured for specialized purposes that cannot be fitted with side guards due to objective reasons.	1 kN (225 lbs.)	550 mm (21.7 in.)	300 mm (11.8 in.)
Peru	2003	Vehicles of categories N_2, N_3, O_3, and O_4.	All other vehicle categories.	Not available	550 mm (21.7 in.)	300mm (11.8 in.)
Brazil	2009	Trucks, trailers, and semi-trailers with a weight exceeding 3,500 kg (7,716 lbs.).	- Those made before 2011; - Tractor trucks; - Bodywork or load platforms that are up to 550 mm (21.7 in.) high in relation to the ground; - Vehicles designed and constructed for specific purposes where it is not possible to provide for the design of side shields; - Unfinished vehicles; - Vehicles and implements intended for export; - Military vehicles; and - Vehicles with sufficient defense built in.	5 kN (1,124 lbs.)	550 mm (21.7 in.)	300 mm (11.8 in.) behind the front wheels and 500 mm (19.7 in.) in front of the rear wheels.

[a] Primary source not available
[b] Included for comparison only

UN Regulation 73

Table 18: List of the 44 parties that have approved Regulation 73 (43 countries and the European Union)

UN Regulation 73 Contracting Parties			
Albania	European Union	Luxembourg	Russian Federation
Austria	Finland	Macedonia, Republic of	San Marino
Belarus	France	Malaysia	Serbia
Belgium	Georgia	Malta	Slovakia
Bulgaria	Germany	Moldova, Republic of	Slovenia
Croatia	Greece	Montenegro	Spain
Cyprus	Hungary	Netherlands	Sweden
Czech Republic	Ireland	Norway	Switzerland
Denmark	Italy	Poland	Turkey
Egypt	Latvia	Portugal	Ukraine
Estonia	Lithuania	Romania	United Kingdom

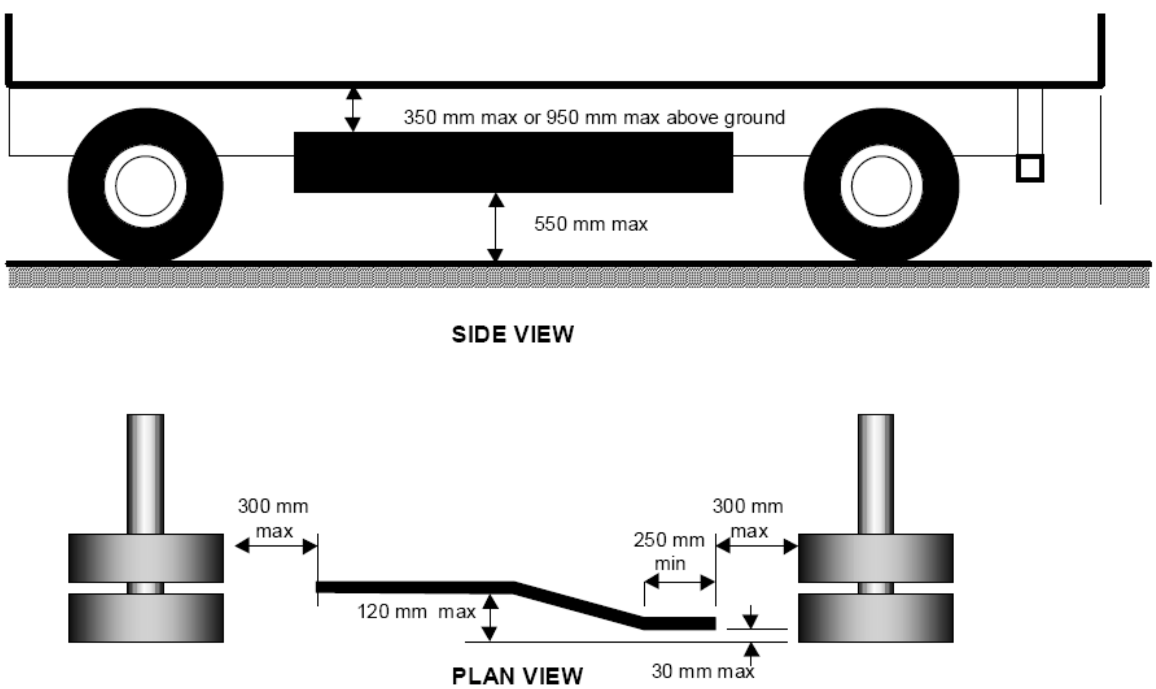


Figure 21: Schematic of the UN Regulation 73 side guard dimensional requirements (Source: UN Regulation 73).

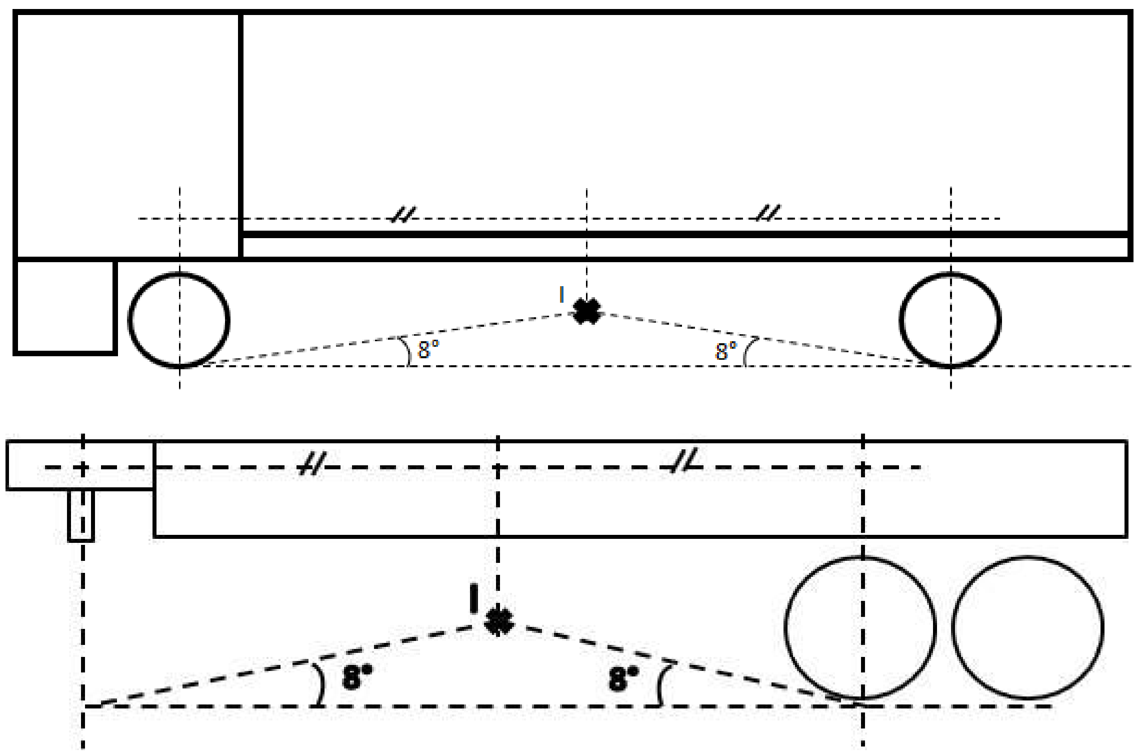


Figure 22. Schematic of 2018 proposed amendment to UN Regulation 73.

As shown in Figure 22, the 2018 proposed amendment to UN Regulation 73 would change the quasi-static force test to 3 kN while increasing the allowable elastic deflection as follows:

(a) **[90]** mm over the rearmost 250 mm of the device; and
(b) **[450]** mm over the remainder of the device.

The amendment would also reduce the allowable maximum ground clearance as follows, based on the wheelbase of the truck or trailer on which the side guard is installed:

(a) If I ≤ 350 mm then the ground clearance can be 350 mm maximum;
(b) If 350 mm < I ≤ 450 mm then the ground clearance is I;
(c) If 450 mm < I then the ground clearance is 450 mm maximum;

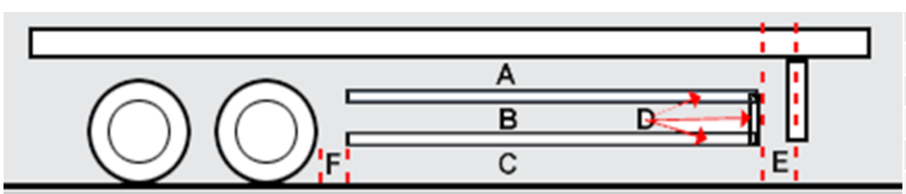
Japan

Instituted with the goal of protecting pedestrians, side guards became required in Japan in 1979, making Japan appear to be the first recorded country to mandate the use of side guards on heavy vehicles (Pedestrian Protecting Side Guards, Article 18-2, 1979). The maximum ground clearance under the Japanese regulation is 450 mm (17.7 in.), more stringent than the 550 mm (21.7 in.) maximum permitted in UN Regulation 73 and in other countries that have harmonized to the UN standard (see Figure 23). In practice, on the largest articulated vehicles this clearance is typically even lower: 380 to 400 mm (15 to 15.75 in.) (Riley, Penoyre, & Bates, Protecting Car Occupants, Pedestrians, and Cyclists in Accidents Involving Heavy Goods Vehicles by Using Front Underrun Bumpers and Sideguards, 1985).

Figure 23: Image showing a rail-style side guard on a truck in Japan (Source: Hirohito Takada, 123rf.com)

United Kingdom

Side guards were first mandated in the UK in 1983 for "new goods vehicles and trailers over certain weights and for some of the larger existing semitrailers" (Riley, Penoyre, & Bates, Protecting Car Occupants, Pedestrians, and Cyclists in Accidents Involving Heavy Goods Vehicles by Using Front Underrun Bumpers and Sideguards, 1985). In 1986, side guards were mandated on all large trucks by an Act of Parliament (The Parliament of the United Kingdom, 1986). In 1988, the UK also agreed to be bound to UN Regulation 73, which had a lower strength requirement and less specific exemptions (see Figure 24).



A	13.8 inches maximum
B	11.8 inches maximum
C	21.7 inches maximum
D	4 inches minimum
E	9.8 inches maximum
F	11.8 inches maximum

Figure 24: Technical specifications of the UK dimensional requirements for side guards on trailers (Adapted from Transports' Friend, n.d.)

China

Side guards first became mandatory in China in 1989 with the implementation of Standard GB 11567, a requirement largely aligned with the UN side guard regulation formulated the year before (see Figure 25). This standard was updated in 1994 under "Requirements for side and rear lower protective devices for automobiles and trailers GB 11567-1994," and again in 2001 as GB 11567-2001 (Car and Trailer Side Protection, 2001).[33] The standard is applicable for vehicles of categories N_2, N_3, O_3, and O_4, with exemptions made for tractors and vehicles designed for a special purpose that cannot therefore be outfitted with side guards. A notable example of this exemption is logging vehicles, as the configuration to hold timber does not permit the installation of a guard. Regarding the design of the guard itself, the regulation specifies a maximum ground clearance of 550 mm (21.7 in.), as well as a strength requirement of 1 kilonewton (kN). Both solid and cross bar designs are allowed, with a maximum of 300 mm (11.8 in.) between cross bars on the guard. The regulation is similar to that put forward by the UN in its strength requirement and its applicability to vehicle types.

Figure 25: Image showing abandoned Chinese dump trucks with side guards (Source: Novyy Urengov, 123rf.com)

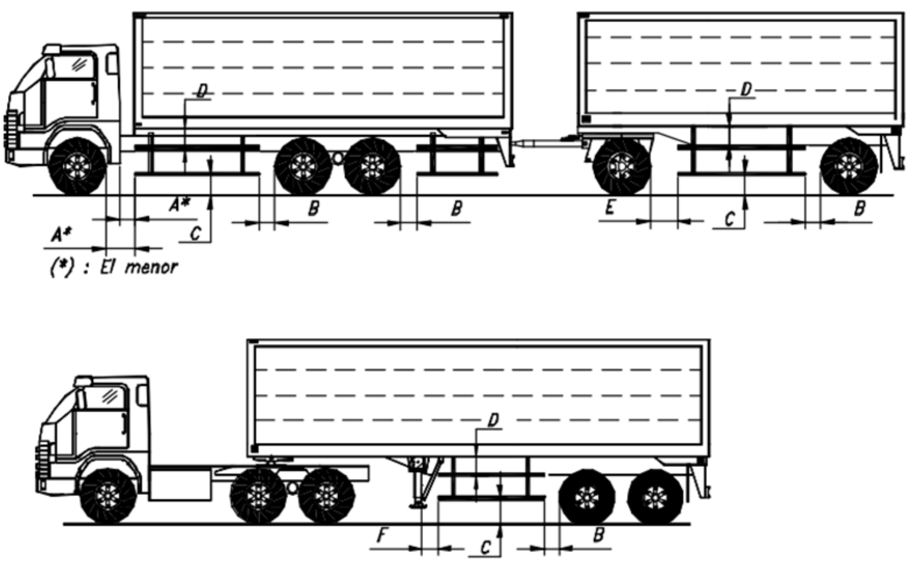
Peru

Side guards have been mandatory in Peru since the 2003 passage of Supreme Decree 58, which mandated that vehicles of categories N_2, N_3, O_3, and O_4 have lateral defenses for the protection of bicyclists, pedestrians, and motorcyclists (Ministerio de Transportes y Comunicaciones, 2003). Like UN Regulation 73, the maximum ground clearance allowed is 550 mm (21.7 in.), and the front and rear edges of the guard should be no more than 300 mm (11.8 in.) from the front and rear tires (see Figure 26 and Figure 27). Also specified in the Peru regulation is that the guards must be a maximum of 120 mm (4.7 in.) from the outer edge of the wheels or friction rail

[33] Primary source documentation could only be found for the 2011 standard, but secondary sources confirmed the existence of the original two standards (Riley, Penoyre, & Bates, 1985).

of the vehicle. Additionally, the regulation specifies that the side guard should have no sharp edges and smooth exterior surface. Unlike many of the other national regulations, there is no strength requirement specified for the guard.

Figure 26: Images of single-unit and combination tractor trailers equipped with side guards in Peru (Source: Volpe)



Cota	Descripción	Valor
A	Distancia desde la banda de rodamiento del neumático o borde posterior de cabina hasta el extremo delantero de la defensa	= 300 mm
B	Distancia desde la banda de rodamiento del neumático hasta el extremo posterior de la defensa	= 300 mm
C	Distancia desde el borde inferior de la defensa hasta el nivel de carretera	= 550 mm
D	Distancia desde el borde superior de la defensa hasta el borde inferior de la plataforma o carrocería .	= 350 mm
E	Distancia desde la banda de rodamiento del neumático hasta el extremo delantero de la defensa	= 500 mm

Figure 27: Technical specifications of the Peru standard (Ministerio de Transportes y Comunicaciones, 2003)

Brazil

With the passage of Resolution 323 to the Brazilian Traffic Code in 2009, trucks in Brazil are required to install side guards (see Figure 28), with the goal of protecting Brazil's large population of motorcyclists, as well as bicyclists and other operators of small vehicles (National Traffic Council, 2009). There are significant differences in the Brazil side guard regulation compared to others: it requires side guards to withstand a load of 5 kN while the UK and UN regulations only require side guards to withstand a load of 2 and 1 kN, respectively. The regulation requires trucks, trailers, and semi-trailers with a total gross weight of more than 3,500 kg, imported or made after 2011, to install side guards to be legally registered.

Similar to UN Regulation 73, the maximum ground clearance allowed is 550 mm (21.7 in.), and side guards must not extend beyond the plane corresponding to the width of the vehicle (see Figure 29). The upper bound of the side guard can be no more than 950 mm (37.4 in.) above the ground; the clearance between the front of the guard and the front wheel should be no more than 300 mm (11.8 in.), and the clearance between the back of the guard and the rear wheels should be no more than 500 mm (19.7 in.).

Figure 28: Image showing a side guard on a truck in Brazil (Source: Sergio Shumoff, 123rf.com)

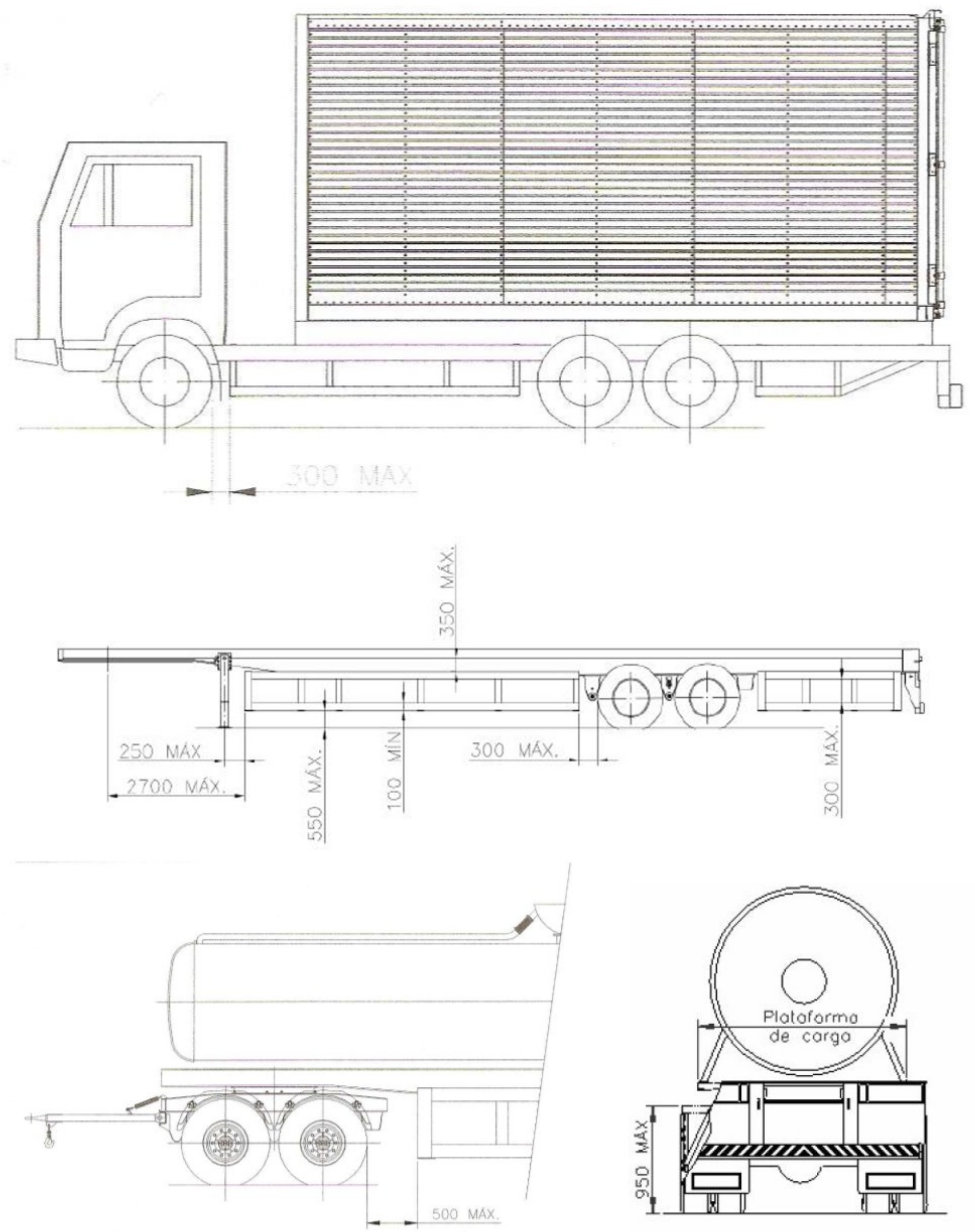


Figure 29: Technical specifications of the Brazil standard (all figures are in millimeters) (National Traffic Council, 2009)

Canada (Saint-Laurent and St. John's)

Pedestrian and bicyclist deaths due to collisions with large trucks and snow removal vehicles have spurred a public campaign for the adoption of side guards in Canada. The Borough of Saint-Laurent in Montréal, Quebec, began testing side guards in 2010, passed a resolution in 2012 to equip all new eligible fleet vehicles with side guards, and by 2014 had equipped 25 of the 33 eligible fleet trucks, with plans to fit all 33 by the end of 2015 (Buteau, 2014). As of 2017, the City of St. John's, Newfoundland and Labrador, has also implemented side guards on 43 fleet vehicles. This addition is not prescribed by any law or regulation, but has instead been implemented as a show of good faith following a number of VRU deaths. In a similar manner, the City of Westmount, an enclave of Montréal, has also begun adding side guards to their snow plows (Macdonald, 2016).

Side guards have been debated on a national scale twice in Canada, first in 2009 and again in 2013. The issue was first brought to the Ministry of Transport by St. John's and the Federation of Canadian Municipalities. The resolution was tabled and reintroduced in 2013, this time with the support of the City of Montréal. At the time of publication, Volpe is not aware of any national regulation for side guards in Canada (The Jessica Campaign, 2016).

Mexico (Mexico City)

The "installation of a safety device designed to prevent pedestrians, cyclists and motorcyclists from being run over by the back wheels of a truck when a lateral collision occurs" became mandatory in Mexico City in 2015 with the implementation of Article 40 of the Federal District Transit Regulations (Salvaguardas para Camiones Urbanos, 2015). The regulation requirements were modeled on the New York City side guard standard (Santillan, 2015), which is consistent with the Volpe specification (see section 0, **Volpe Side Guard Specification**).

The standard applies to vehicles of more than 3.5 tons, with the exception of fire trucks, sweepers, and car carrier trailers. The maximum ground clearance is 350 mm (13.8 inches), lower than the maximum permitted in the national regulations that Volpe identified. The top edge must be no more than 350 mm (13.8 inches) below the truck platform or between 1.00 and 1.50 m (39.4 and 59 in.) above the level of the road. Additionally, the side guard must be able to withstand a force of 200 kg (2 kN) without deflecting more than 30 mm (1.2 inches) in the rearmost 0.25 m (11.8 inches) and 0.15 m (5.9 inches) along the remaining length (see Figure 30). This 2 kN strength specification is consistent with the UK standard, higher than UN Regulation 73, and lower than the Brazil standard.

In order to minimize the risk of injury to pedestrians or cyclists, the regulation includes several additional geometric requirements, and the regulation recommends—but does not require—a panel-style side guard instead of horizontal rails or bars. Finally, the regulation specifies that the side guard must be made of stainless steel.

From secondary sources, Volpe found that a national Mexican side guard standard may be in development as of 2015 by the Auto Parts Committee of the Mexican Institute of Normalization and Certification (Comité de Autopartes del Instituto Mexicano de Normalización y Certificación) under the National Standardization Program (Santillan, 2015).

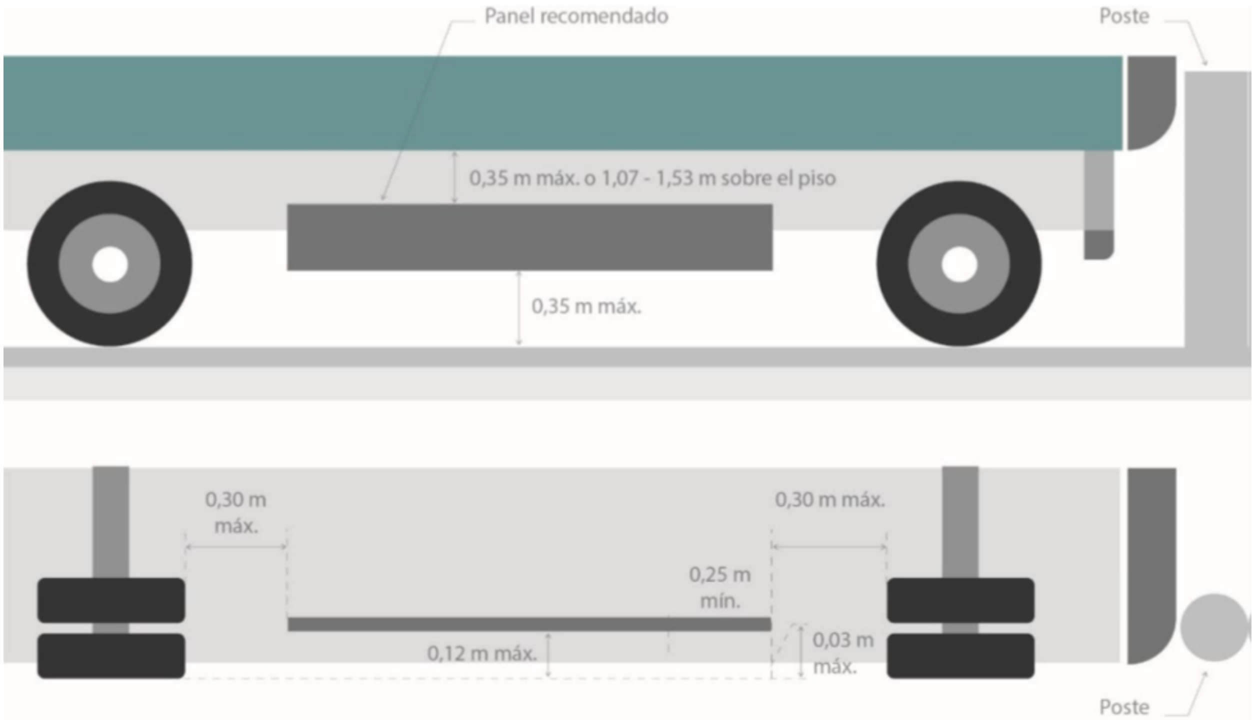


Figure 30: Specifications of the Mexico City standard (Salvaguardas para Camiones Urbanos, 2015)

Other Potential Side Guard Adoption in Foreign Countries

A non-exhaustive Volpe review of vehicle images indicates that up to and possibly more than 14 additional countries likely see relatively widespread adoption of side guards and may have implemented their own requirements or guidance.[34] When added to the 43 countries that abide by UN Regulation 73, the 4 unique countries identified previously as having national side guard regulations (i.e., not counting the UK, which is already counted in the list of countries that have adopted UN Regulation 73), and the 4 countries with sub-jurisdiction regulations or industry standards, **at least 65 countries appear to have widespread side guard usage**, whether or not actually required. While some of these countries may have implemented side guard standards and requirements, additional research would be needed to confirm the existence and details of any regulations in these countries.

Prior Recommendations for Side Guard Requirements

The first publication considered, from the National Transportation Safety Board, is included for completeness only, as its focus is on mitigating vehicular underride, not VRU underride, in collisions with trucks.

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[34] Based on online image search results and news articles, countries that may have widespread adoption of truck side guards include the following: Cambodia, Colombia, India, Israel, Myanmar, New Zealand, Pakistan, the Philippines, South Korea, South Africa, Thailand, Tunisia, Uruguay, and Vietnam.

Table 19: Summary table of recommended specifications from studies conducted in Australia, the United Kingdom, and the United States

Published Recommendation		Year Published	Vehicles Covered	Strength Rqmt.	Maximum Ground Clearance	Maximum Gap Between Wheels and Guard
NTSB **(National Transportation Safety Board, 2014)**		2013, 2014	Single-unit trucks over 10,000 lbs., trailers over 10,000 lbs., truck tractors over 26,000 lbs.	Not specified	Not specified	Not specified
TRL studies	Protecting Car Occupants, Pedestrians, and Cyclists in Accidents Involving Heavy Goods Vehicles by Using Front Underrun Bumpers and Side guards (Riley, Penoyre, and Bates, 1985)	1985	Vehicles of categories N_2, N_3, O_3, and O_4.	Not specified	300 mm (11.8 in.) – 400 mm (15.7 in.)	300 mm (11.8 in.)
	Review of side and underrun guard regulations and exemptions (Smith & Knight, 2004)	2004	Vehicles of categories N_2, N_3, O_3, and O_4.	Not specified	300 mm (11.8 in.)	Not specified
	Integrated Safety Guards and Spray Suppression - Final Summary Report (Knight, et al., 2005)	2005	Vehicles of categories N_2, N_3, O_3, and O_4.	Not specified	300 mm (11.8 in.) – 550 mm (21.7 in.)	300 mm (11.8 in.)
Monash University		2002	Vehicles over 3 tons.	2 kN	350 mm (13.8 in.)	300 mm (11.8 in.)
University of Ontario Master's Thesis **(Galipeau-Belair, 2014)**		2014	Vehicles of categories N_2, N_3, O_3, and O_4.	Not specified	350 mm (13.8 in.) – 400 mm (15.7 in.)	Not specified

National Transportation Safety Board

The National Transportation Safety Board (NTSB) issued two related Safety Recommendations to NHTSA, in July 2013 and April 2014, for the development of national performance standards and for requiring the installation of heavy-duty side underride guards on single-unit trucks over 10,000 lbs. gross vehicle weight rating (GVWR), trailers over 10,000 lbs., and truck tractors over 26,000 lbs., with the objective of stopping motor vehicles from intruding under the sides of the large truck or trailer (National Transportation Safety Board, 2014).

It is important to note that the NTSB recommendations focus on far heavier, more expensive, and less commercially available devices designed to arrest a motor vehicle at high speed instead of a VRU at low speed. Although side guards consistent with such a standard could also mitigate crashes involving VRUs, such heavy-duty equipment would be massively overdesigned for this type of crash. Hundreds of times more kinetic energy must be managed to stop a high-speed passenger vehicle as compared to a low-speed VRU.[35] Therefore, while the authors reference the NTSB recommendations for completeness, **it is critical to separate the lightweight VRU side guards considered in this study and the concept of heavy-duty vehicle-arresting side underride guards for any potential future regulatory or standard-setting action.**

Transport Research Laboratory (TRL)

Three reports—drafted in 1985, 2004, and 2005—prepared by TRL for the UK Department for Transport detail recommendations for the design and usage of side guards in the UK (Riley, Penoyre, & Bates, Protecting Car Occupants, Pedestrians, and Cyclists in Accidents Involving Heavy Goods Vehicles by Using Front Underrun Bumpers and Sideguards, 1985). Included are recommendations for the reduction of exemptions from UK side guard legislation, suggesting that adjustable side guards be considered before ruling vehicle types exempt. One report advises a ground clearance of 300 mm (11.8 in.), citing a UK crash database and suggesting that reducing the clearance will reduce the incidence of bicyclists being run over when they fall onto the truck side (Smith & Knight, 2004).

Monash University

A study done by Monash University in 2002 also provided recommendations for vehicles over three tons (Lambert & Rechnitzer, 2002). Researchers focused on the impact of side guards on pedestrians and cyclists, finding that the usage of flat panels is preferable as it limits the chance of rails catching on pedestrians and cyclists. The study also found that a strength of 2 kN is ideal for testing, and that the ground clearance of 350 mm (13.7 in.) is preferred to one of 550 mm (21.7 in.), where a pedestrian or cyclist may not be protected from the vehicle wheel path. Lastly, researchers noted that most buses and car-carriers would not need side guards due to their low ground clearance.

University of Ontario Master's Thesis

A 2014 University of Ontario Master's Thesis titled Design and Development of Side Underride Protection Devices (SUPD) for Heavy Vehicles focused on the design and implementation of side guards to prevent fatalities from crashes involving large trucks. While much of the research focused on preventing crashes between small cars and trucks, the author made some recommendations as to side guard design that could reduce pedestrian and bicyclist deaths (Galipeau-Belair, 2014). Advocating for side guard usage on vehicles of categories N_2, N_3, O_3, and O_4, the author agreed with the UK standard of applicability. Additionally, the recommended

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[35] Kinetic energy $E = ½*mass*velocity^2$. A light duty vehicle weighing 4,000 pounds and traveling 30 mph possesses *240* times the kinetic energy of a 200 pound VRU traveling at 10 mph.

ground clearance was between 350 mm (13.7 in.) and 400 mm (15.7 in.), a value higher than that recommended by the TRL studies but lower than that required by the UN Regulation 73.

Industry Standards

Australian Trucking Association Standard

The Australian Trucking Association standard was developed with the desired goal of providing guidelines and instructions for truck and trailer manufacturers as well as truck operators in Australia to comply with UN Regulation 73 side guard standards (Australian Trucking Association, 2012). The standard is in the form of a Technical Advisory Procedure developed by the Australian Trucking Association Industry Technical Council and endorsed by the Australian Trucking Association General Council that provides general construction guidelines for a lateral protection device. The Australian Trucking Association standard provides trailer and truck body builders with off-the-shelf designs that would be deemed to comply with the requirements of UN Regulation 73, for which it maps European and Australian vehicle category designations. The designs provided cover three materials: steel, aluminum, and a fiber composite panel material. According to the Technical Advisory Procedure, “the fiber composite panel material design is low weight and may be designed to improve dynamic airflows around trailers offering potential to achieve safety and efficiency gains” (Australian Trucking Association, 2012). The technical specifications are equivalent to those required in UN Regulation 73, with two exceptions that make it somewhat more stringent: first, the Australian Trucking Association standard additionally specifies side guards rearward of the axle group; second, it recommends, though does not require, a lower maximum ground clearance of 525 mm (20.7 in.) (see Figure 31). In Australia, the Melbourne Metro Rail Authority is requiring all trucks involved in the construction of a metro system project starting in 2017 to be fitted with side guards (Carey, 2017), and some amount of adoption of the standard was identified (Bikes and trucks, 2017).

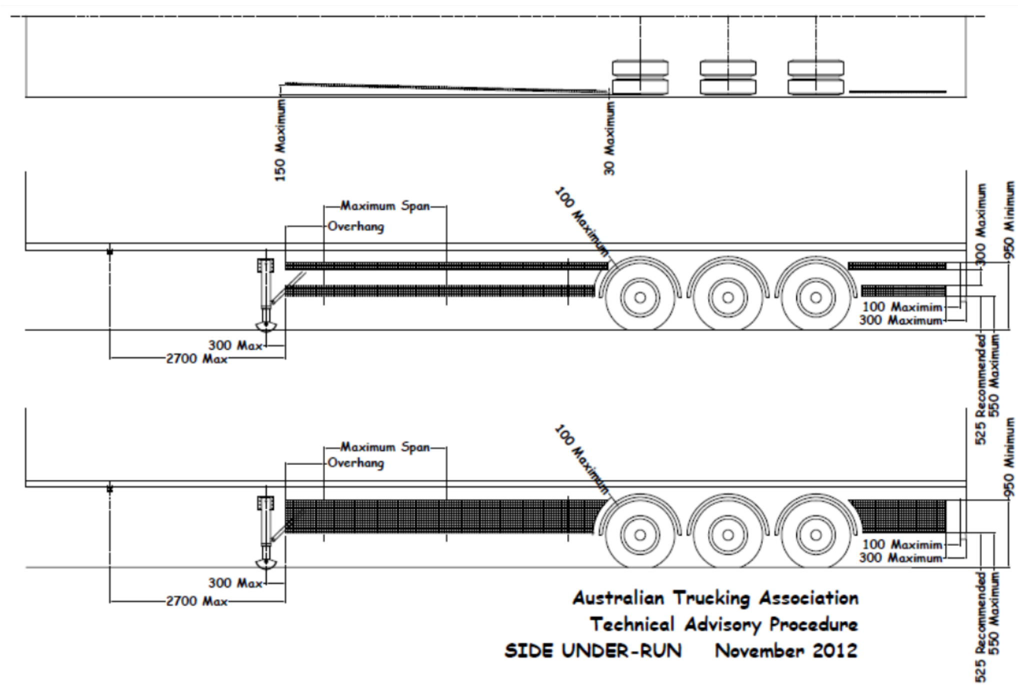

Figure 31: Technical specifications of the ATA standard (Australian Trucking Association, 2012)

Construction Logistics and Cyclist Safety (CLOCS) and Fleet Operators Recognition Scheme (FORS) Standards

The Construction Logistics and Cyclist Safety (CLOCS)[36] Standard for Construction Logistics and the Fleet Operator Recognition Scheme (FORS) are industry standards used initially in London and more recently throughout the UK. Implemented by construction clients through contracts, CLOCS provides a way for owners to manage road risks in a standardized way (Construction Logistics and Community Safety (CLOCS), 2015). To comply with CLOCS, clients must fit side guards to all vehicles that are currently exempt from side guard use under the Road Vehicles Construction and Use Regulations of 1986, including mixer and tipper (dump) vehicles over 3.5 tons in weight.

FORS is an accreditation that demonstrates fleet operators' compliance with CLOCS standards, and it represents the fleet-facing side of the same requirements. Adopters include the City of London, the borough of Camden, and over 400 UK industry members (referred to as "Champions") of the program (London Cycling Campaign, 2017).

Volpe Side Guard Specification

In 2016, Volpe and the Office of the Assistant Secretary for Research and Technology developed and published "Truck Side Guard Technical Specifications: Recommended Standard DOT-

[36] CLOCS was recently renamed Construction Logistics and Community Safety, though the original terminology still appears in the published standard.

VNTSC-OSTR-16-05" for side guards in the U.S. The origin and basis of the standard included Volpe's initial review of international precedents, published recommendations from the Transport Research Laboratory (TRL) and Monash University (as discussed later in this section), and fleet feedback from side guard operational pilots in the cities of Boston, Cambridge, New York, and San Francisco. The Volpe specification was published in U.S. customary units based on the 350 mm maximum ground clearance recommended by TRL and Monash and the 2 kN force test criteria (see Figure 32). Volpe recommended the stronger 2 kN standard (identical to the UK standard) to provide a larger safety margin and to account for the heavier average weight of people today compared to when the first side guard requirements were developed more than 30 years ago (Volpe National Transportation Systems Center, 2014).

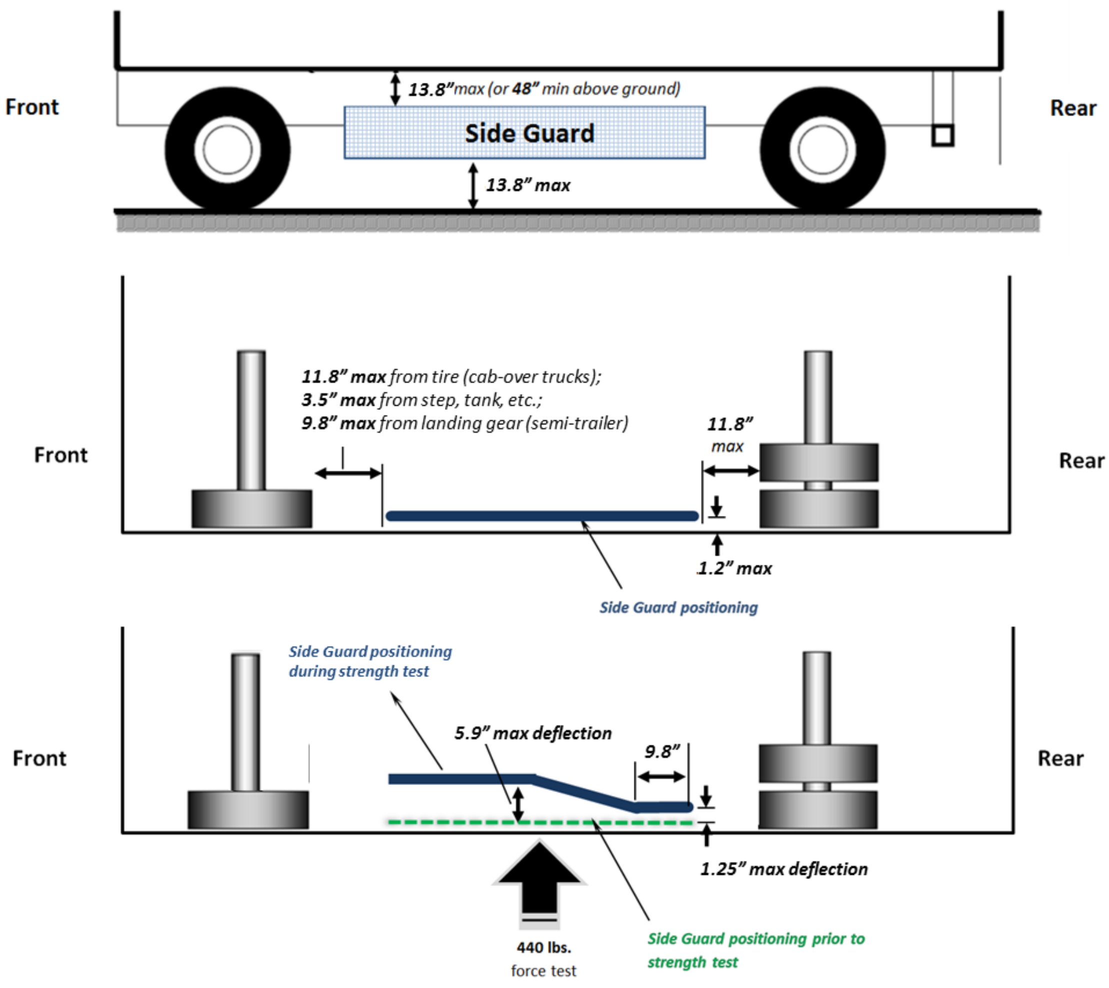

Figure 32: Technical criteria of the Volpe specification (Source: Volpe)

Figure 33: Private sector rail and panel style side guards in the Boston and New York City (NYC) metro areas (Source: Volpe)

Private Sector Installations

Whether complying with local laws or doing so voluntarily, a growing number of private sector U.S. fleets operating in urban areas have been installing side guards. In the Boston area, these have included Save That Stuff, Sunrise Scavenger, Capitol Waste, EarthWorm, and Harvard University; in New York City, these have included FreshDirect, Action Carting, New York Post, and Coca-Cola; and in Seattle, the University of Washington. Additionally, U-Haul has implemented and markets aerodynamic side skirts that may also function as side guards on 26' box trucks, as shown in Figure 33.

Existing Exemptions

Volpe research showed that the UK Construction and Use regulation, which predates UN Regulation 73, includes a substantially larger number of vehicle exemptions. These exemptions have been gradually reduced (Hammond, 2013) in recognition that a large fraction of VRU fatalities in London have involved side guard-exempted vehicles (Transport for London , 2014).

The UN Regulation 73 side guard regulation does not apply to tractors for semi-trailers, trailers designed and constructed for transporting "very long loads of indivisible length, such as timber, steel bars etc.," and vehicles designed and constructed for special purposes where it is not possible to fit lateral protection.

Also, there are four specific derogations in the UN Regulation 73 language:

- An *extendable trailer* shall comply with all the dimensional and strength requirements when closed to its minimum length; when the trailer is extended, however, the gap between the side guards and either the forward or rear tire can be greater than normal.

- *Cargo tank* trucks provided with hose or pipe connections for loading or unloading must be fitted with side guards “which comply so far as is practicable with all the [dimensional and strength] requirements of paragraph 7; strict compliance may be waived only where operational requirements make this necessary.”

- On a vehicle that has *extendable legs*—e.g., a crane—to provide additional stability during loading, unloading or other operations, the side guard can have additional gaps to permit extension of the legs.

- On a vehicle equipped with anchorage points for *roll-on/roll-off* transport, gaps are permitted within the side guard for tie down points for ropes used to cover loads.

Due to flexibility in the language of the regulations, if the sides of the as-built vehicle or a combination of appropriately located toolboxes, fuel tanks, etc., already meet the dimensional and strength requirements of side guards, they are regarded as replacing the side guards.

Street sweepers are among the UK exempt vehicles, due to their “ancillary equipment” and possibly due to their low top speed. The TRL report is ambivalent about whether sweepers should be exempted or whether they should have removable guards, though the report acknowledges the added complexity associated with removable guards.

The TRL report is definitive, however, in its assessment that refuse collection trucks are not a technically justified exemption (Smith & Knight, 2004). The off-road capability of collection trucks is generally limited and existing devices and structures mounted under the body typically limit the ground clearance between the wheels, so there is no ground clearance justification for an exemption.

Exempted trucks have been found to be overrepresented in VRU fatalities. The predicted benefits of ending the exemptions from the UK side guard regulations have been estimated by TRL as preventing about 6 percent of bicyclist fatalities and close to 1 percent of pedestrian fatalities (Knight, et al., 2005).

Brazil’s regulation does not apply to tractor trucks, those with load platforms up to 550 mm (21.7 in.) above the ground, vehicles intended for export, unfinished vehicles, military vehicles, those whose design is sufficient to meet the requirement, and those constructed for specific purposes where, for technical reasons, lateral protection cannot be installed.

Table 20: Summary table of vehicle types exempted from side guard fitment under UN or UK regulations and technical justification based on published assessments

Vehicle Type	UN / UK Exemptions	TRL Study Findings	Exemption Technically Justified?
Tractor for semi-trailer	Exempt from UN standard	Fuel tanks and other structures often fill the space between axles, but there is no real reason to maintain exemption. Flat panel side guards would be beneficial.	No
Special purpose vehicle where side protection is impractical	Exempt from UN standard	This catch-all category is too open to subjective interpretation.	Unclear
Trailer designed for very long loads	Previous UN exemption has been repealed; UK exemption remains	Continued exemption is warranted when distance between axles is extremely long. These vehicles also move at low speed, often with a police escort.	Yes
Low-speed vehicle (max. 15 mph)	Exempt from UN standard	Exemption is not warranted based on speed alone (as distinct from vehicle type).	No
Tipping / dump truck	Additional UK exemption	Exemption is generally not warranted. Side guards do not interfere with hydraulics and vehicles seldom require extreme off-road capabilities. Ground clearance is already limited by other vehicle components.	No
Refuse / collection truck	Additional UK exemption	Exemption is generally not warranted. Ground clearance is already limited by bodywork and equipment, so side guards do not pose an issue and are generally compatible with operation.	No
Street sweeper	Additional UK exemption	Fitting side guards could interfere with operations, though a stowable side guard could work.	Unclear
Military vehicle	Additional UK exemption	Continued exemption is warranted given the range of use for these vehicles, even though not always technically justified.	Yes
Fire engine	Additional UK exemption	Typical design meets dimensional requirements. In cases where it does not, side guards are indicated except when used off-road.	Unclear
Car carrier	Additional UK exemption	Vehicle design generally already has very low ground clearance.	Unclear

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APPENDIX B – SYSTEMATIC REVIEW OF EFFECTIVENESS STUDIES

Field evaluation studies

Several UK studies have demonstrated the safety effectiveness of side guards on large trucks, showing decreases in pedestrian and bicyclist injury severity for the most side guard-relevant crash types after the UK mandated side guards for most heavy duty vehicles (Patten & Tabra, 2010). A 2005 UK TRL study (Knight, et al., 2005) compared 1980-1982 ("before") data with 1990-1992 ("after") data, and a 2010 TRL study (Cookson & Knight, 2010) compared 1980-1982 ("before") data with 2006-2008 ("after") data. According to both studies, the most relevant crashes for side guards are passenger side ("nearside") impacts where the heavy vehicle was traveling straight ahead and passing the VRU (i.e., passing/overtaking crashes). In the UK crash databases these are classified as "going ahead other" (2005 and 2010 TRL studies) and "overtaking moving vehicle" (2010 TRL study).

The TRL 2005 study results (Knight, et al., 2005) show that the bicycle injury distributions for the passing/overtaking crash category before and after the nationwide installation of side guards changed substantially and favorably. In contrast, the before and after data did not show any appreciable change in the injury distribution for "passenger side turning maneuver" crashes, or for any other crash categories. Based on this, the authors conclude that the primary safety impact of side guards is in passing/overtaking crashes, where the heavy vehicle is moving straight ahead. Figure 35 depicts these same results in a different way, showing a 61 percent reduction in the proportion of bicyclist fatalities in the passing/overtaking crash category. This was reported in the 2005 TRL report (Knight, et al., 2005) and cited by National Research Council Canada in a 2010 study (Patten & Tabra, 2010).

The 2010 TRL report (Cookson & Knight, 2010) comparing crash data from 2006-2008 also showed lower bicyclist and fatality and serious injury rates for side guard-relevant crashes when compared to the pre-side guard 1980-1982 period.

Before and after data from the 2005 TRL study revealed there was a greater reduction in the proportion of severe injuries and deaths for bicyclists than for pedestrians. Still, **the fraction of fatal pedestrian casualties in the passing/overtaking passenger side-impact crash type decreased 20 percent,** compared to the 61 percent observed for bicyclists. More detail on this is available in a companion TRL report (Smith, Neale, & Knight, 2005). Case studies from the Heavy Vehicle Crash Injury Study (HVCIS) and the Truck Crash Injury Study (TCIS) databases in the UK suggested that the reason for this difference might be that the crash mechanisms are different; according to these data sources, pedestrians more commonly walked into the side of vehicles rather than falling against them (Knight, et al., 2005).

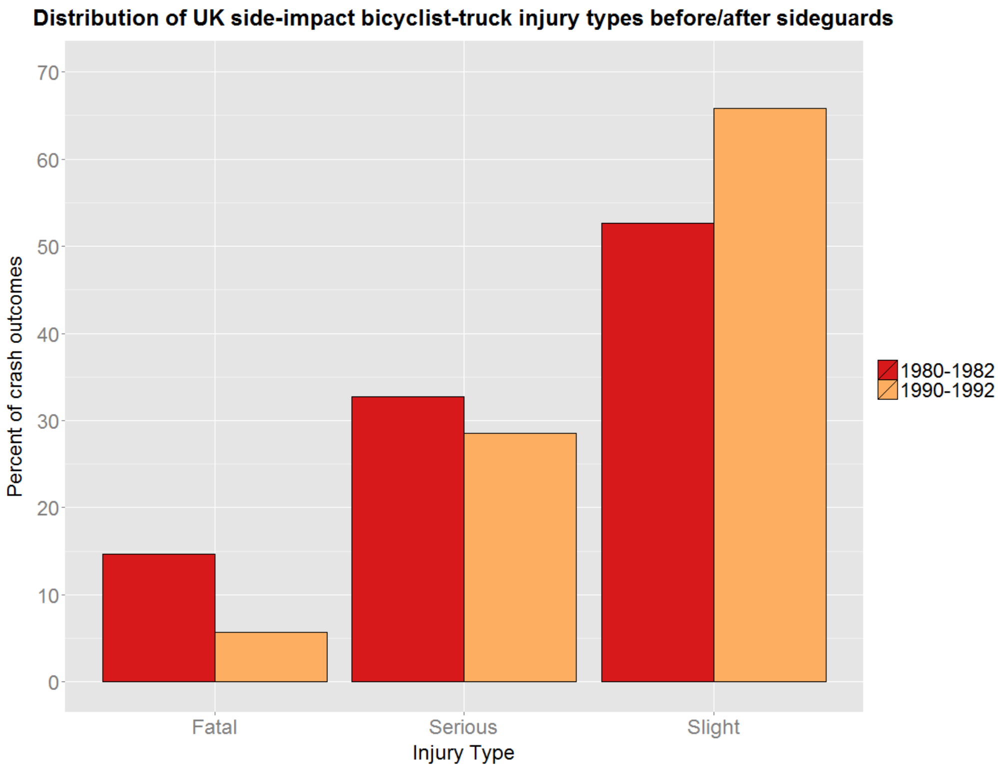

Figure 34: Fatality and injury distribution of bicyclists in passing/overtaking side impacts with trucks 4-6 years before and 4-6 years after the mandatory introduction of side guards in the UK (74 crashes in 1980-82 and 66 crashes in 1990-92) (Volpe National Transportation Systems Center, 2014)

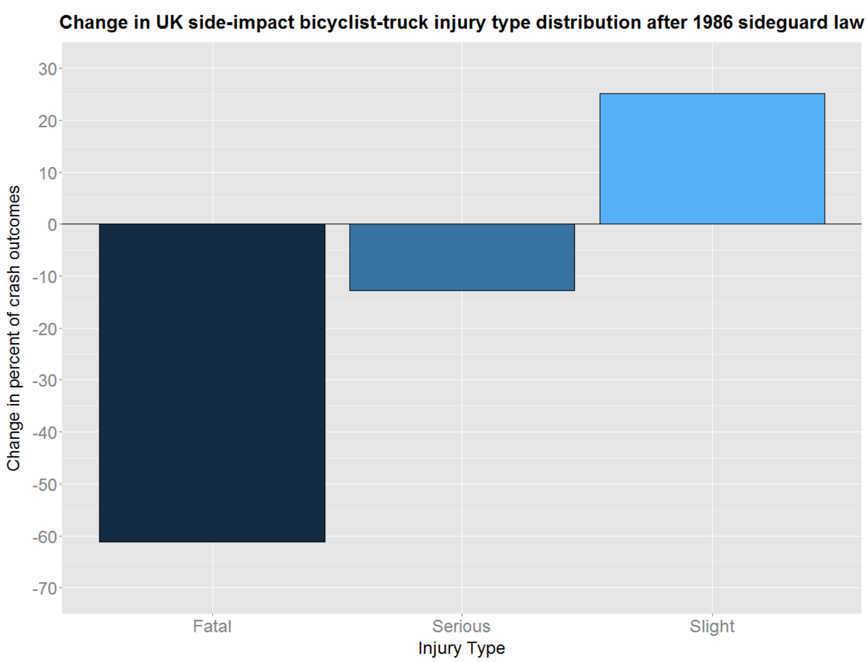

Figure 35: Decrease in fatality and serious injury rates for bicyclists in passing/overtaking crashes following side guard implementation in the UK (74 crashes in 1980-82 and 66 crashes in 1990-92)

It is possible that other confounding factors may have changed from the before to the after measurement periods, and some may question the extent to which these uncontrolled factors, whether known or unknown, may have distorted the apparent side guard effectiveness in either direction. While confounding factors can never be ruled out entirely in real-world experiments, all of the knowledge that we have suggests that any confounding factors would only have influenced the ***frequency*** of crashes (e.g. ***preventative*** countermeasures such as mirrors, safety education campaigns, etc.), but would not have influenced the ***severity*** of crashes in the way that a ***mitigating*** countermeasure, like a side guard would. For this reason, the TRL reports focus their analyses on the changes in severity (the injury distribution).

Even if there were other unexplained factors arising in the "after" observation periods with a significant impact on crash severity, we would expect them to affect crash severity in multiple categories, and not just the side guard-relevant categories. However, according to the 2005 TRL report, "in the non-side guard-relevant crash types the proportion of killed or seriously injured (KSI) cyclists and pedestrians were broadly similar before and after side guard introduction, or even increased slightly." This further supports the hypothesis that side guards were a primary factor reducing crash severity in the "after" period.

In addition to comparing crash outcomes from two different time periods (before and after the side guard phase-in), the 2005 TRL report also compared crash outcomes in the same time period (after phase-in), for trucks that were exempt and non-exempt from the side guard regulation.[37] The results were consistent with the before and after results, again suggesting that side guards effectively mitigated crash severity in the passing/overtaking crash category. Exempt vehicles had a higher proportion of the most severe crashes (killed or seriously injured) and were overrepresented in those serious crashes when compared to non-exempt vehicles, and the differences were statistically significant. Table 21 shows the comparison of exempt and non-exempt vehicle crash outcomes for 1990-1992.

The 2010 TRL report performed a similar comparison of exempt and non-exempt vehicles in 2006-2008, and Table 22 shows that the results for the passing/overtaking crashes were consistent with the 2005 exempt/non-exempt comparison and with the before and after comparisons for both studies. **All of these results support the hypothesis that side guards helped reduce the severity of crashes.** The 2010 TRL report also added a separate comparison of exempt and non-exempt crash data for passenger side turning maneuvers. These results were unexpected, because they show that exempt vehicles were more likely to have crashes in these maneuvers, and also had a higher proportion of more severe crashes. The before and after data, by contrast, only showed a minor change in the injury distribution for this crash type, which was not statistically significant. The authors note that other factors could explain these conflicting results, such as the

[37] An advantage of this comparison is that it considers crashes over the same time period, eliminating potential confounding factors that may have changed from the before to the after period. A different confounding factor could exist, however, if exempt vehicles were inherently more fatal in side-impact crashes for unknown reasons that are not related to the presence of side guards. However, both the time-series and the exempt/not exempt safety analyses are consistent and show reduced fatality rates among side guard-equipped large trucks.

use of these vehicles in different environments, driver behavior, or field of view (e.g. close proximity mirrors required as of 2006).

Table 21: 1990-1992 crash severity distribution in truck-bicycle passing/overtaking crashes in the UK when the truck was either exempt or not exempt from side guard installation (KSI = killed or seriously injured) (Knight, et al., 2005)

	Fatal	Serious	Slight	% fatal	% KSI
Exempt (no side guards)	6	18	22	**13%**	**52%**
Not exempt (equipped with side guards)	5	34	103	**4%**	**27%**

Table 22: 2006-2008 crash severity distribution in truck-bicycle passing/overtaking crashes in the UK when the truck was either exempt or not exempt from side guard installation. (KSI = killed or seriously injured) (Cookson & Knight, 2010)

	Fatal	Serious	Slight	% fatal	% KSI
Exempt (no side guards)	4	11	15	**14%**	**52%**
Not exempt (equipped with side guards)	3	23	43	**4%**	**37%**

A 2014 TRL report revisited the data from the prior TRL reports, and suggested extrapolating from the results. The authors of the TRL report pointed out that **the before and after comparisons from the prior studies likely underestimated the effectiveness of side guards, since the "after" period did not have universal side guard fitment.** Instead, the authors estimate that only 74 – 89.5 percent of heavy vehicles were actually equipped. The remaining vehicles were exempt. Thus, assuming a linear dose-response relationship, the authors suggest a proportional amplification of the observed reductions in fatalities and severe injuries in order to estimate the actual effectiveness of side guards. So, for example**, for the 2010 TRL results, this would translate to an estimated reduction in bicyclist fatalities of 61.7 - 74.6 percent. For the 2005 TRL results this would result in an estimated reduction in bicyclist fatalities of 68.4 – 82.7 percent, and an estimated reduction in pedestrian fatalities of 22.7 – 27.4 percent** (Robinson & Cuerden, 2014)**.**

A study performed by the Dutch Road Safety Research Institute (SWOV) on behalf of Transport and Logistics Netherlands (TLN) analyzed crash and exposure data and then completed cost-benefit assessments for certain safety measures, including side guards. The study used buses as a proxy for side guard-equipped trucks, since the side of a bus presents a smooth surface that extends very close to the ground (often lower than most side guards), whereas trucks without side guards typically have gaps in the side of the vehicle. With this difference in mind, the study compares the severity of VRU crashes for buses turning right (passenger side) and trucks turning right, from 1989-1997, noting that **serious injuries are 50 percent less likely in a bus side-impact crash with a VRU (defined in the study as a pedestrian, bicyclist, or moped rider)**

than in a comparable truck crash.[38] This is calculated based on "deaths or hospital admissions as a percentage of all injuries." In contrast, there was little difference in injury severity for left-hand (driver's side) crashes. The study draws a distinction between "open" side guards (i.e. rail-style) versus "closed" side guards (i.e. smooth-style), and assigns a different effectiveness to each. The study assigns an effectiveness of 35 percent to "closed"/smooth-style side guards, based on the above analysis, and assigns a slightly lower (and admittedly arbitrary) effectiveness of 25 percent to "open"/smooth-style side guards. The study lists four scenarios of side guard adoption and assigns cost-benefit estimates to each (estimate of number of lives saved per guilders invested) (Van Kampen & Schoon, 1999).

Some studies used a hybrid qualitative/quantitative approach to assess the relevance of side guards. These studies reviewed fatal crash data for which detailed "case study" information was available, such as: reports by experts, diagrams showing pre-impact trajectories and post impact positions, photographs of the scene and vehicles involved, transcriptions of interviews with drivers and witnesses, and detailed injury and trauma assessments. Unfortunately, since the data sets for these case studies are limited to fatal crashes, the studies were not able to analyze the instances where a side guard prevented a fatality. Instead, for vehicles that did not have side guards fitted, they judged whether a side guard would have potentially mitigated the fatal injuries, based on the data and expert input available. For fatal crashes where the vehicles had side guards fitted, they noted how the side guard performed, and why it did not save the VRU.

- One study had a sample size of n>300 fatal crashes, and estimated that side guards would have prevented fatal injuries to over 15 percent of the bicyclists, motorcyclists, and pedestrians that were killed. Approximately two-thirds of the 300 crashes were side impact crashes, meaning that the effectiveness percentage specific to side impact crashes was about 24 percent (Riley, Chinn, & Bates, An analysis of fatalities in heavy goods vehicle accidents, 1981).

- Another study had a sample size of n=27 relevant fatal crashes, including n=16 "type A" crashes, in which the vehicle made contact with the cyclist by turning left or changing lanes, and n=11 "type B" crashes, in which the cyclist lost control or wobbled while alongside the vehicle. **Researchers determined that 20 of these 27 could have been prevented had the heavy duty vehicle been fitted with a side guard** (or if it had been a side guard with more rigorous technical specifications). This included 15 out of 16 "type A" crashes and 5 out of 11 "type B" crashes (Keigan, Cuerden, & Wheeler, 2009).

- Another study had a sample size of n= 24, including front and side fatal collisions of all types (not limited to side guard relevant crashes). It found that all of the fatally injured cyclists were already on the ground before any side guard interaction could have occurred. Since the UK side guard requirement allows a gap of up to 550 mm from the bottom of the side guard to the road surface, this was large enough to pass over a person already completely prone on the ground, and side guards were not seen to be effective in

[38] It is not completely clear from the translation whether the study is truly only analyzing turning maneuvers, or whether it is analyzing all side-impact crashes (including the passing/overtaking maneuvers deemed most relevant by the UK studies).

this sample. The authors note that this is not to say that they are not effective; the data from the study were insufficient to prove or disprove their effectiveness, given the circumstances of the crashes in this sample (Thomas, Talbot, Reed, Barnes, & Christie, 2015).

- Another study had a sample size of n=4 fatal rear wheel run-over crashes with side guards fitted, and n=8 fatal rear wheel run-over crashes without side guards fitted. In the four cases where side guard were fitted, they were not effective in preventing the bicyclist from going under the truck, for two reasons: (1) in two cases, the cyclist passed through a gap in the side guard in the vicinity of the fuel tank, and (2) in the remaining two cases, the cyclist was already on the ground and went underneath the side guard, as described in the study above. **For the crashes where the vehicle was not fitted with a side guard, the researchers estimated that a side guard may have prevented the bicyclist from going under the vehicle in three out of eight cases** (Talbot, Reed, Barnes, & Thomas)**.**

An Australian study estimated that side guards would convert 20 percent of all fatalities to injuries and 25 percent of all serious injuries to minor injuries for both pedestrians and bicyclists. In contrast to other studies, this "effectiveness" percentage is expressed as a percentage of all fatalities and serious injuries, rather than as a percentage of the side guard-relevant crashes. The author determined these percentages by combining the benefit estimates derived from the Australian crash investigations with European estimates from cited references. However, the author of this Australian study did not explain the details of this combination and derivation, so the assumptions and rationale are not explicit (Rechnitzer, 1993). The European estimates are from two other studies cited in this section (Hogstrom & Swensson, 1986) (Riley, Chinn, & Bates, 1981).

Empirical Studies

A 1985 UK study used a crash dummy on a bicycle to test the effectiveness of a side guard for the typical side guard-relevant crash, where a heavy duty vehicle overtakes a bicyclist at low speed and the bicyclist falls into the path of the rear wheels. Researchers began by testing a side guard with the maximum allowable gaps and inset under the UK regulation, and then tested improved side guards with smaller horizontal and vertical gaps and reduced inset (i.e., surpassing contemporary UK regulatory requirements). The minimum legal side guard reduced the likelihood of running over the bicyclist by 60 percent, from 100 percent to 40 percent of the test runs. An improved guard with lower ground clearance, less inset, and smaller gap between the guard and the rear wheels reduced the incidence to near zero. Based on the tests, researchers recommended changes to side guard specifications to improve effectiveness (Riley, Penoyre, & Bates, Protecting Car Occupants, Pedestrians, and Cyclists in Accidents Involving Heavy Goods Vehicles by Using Front Underrun Bumpers and Sideguards, 1985).

A 1986 Swedish study by the Volvo truck manufacturing company carried out a number of tests and experiments with a crash dummy on a moped in order to assess the effectiveness of a side guard for protecting a motorcyclist or bicyclist. The study concluded that a side guard would have a positive (mitigating) influence in 35 percent of accidents (Hogstrom & Swensson, 1986).

A 2012 Canadian study conducted a performance test to see how aerodynamic side skirts would perform when impacted by a loaded bicycle. Although they were not originally designed for preventing side underride, all three side skirts prevented the loaded bicycles from entering under the trailer. Their performance differed in terms of the amount of deformation, rebound, energy absorption, and permanent skirt damage after the test, but none of the side skirts were damaged to the point where they could become hazardous to other motorists if the trailer were to continue driving after an impact with a bicycle (Patten, Lalonde, Mayda, & Poole, 2012). This research only tested the strength and behavior of the side skirt and did not attempt to understand what would happen to the human rider in terms of injury severity. Nevertheless, this experiment suggests that the side skirts already employed on some trucks for fuel efficiency reasons could provide some amount of ancillary safety benefit.

Simulation-based studies

A 2005 UK study used computer simulation supplemented by accident analysis to estimate the incremental safety benefit of fitting a smooth-style side guard rather than a rail-style side guard. In the simulated experiment, both side guard designs were effective at preventing the upper body of the VRU from being run over by the rear wheels but the smooth side guard was more effective at reducing overall injury risk, especially for head impacts. Replacing rail with smooth style side guards would result in an incremental additional reduction in bicyclist fatalities of 0.65 to 5 percent and a reduction in serious pedestrian casualties of 0 to 3.9 percent. The study also noted that evidence from crash studies supports the findings of the computer simulation. According to the author, estimates of casualty reduction potential (of replacing "rail" with "smooth" style side guards) are conservative because they “exclude a number of possible benefits from other maneuvers not evaluated and a number of simulated differences to body loads for which there is no known translation to probability of injury risk.” Also, based on the results, the author concludes that a pedestrian falling against the side of a vehicle is even more likely to be benefitted by a side guard than a bicyclist falling against the side of a vehicle; however, pedestrians have less exposure to this type of accident, so the overall benefit is less. The author posits that a pedestrian more commonly walks into the side of a vehicle rather than falling against it (Smith, Neale, & Knight, 2005).

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APPENDIX C: TRUCK PART AND INSPECTION INTERACTIONS

This section examines potential installation and operational interactions between the U.S. truck fleet's most common cargo body types, vehicle components, and the installation of factory-installed as well as aftermarket side guards. The report also examines potential interactions between side guards—whether aftermarket or premarket—and FMCSA commercial vehicle safety inspections. The analysis identifies potential incompatibilities (costs) as well as potential synergies (avoided costs) between side guards and specific truck parts, which are categorized in this report as synergistic, adaptable, re-positioned, or potentially incompatible; incompatible truck parts are defined as parts that conflict with truck side guard installation and cannot be adapted or re-positioned.

Methodology

The analysis of potential interactions between side guards and truck components used three distinct methodologies. First, Volpe performed a quantitative and qualitative analysis of the results of the 2002 Vehicle Inventory Use Survey (VIUS) to determine the suitability of the most prevalent truck types in the U.S. fleet with GVWR greater than 10,000 pounds for aftermarket installation of side guards. Second, Volpe itemized truck parts and components associated with the identified truck types, assessed potential interactions and compatibilities between aftermarket side guards and each component, and estimated whether there would be a cost associated with mitigating any conflicting interactions and/or taking advantage of any potentially positive or synergistic interactions. This second analysis was a systematic tabulation based on online research and visual assessments of specific truck parts. Finally, Volpe conducted interviews with the Acting Director for the FMCSA Field Operations Office and with select truck and truck part manufacturers to identify and examine potential interactions related to commercial vehicle safety inspections, along with any other potential interactions not revealed through the analysis of individual components.

Common Truck Types

Truck fleet composition data for this report originated from the Vehicle Inventory and Use Survey (VIUS), a part of the 2002 Economic Census. This survey, still considered the most complete census of the U.S. truck fleet,[39] is based on a sample of 136,113 private and commercial trucks registered in the United States. Commercial vehicles relevant for side guards' installation and subject to FMCSA regulation are principally those with gross vehicle weight rating (GVWR) greater than 10,000 lbs. Of the 85 million trucks of all weight ranges estimated by VIUS, 6.4% (5,415,200) were estimated to exceed 10,000 lbs.

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[39] Per interviews with the National Truck Equipment Association and with the FleetDNA project team (Kenneth Kelly, Kevin Walkowicz, and Adam Duran) at the Department of Energy National Renewable Energy Laboratory.

The 2002 VIUS's Table 3a, "Trucks, Truck Miles, and Average Annual Miles for Trucks, Excluding Pickups, Minivans, Other Light Vans, and Sport Utilities: 2002 and 1997," includes the number of trucks by truck type.

Table 23 below is based on Table 3a from the 2002 VIUS and shows ten of the most common truck types listed in the 2002 VIUS.[40] These ten most common truck types include designations of single-unit and tractor-trailer. Single-unit trucks include a single frame, often with two axles, and tractor-trailer trucks include a power unit that tows one or more trailer(s). The total of these ten types account for approximately 80% of the total fleet, and their compatibility with side guards is considered in the following chapters. The remaining light-heavy, medium, and heavy-heavy vehicles include other body types (United States Census Bureau, 2017)

The 2002 VIUS excludes vehicles owned by federal, state, and local governments; ambulances; buses; motor homes; farm tractors; trailer units; and trucks reported to have been disposed of prior to January 1, 2002. Trailer unit information is important in quantifying the potential costs and benefits of side guards because these additional trailers could impact the costs associated with side guard installation and the benefits of crash mitigation and aerodynamic fuel efficiency. Americas Commercial Transportation (ACT) Research Co. documents U.S. trailer factory shipment data that can be used to fill in this knowledge gap. Using ACT data, the total population of truck trailers was estimated to be approximately 2.3 million in 2011. Forecasts of truck trailers in future years include a one percent sale growth rate, based on 2012 sales that increased by 244,186 trailers. These sale shipments are further broken down into categories such as Dry Van, Refrigerated, Container Chassis, Flatbed, Tank, Other On-Highway, and Off-Highway (ACT Research Co., 2014).

Conclusion

Using the 2002 VIUS data, Volpe has identified the top 10 most common truck types by calculating the highest percentages of truck types in the U.S. truck fleet over 10,000 pounds. These truck types include: Flatbed, Stake, or Platform (Single-Unit); Dump (Single-Unit); Van Basic Enclosed (Tractor Trailer); Van Basic Enclosed (Single-Unit); Van, step, walk-in or multistep; Service, utility or other (Single-Unit); Flatbed, Stake, or Platform (Tractor-Trailer); Van, open top (Single-Unit); Tank, liquids or gases (Single-Unit); and Dump (Tractor-Trailer). The total of these truck types account for approximately 80% of the fleet, and each individual truck type ranges from 2% to 17% of the fleet. The distribution of these truck types dictates the distribution of their associated, commonly installed parts and accessories. These parts and accessories may interact with side guard installation differently: some parts and accessories may be less costly to accommodate, while others may require more costly adaptations or alternatives.

Truck Parts and Accessories

This section examines different truck body components, both those required by FMCSA safety regulations and those commonly installed for vocational applications, and their potential

[40] The category "Service, Other" was omitted due to the wide range of included cargo body types.

interactions with side guards. This section considers each truck part's expected compatibility with side guards, the types of fleets impacted by this interaction, and whether there is a potential added cost associated with this interaction. Several different sources informed this analysis, including the U.S. Federal Motor Carrier Safety Administration (FMCSA) Regulations Part 393 ("Parts and Accessories Necessary for Safe Operation") and the 2010 Side guard Compliance Guide published by the United Kingdom's Freight Transport Association. Table 24 presents these truck parts and is followed by figures that illustrate the points of potential interaction.

Volpe's analysis assumes that side guards would be installed as either aftermarket products on trucks and trailers, mirroring early adopter U.S. fleets that have been retrofitting their vehicles, or as factory-installed, pre-market products. Aftermarket installation can increase upfitting costs related to relocating or replacing existing common truck parts and accessories, which truck manufacturers currently install without consideration for side guard placement.

Original equipment manufacturers, which produce the chassis and cab, appear to be unlikely candidates for factory installing side guards in the U.S. Final manufacturers, or "body builders," perform extensive modifications to the chassis when they install cargo bodies on the chassis.[41] Therefore, these final manufacturers as well as trailer manufacturers can—and a number already do[42]—install side guards pre-market. If this were the predominant way that side guards became implemented in the U.S., the coordinated pre-market placement of truck parts and accessories with side guards could be expected to avoid the costs of part repositioning or adaptation. This scenario is included in Table 2.

Conclusion

Referencing the Federal Motor Carrier Safety Regulations Part 393, "Parts and Accessories Necessary for Safe Operation" and considering truck parts often present on the ten most common truck types, Volpe has assessed the potential for added-cost interactions between these truck parts and either pre-market or aftermarket side guards. As summarized in Table 24, if truck and trailer manufacturers installed side guards pre-market, the coordinated placement of truck parts and accessories with side guards could potentially avoid the costs of part repositioning and adaptation. Aftermarket side guards introduce more uncertainty about added cost due to their varying compatibility with typical parts and accessories. Truck components with such uncertainty have been categorized in this analysis as "synergistic or adaptation," and they include underbody fuel tanks, aerodynamic skirts, and ladders. Some components can result in cost savings for side guard fitment when they already cover the same underbody space as the side guard. These parts include wheels (including lift axles), underbody toolboxes, air reservoirs, stored spare tires, underbody fuel tanks, aerodynamic truck skirts, and ladders. Truck parts that may require adaptation or repositioning for compatibility with side guards include fire extinguishers, which may be stored in the cab, and side marker lamps. No truck parts were categorized as incompatible with side guards, meaning that no truck parts would conflict with the installation of truck side guards in a way that adapting or re-positioning those parts could not solve.

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[41] Interviews with John Stuart (Mack Trucks) and Skip Yeakel (Volvo North America), August 31, 2017; and with Paul Jarossy and Corby Stover, Morgan Corporation, September 25, 2017.

[42] For example, Morgan Corporation (https://www.morgancorp.com/news/morgan-offers-customers-improved-step-toolbox-and-side-guard-protection-options) and McNeilus.

Inspection Considerations

In addition to side guards' potential interaction with required and common truck components, Volpe assessed side guards' potential interaction with roadside commercial motor vehicle safety inspections. Vehicle inspections are categorized into eight levels, only some of which may be impacted by side guards. Levels 1 through 3 are considered the most common and are detailed below (CVSA, 2017):

- **Level 1 – North American Standard Inspection**: This inspection is the most comprehensive inspection level. This inspection includes mainly three components: (1) inspection of driver and credentials, involving the driver's license, Medical Examiner's Certificate and Skill Performance Evaluation Certificate (if applicable), alcohol and drugs, driver's record of duty status (as required), hours of service, seat belt, vehicle inspection report(s); (2) a vehicle walk-around inspection; and (3) an inspection of some underbody truck components, which requires the inspector to physically go underneath the commercial vehicle to examine and measure the brakes, check for cracks in the frame, and observe other components.

- **Level 2 – Walk-Around Driver/Vehicle Inspection**: This inspection includes the same inspection activities as Level 1, but does not require the inspector to climb underneath the vehicle.

- **Level 3 – Driver/Credential Inspection**: This inspection must include, where required and/or applicable, the examination of the driver's license, Medical Examiner's Certificate and Skill Performance Evaluation (SPE) Certificate, driver's record of duty status, hours of service, seat belt, and vehicle inspection report(s).

Limiting the ability of inspectors to perform Level 1 inspections on the entire fleet due to side guard implementation could be a potential concern. However, several existing inspection practices and precedents would still permit proper inspection of trucks that have side guards.

Trucks and trailers with low-boy, car carrier, or other low ground clearance cargo body types, as well as motor coaches, can receive Level 1 inspections at inspection facilities with pits or ramps. At other inspection locations, these vehicle types typically receive Level 2 inspections. These vehicle types commonly present ground clearances from 8 to 10 inches, and some present ground clearances as low as 6 inches due to their construction.[43] FMCSA permits these vehicle types to receive a Level 2 inspection in most cases when inspection facilities do not have pits or ramps (Yessen, 2017).

Trailers with aerodynamic side skirts also have a low ground clearance on the sides of the trailers but do not restrict access to the underbody in the front or rear. Most aerodynamic side skirts are not easily removable or foldable for inspection and are commonly installed with 4 to 12 inch ground clearance.[44] When side skirts are installed, an inspector cannot easily go underneath the

[43] Interview with Rick Farris, Trail King Industries, September 26, 2017.
[44] For example: https://www.windyne.com/ and: https://www.wabashcomposites.com/docs/default-source/ctp-warranty-pdfs-and-files/duraplate-aeroskirt-data-sheet.pdf?sfvrsn=2

trailer from the side. However, the inspector can still slide beneath the vehicle on a “creeper”, or a low, rolling cart, from the rear to conduct a Level 1 inspection.

By comparison, a number of U.S. jurisdictions and fleets have implemented a 13.8-inch maximum ground clearance for side guards, which may permit an inspector to enter from the side. Non-removable side guard designs that are installed lower would still permit access from the rear, similar to aerodynamic side skirts.

In the U.S., relatively few vehicles are equipped with side guards for the purpose of protecting VRUs, therefore direct knowledge about the experience of inspecting them is limited.[45] However, common side guard designs include hinges or pins to permit removal or opening of the device for access underneath the vehicle from the side. Such designs are unlikely to interfere with Level 1 roadside safety inspections. For side guard designs that are non-removable and are permanently installed, the inspection experience with aerodynamic side skirts, which have been widely deployed and are geometrically similar to side guards, provides several solutions.

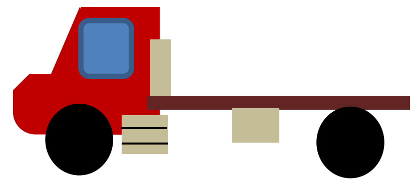
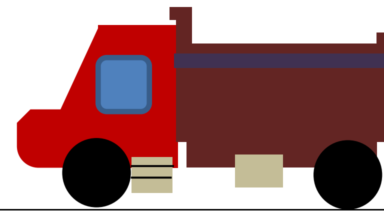
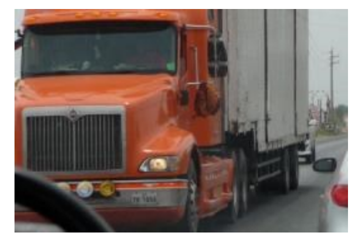
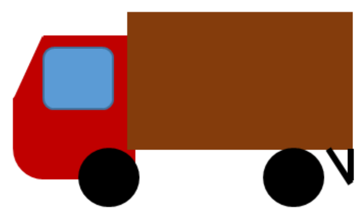
Conclusion

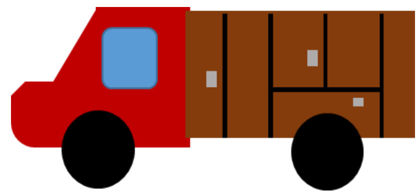
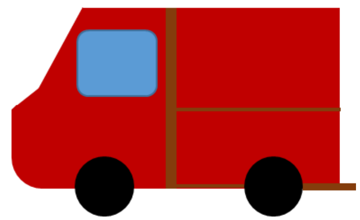
The interview with FMCSA’s Field Operations Office Acting Director identified side guards’ potential interaction with roadside commercial motor vehicle safety inspections. Level 1 is the most comprehensive inspection and includes the inspector physically getting underneath the commercial vehicle to see and measure the brakes, check for cracks in the frame, and observe other components. Level 1 inspections can be performed on a national fleet installed with side guards, using adaptations, some of which are already implemented in the field:

- Partial Level 1 inspections that check brakes without the inspector going underneath the vehicle
- Inspection facilities with pits and ramps for Level 1 inspections
- Removable or hinged side guards that permit regular access
- Inspectors perform Level 1 inspections with a “creeper” or low, rolling cart from the truck rear
- Anticipated transition to roadside wireless inspections in the future

[45] Volpe estimates that between 1,500 and 2,000 U.S. trucks with side guards are in service as of August, 2017.

Table 23: Top ten common truck types, common elements, and representative images.

Truck Type	% of Fleet	Description of Truck	Common Elements	Diagram	Image
Flatbed, Stake, or Platform (Single-Unit)	17%	A flatbed, single-unit truck that has a cargo body type without sides or a roof, with or without readily removable stakes which may be tied together with chains, slats or panels. This includes "stake body" trucks.	Underbody toolbox, flat bed extending backwards, stakes, entrance steps, fuel tanks.		 Source: City of Seattle
Dump (Single-Unit)	13%	Has a cargo body type that tilts to discharge its load by gravity. This category can include "belly dump" trailers that discharge a load through the lifting of the bed, or those with body type of "grain, chips or gravel" that discharge the load through a gate in the bottom without tilting.	Entrance steps, underbody toolbox, underbody fuel tanks.		 Source: Alexander Epstein, Volpe
Van, basic enclosed (Tractor-Trailer)	11%	Has a cargo body type with an enclosed body integral to the frame of the motor vehicle or trailer. This category may apply to both enclosed trailers and cargo vans. This is the most common cargo body type for trailers.	Underbody tool box, stored spare tire, landing gear, rear underride guard.		 Source: Alexander Epstein, Volpe
Van, basic enclosed (Single-Unit)	10%	Has a cargo body type having an enclosed body integral to the frame of the motor vehicle or trailer. It applies to both enclosed trailers and cargo vans. As a single-unit truck the cargo carrying capability of the vehicle is integral to the body of the vehicle.	Rear guard. Less common but still found on some vehicles: entrance steps, underbody tool box.		 Source: Alexander Epstein, Volpe

Truck Type	% of Fleet	Description of Truck	Common Elements	Diagram	Image
Service, utility or other (Single-Unit)	9%	A vehicle designed for usage by utility or other service companies. A single-unit vehicle, the back of the truck is specially designed for the storage and transportation of tools, composed of separate compartments. There is a high level of variation in design type for these vehicles.	Entrance step, enclosed compartments. Less common but still found on some vehicles: raised arm for utility line work, electrical line storage.		 Source: City of New York
Van, step, walk-in or multistep	7%	A medium-duty truck designed for usage that includes multiple stops or deliveries. The height of a walk-in or multistep van is typically higher than that of a regular van.	A sliding or open door, extremely low clearance, and a step-in that is incorporated inside the vehicle body.		 Source: City of New York
Flatbed, Stake, or Platform (Tractor-Trailer)	4%	Has a cargo body type without sides or a roof, with or without readily removable stakes which may be tied together with chains, slats or panels. This would include "stake body" trucks. As a tractor-trailer truck these have a separate trailer that is not integral to the operation of the vehicle.	Underbody fuel tanks, underbody tool box, spare tire, extended flatbed. Less common: rear underrun guards, entrance step, landing gear.		 Source: Alexander Epstein, Volpe

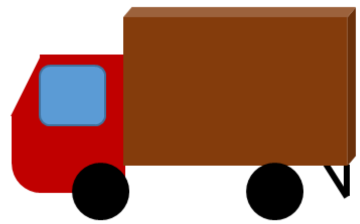
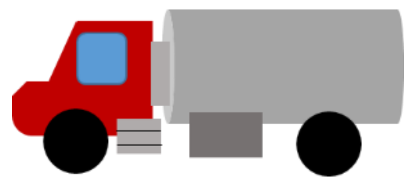
Truck Type	% of Fleet	Description of Truck	Common Elements	Diagram	Image
Van, open top (Single-Unit)	3%	Has a cargo body type having a mostly enclosed body integral to the frame of the motor vehicle or trailer. A variation of the enclosed van, this body type has all sides covered but the top open. This allows for cargo that may be higher than the height of the truck.	Rear guard. Less common but still found on some vehicles: entrance steps, underbody tool box.		 Source: Alexander Epstein, Volpe
Tank, liquids or gases (Single-Unit)	3%	Has a cargo body type with an enclosed tank that contains liquids or gases; this body is integral to the frame of the motor vehicle or trailer. Due to the wide variety of liquids that can be transported, a high level of variation exists, including insulated, non-insulated, pressurized, non-pressurized, single-load design, multiple loads with internal divisions in the tank, and more.	Underbody fuel tank and underbody tool box. Less common but still found on some vehicles: entrance steps, lift axle, rear underride guard.		 Source: Alexander Epstein, Volpe
Dump (Tractor-Trailer)	2%	Has a cargo body type that tilts to discharge its load by gravity. Unlike the single-unit dump truck, this vehicle has its dumping functionality on an attached trailer. Live-bottom trailers (bottom image at right) have a similar cargo body but use a conveyor belt instead of gravity to discharge the load.	Underbody fuel tank, underbody tool box, rear underride guard. Less common but still found on some vehicles: entrance steps.		  Source: Alexander Epstein, Volpe
Source for "Description of Truck" and "Common Elements": (United States Census Bureau, 2017); (NCHRP, 2017); (FMCSA, Vehicle Configuration and Cargo Body Types, 2017) Source for "Diagram": United States Department of Transportation, Volpe Center					

Table 24: Truck parts and their associated conflicts, compatibility, and costs

Truck Part	Side Guard Interaction (Yes/No)	Side Guard Interaction Details	Compatibility (Synergistic, Re-position, Adaptation, Incompatible)	Compatibility Details	Likely Fleet(s) Impacted	Potential Added Costs (Yes/No)
Fuel Systems						
Underbody fuel tanks -liquid fuel tank -compressed natural gas -liquefied petroleum gas	Yes, see Figure 36	The position of fuel tanks can vary, but these components tend to be located below the cab or along the body of the vehicle, which is where the fuel tank may interact with the side guard.	Synergistic or Adaptation	Fuel tanks can be placed along the bottom edge of the body with an adjacent side guard attachment or the side guard can be continuous, covering the fuel tank.	All	Pre-market: No Aftermarket: Yes
Cargo Securement						
Steel strapping	No					
Chain	No					
Webbing	No					
Wire rope	No					
Cordage	No					
Bolster	No, see Figure 37					
Winch	No					
Bunks	No, see Figure 3					
Stakes	No, see Figure 3					
Frames, Cab, and Body Components						
Wheels	Yes, see Figure 39	Wheels may be located adjacent to side guards.	Synergistic	Similar to side guards, tires may also act as a barrier between VRUs and the exposed space beneath the truck body.	All	Pre-market: No Aftermarket: No
Frame or chassis	Yes, see Figure 40	The chassis or the truck body frame is the truck part where many side guards are fastened.	Synergistic	The chassis is often used synergistically for side guard attachment.	All	Pre-market: No Aftermarket: No
Cab and body components	No					
Suspension system: axles	No					
Suspension system: springs	No					
Suspension system: torsion bar	No					

Suspension system: air pressure regulator	No					
Suspension system: exhaust controls	No					
Steering wheel systems	No					
Additional Parts or Accessories						
Underbody toolbox	Yes, see Figure 7	The position of the underbody toolbox can vary, but they are often located along the underbody of the body of the vehicle.	Synergistic	Underbody toolboxes can be placed along the bottom edge of the body with an adjacent side guard attachment.	Flatbed, Stake, or Platform (Single-Unit); Van, basic enclosed (Tractor-Trailer); Van, basic enclosed (Single-Unit); Tank, liquids or gases (Single-Unit); Dump (Tractor-Trailer)	Pre-market: No Aftermarket: No
Fire Extinguisher	Yes, see Figure 8	Power units of trucks are required to have fire extinguishers. Fire extinguishers are sometimes stored along the underbody of the truck.	Adaptation	Fire extinguishers can be placed inside of the truck cab or they can be placed behind the side guard, but still accessible; this is accomplished by adapting the side guard to allow access to the fire extinguisher.	All	Pre-market: No Aftermarket: Yes
Exhaust System	No					
Side marker lamps	No, see Figure 9					
Aerodynamic truck skirt	Yes, see Figure 45	Aerodynamic truck skirts are attached along the underbody of the truck, where a side guard is attached.	Synergistic or Adaptation	Aerodynamic truck skirts can be used synergistically to have the same effect as a side guard or they can be adapted to have a safety impact like side guards.	Flatbed, Stake, or Platform (Single-Unit); Dump (Single-Unit); Van, basic enclosed (Tractor-Trailer); Van, basic enclosed (Single-Unit); Dump (Tractor-Trailer); Flatbed, Stake, or Platform (Tractor-Trailer); Van, open top (Single-Unit); Tank, liquids or gases (Single-Unit)	Pre-market: No Aftermarket: Yes
Air reservoir	No					
Load platform	No					

Landing Gear	No, see Figure 5					
Stabilizer Leg	Yes, see Figure 6	Stabilizer leg, used to brace or balance the truck's body (often with a crane or an aerial device), sometimes have components that extend past the bottom of the truck's body.	Synergistic or Adaptation	Adaptations to side guards, such as a longitudinal gap, may be needed to allow for the use of the stabilizer leg. On new vehicles, the placement of stabilizer legs may be appropriate at the rear of the truck.	Flatbed, Stake, or Platform (Tractor-Trailer)	Pre-market: No Aftermarket: No
Ladder	Yes, see Figure 11	Ladders may be positioned along the body of the vehicle.	Synergistic or Adaptation	Ladders can be designed to be a barrier between VRUs and the area below the body of the truck.	Flatbed, Stake, or Platform (Single-Unit); Dump (Single-Unit); Flatbed, Stake, or Platform (Tractor-Trailer); Tank, liquids or gases (Single-Unit); Tank, liquids or gases (Single-Unit); Dump (Tractor-Trailer)	Pre-market: No Aftermarket: Yes
Stored spare tire	Yes, see Figure 12	The position of the stored spare tire can vary, but they tend to be along the body of the vehicle.	Synergistic	Stored spare tires can be designed to be a barrier between VRUs and the area below the body of the truck; alternatively, the side guard could be removable to allow access when the spare tire is needed.	Van, basic enclosed (Tractor-Trailer); Flatbed, Stake, or Platform (Tractor-Trailer)	Pre-market: No Aftermarket: No
Tires	Yes, see Figure 4	Tires may be located adjacent to side guards.	Synergistic	Similar to side guards, tires may also act as a barrier between VRUs and the exposed space beneath the truck body.	All	Pre-market: No Aftermarket: No
Lift axle	Yes, Figure 13	Lift axles are used to carry additional weight and can be raised off the ground when they are not needed. Lift axels are installed ahead of or behind the driving tandem axles.	Synergistic	Lift axles may also act similarly to side guards, as a barrier between VRUs and the exposed space beneath the truck body.	Flatbed, Stake, or Platform (Single-Unit); Dump (Single-Unit); Van, basic enclosed (Tractor-Trailer); Flatbed, Stake, or Platform (Tractor-Trailer); Tank, liquids or gases (Single-Unit); Dump (Tractor-Trailer)	Pre-market: No Aftermarket: No
Sleeper berths	No					
Heaters	No					

Windshield wiping and washing systems	No					
Windshield defrosting and defogging systems	No					
Rear-vision mirrors	No					
Horn	No					
Speedometer	No					
Exhaust systems	No					
Floors	No					
Rear impact guards and rear end protection	No					
Warning flags on projecting loads	No					
Television receivers	No					
Buses, driveshaft protection	No					
Buses, standee line or bar	No					
Buses, aisle seats prohibited	No					
Seats, seat belt assemblies, and seat belt assembly anchorages	No					
Interior noise levels in power units	No					
Sources: (FMCSA, FMCSA Regulations Part 393, 2017); (FTA, Freight Transportation Association, 2017); (FMCSA, Driver's Handbook on Cargo Securement, 2017)						

Figure 36: Truck with underbody fuel tank. (Source: Volpe)

Figure 37: Truck trailer with bolsters (vertical posts). (Source: FMCSA)

Figure 38: Truck trailer with bunks (horizontal structure) and stakes (vertical structures). (Source: Taina Sohlman, 123rf.com)

Figure 39: Truck with wheels and tires. (Source: Rob Wilson, 123rf.com)

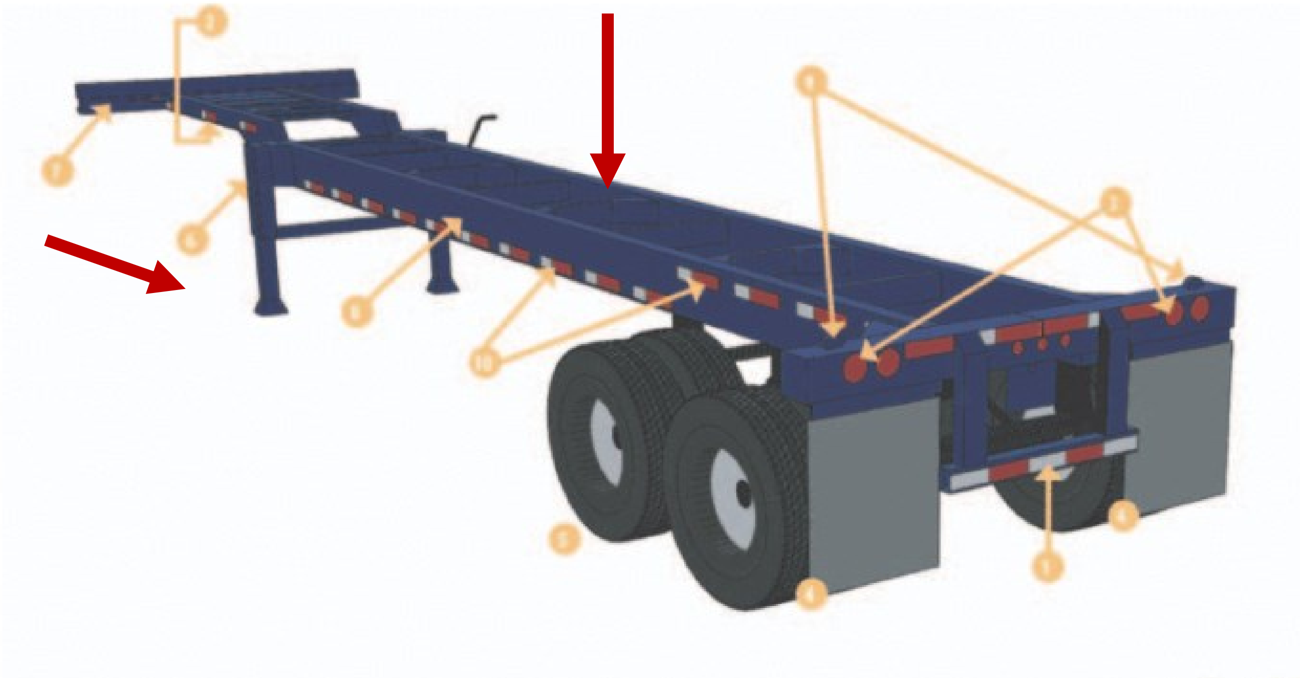


Figure 40: Diagram of truck trailer chassis and truck landing gear. (Source: NCHRP)

Figure 41: Truck with a crane and stabilizer leg. (Source: Volpe)

Figure 42: A truck with an underbody toolbox. (Source: FMCSA)

Figure 43: Truck with fire extinguisher behind side guard (Source: Nuttapong Wannavijid, 123rf.com)

Figure 44: Truck with side lamps. (Source: Sergio Shumoff, 123rf.com)

Figure 45: Truck with aerodynamic skirt. (Source: Vitpho, 123rf.com)

Figure 46: Truck with ladder. (Source: Сергей Сергеев, 123rf.com)

Figure 47: Truck with a stored spare tire. (Source: Volpe)

Figure 48: Truck with a lift axle. (Source: Volpe)

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APPENDIX D: ADDITIONAL BENEFIT-COST ASSUMPTIONS AND PROJECTIONS

Structural and Data Limitations

The following is a discussion of the structural and data limitations of the analysis. Structural limitations are those limitations in the methodology that fail to account for real-world features or dynamics.

The trucking fleet model assumes no dynamic relationship between aerodynamic benefits (fuel efficiency) and VMT. However, in the real world, as the cost of driving per mile is reduced from reduced fuel use, the price of driving is expected to decrease. In a competitive market, the reduction in cost per mile for carriers would lead to an outward shift in the supply curve—suppliers competing for consumers would offer lower prices and this shift in the supply curve would induce more demand in truck VMT. Estimates of the rebound effect on fuel efficiency range from 2 to 10 percent. A conservative estimate would then reduce the fuel savings benefits by 10 percent, though this is not explicitly incorporated into the results of the analysis.

The fleet trucking model does not incorporate scrappage of trucks. Some portion of trucks that are equipped with side guards will be scrapped each year. This gap in the analysis is partially offset by the fact that newer trucks are driven more than older trucks, and the model assumes that trucks of all model years drive at the same levels.

Data limitations are those gaps that were identified but were not possible to include because the data were not available. Many of these limitations were related to the fact that relevant information is not available by specific cargo body type. In particular, the model does not use unique gallons per mile (GPM) for SUT cargo body types (such as box or dump trucks) and for CT trailer types (such as box, or low boy).

Finally, the light-weight side guards considered in this report may produce other benefits not accounted for in the methodology, particularly safety benefits that accrue from reduced crash costs of crashes not involving vulnerable road users (VRUs):

- Crash cost reduction for truck crashes involving motorized two-wheelers, i.e., motorcycles, mopeds, etc.
- Crash cost reduction related to improved wind stability for side guard-equipped trucks.
- Crash cost reductions from reduced road spray from side guard-equipped trucks and trailers.

- Improved automotive collision avoidance sensor detection of trucks/trailer[46]

No evidence at this time suggests that side guards are likely to increase the occurrence or severity of accidents in the above list. Therefore, the above list can be seen as evidence that the net benefits computed in this report are likely an underestimate.

Crash Cost

Crash costs are determined by the severity of the injury. There are two primary injury classification taxonomies used in the U.S.:

1. **The Maximum Abbreviated Injury Scale (MAIS)** defines 6 categories of injury, which are defined by the type, location on the body of the injury, and severity of the injury. For benefit-cost analysis, USDOT's recommended monetary values are based on these MAIS levels.

2. **The KABCO injury scale,** named for the letter categories used in its classification system, places injuries in the following severity levels: fatality (K), disabling injury (A), non-incapacitating injury (B), possible injury (C), and no injury (O). This scale is typically used by emergency responders to assess crash outcomes, as it is more readily assessed on-scene than the more fine-grained MAIS levels.

Although the KABCO scale is in widespread use, on-scene assessment does not always correctly predict the actual severity of injuries on the more medically precise MAIS scale. Based on prior research that tracked the correspondence between KABCO and MAIS levels for a sample of crashes, it is possible to convert injury data from KABCO to MAIS using conversion factors. For instance, a KABCO injury rating of O, "no injury," has a roughly 7 percent chance of actually being an MAIS level one injury, and a roughly 2 percent chance of being an MAIS level two injury (U.S. DOT, 2017). The U.S. Department of Transportation (U.S. DOT) provides a conversion between KABCO-rated injuries and the probability distribution of MAIS for more accurate costing of injury.

This report uses the KABCO scale because it is consistent with the reporting of injury severity in the available crash data (GES, FARS, and TIFA), but converts the KABCO values to their appropriate MAIS figures for consistency with USDOT's recommended monetary values.[47]

The cost of each bodily injury category is represented by the fraction of the cost of that injury crash to the cost of a fatal crash. While no value can be put on a human life, in order to conduct a

[46] For example, if side guards had been deployed on the tractor trailer involved in the 2016 fatal Florida Tesla crash, the truck may have been more easily detected by the vehicle's forward sensors: https://www.ntsb.gov/news/press-releases/Pages/PR20170912.aspx

[47] This report assumes that there is no cost of damage to the truck in VRU and truck-involved crashes, and only considers the cost of injury to the VRU.

benefit-cost analysis that accounts for prevented fatalities, some monetization of these avoided fatalities must be provided.

Economists resolve this valuation issue by using a measure called the Value of Statistical Life (VSL). VSL is essentially a measure of the amount that a group of individuals would be willing to pay to reduce their risk of dying in a crash. U.S. DOT sets this value at $9.6 million. Table 25 provides the schedule of KABCO severity categories, the fraction of VSL, and the unit value in U.S. dollars (U.S. DOT, 2017).

Table 25: KABCO Schedule of Injury Severity and Cost (in 2016 dollars) (U.S. DOT, 2017)

KABCO Level	KABCO Severity Description	Fraction of VSL	Unit value ($2016)
O	No Injury	0.0003	$ …………..3,200.00
C	Possible injury	0.007	$ 63,900.00
B	Non-Incapacitating Injury - Minor Injury	0.013	$ 125,000.00
A	Incapacitating Injury - Serious Injury	0.048	$ 459,100.00
K	Not Survivable	1	$ 9,600,000.00
U	Injured, Severity Unknown	0.018	$ 174,000.00

Effectiveness of Side Guard Crash Reduction

The final assumption of safety benefits is how effective side guards are at reducing crash costs. The *Truck Side Guards to Reduce Vulnerable Road User Fatalities* report in this series reviewed various studies that reported on the effectiveness of side guards to reduce the proportion of fatalities and serious crashes as a share of total injury crash types. Crash costs can be reduced through two means: Crash costs can be avoided entirely because the potential crash entities do not make contact, or they can be mitigated through a reduction in the severity of the impact. Side guards do not provide crash avoidance but rather provide crash mitigation by preventing VRUs from entering under the truck and being struck by the underside of the vehicle or run over by the vehicle.

Therefore, as with the studies reviewed in *Truck Side Guards to Reduce Vulnerable Road User Fatalities* the crash cost effectiveness in this report is mitigation, or reducing the crash severity from more severe to less severe.

Side guards are assumed to be able to mitigate some injuries and not others. KABCO crashes rated as level O (No Injury) are considered not mitigatable by side guards because there is essentially no injury. For all other injury severities, the analysis assumes that the injury severity is reduced to a fixed minimum injury severity. A study of injury crashes in the UK converted crashes rated as slight in the UK scale (with limited exceptions) as level one crashes in the MAIS scale (Morris, Welsh, Barnes, & Chambers-Smith, 2006). The dollar value of MAIS level one is 0.003 percent of VSL, or $28,800.00 (distinct from KABCO crash type O), which was then treated as the minimum cost of an injury crash with a VRU. The safety benefit accrued by side guards then is the difference in value between the MAIS level one crash cost of $28,000 and the KABCO value of the crash cost.

Table 26 provides the range of effectiveness of side guards at mitigating crash severity. These effectiveness figures are the reduction in fatal or serious injuries as proportion of all injury crashes.

Table 26: Side Guard Effectiveness from Four UK Studies Comparing National Data 1980-2008

Crash Type Mitigated by Side Guards	Range of Effectiveness in Reducing Given Crash Type to MAIS Minor Crash
Bicyclist fatalities	55-75%
Bicyclist serious injuries	3-17%
Pedestrian fatalities	20-27%
Pedestrian serious injuries	<1%

Liability

Crash cost values provided by FHWA are the total social cost of crashes and include medical costs, costs of repair or loss of truck, loss of revenue in the case of commercial trucks, among others. Consistent with benefit-cost analysis, the crash cost reductions in this report are framed as total social costs of crashes. They represent the total cost of a fatality or bodily injury to society as a whole and are not just the costs incurred by truck operators. However, a rough value of the estimate of safety benefits that accrue for truck operators caused by the deployment of side guards as a safety countermeasure for crashes involving VRUs can be constructed.

Assuming for the purposes of simplicity that insurance premiums perfectly capture the expected value of crash costs for heavy-duty vehicles and VRUs in addition to expected crash costs from non-VRU- and truck-involved crashes, then in principle a reduction in the risk of high crash cost from deploying crash-cost-mitigating side guards would reduce insurance premiums. If insurers recognized the side guard's potential safety mitigation to reduce the costs of crashes with VRUs, then trucks equipped with side guards would, in principle, be charged a lower premium.

A report by the U.S. DOT Volpe Center reviewed the current federal insurance requirements for commercial motor vehicles, which require motor carriers to carry a minimum level of insurance (Hymel, Lee, Pearlman, Pritchard, & Rainville, 2012). The report provides the average insurance premium per truck in 2009 of $6,449 ($2016). Using this value, the insurance premium savings for side guard-equipped vehicles can be constructed.

As the *Truck Side Guards to Reduce Vulnerable Road User Fatalities* report states, "in 2015, over 4,000 people including 410 VRUs were killed and more than 111,000 people were injured in crashes involving large trucks (United States Department of Transportation, 2017)." Therefore, the share of VRU-involved fatalities in 2015 is roughly 10 percent. The risk premium value of side guard deployment would be 10 percent of the insurance premium multiplied by the effectiveness of the side guard at reducing crash costs.[48] The annual cost savings for side guard-equipped trucks would be roughly $665.

This figure cannot be incorporated into a benefit-cost analysis because a reduction in insurance premiums would be considered a transfer.[49] However, it is helpful in considering the business case for a truck owner or operator. This rough estimate of cost savings would cover the cost of installing side guards on a truck in no more than four years.

Domestic supplier and cost data

Table 27: Example North American side guard aftermarket suppliers identified by market research

Company	Headquarters	Design type
Air Flow Deflector	Quebec	Panel
Laydon/WABCO*	Ontario	Panel/aero skirt
Transtex	Ontario	Panel/aero skirt
Walker Blocker	Washington	Panel
Shu-Pak Corporation	Ontario	Rail-style
Takler USA	New Jersey	Rail-style
Duragard	New Jersey	Rail-style
McNeilus	Minnesota	Rail-style
American Road Machinery Company	Ohio	Rail-style

As early data points shown in Table 28, the City of Boston's 2013-2014 pilot installations cost $1,200-$1,800 per vehicle; New York City (NYC) pilot installations cost about $2,000-3,000 per vehicle, including approximately $1,500 in materials; and Portland's installations, which were among the first in the U.S. and involved a combination of custom panels and toolboxes, cost an average of $2,500 per vehicle. The University of Washington paid ~$3,000 per truck in 2015.

Table 28: Example North American side guard retrofit reported costs

U.S. city	Reported approximate cost per vehicle	Side guard type
Boston (Mayor's Office, 2015)	$1,200-1,800	Steel rail; fiberglass panel
Cambridge (Witts, 2016)	$1,800	Steel and aluminum rails
New York City (Mayor's Office, 2015)	$3,000 / $2,000	Fiberglass panel; steel rail; aluminum rail
Portland (DePiero & Leader, 2012)	$1,000 small trucks - $4,000 trailers; $200-$250 per toolbox	Metal panel and toolbox

New York City's Vision Zero Side Guard Incentive Program was established in 2016 and has awarded grants up to $2,000 per truck for 88 trucks to date, reflecting an upper bound for

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48 Assume the risk premium does not consider the risk of non-fatal bodily injury for simplicity.

49 In BCA when the result of an action is a transfer of goods from one part to another with no creation or loss of real value it is called a transfer, and for the purposes of BCA does not impact the net benefits of the action. No transfers are proposed as part of scenarios considered in the report.

reasonable cost (NYC Business Integrity Commission, NYC Department of Transportation, and NYC Department of Citywide Administrative Services, 2016).

Another indication that, at larger volume, side guard costs in the U.S. could approximate the costs illustrated in Table 11 is provided by a U.S. Department of Commerce National Institute of Standards and Technology (NIST) Manufacturing Extension Partnership (MEP) Supplier Scouting analysis completed in May-June 2016. On request from Volpe and the San Francisco Municipal Transportation Agency, the nationwide network of MEP Centers, with coordination from NIST MEP, performed Supplier Scouting for domestic manufacturing capabilities and capacity for the production of side guards. The Opportunity Synopsis, essentially a Request for Information, provided for a wide range of trucks and trailers over 10,000 pounds found in the San Francisco City Fleet and set a maximum purchase price of $1,000. The results of this Supplier Scouting analysis were as follows:

- MEP Supplier Scouting identified **21 U.S. manufacturers as potential matches**.
- **19 of the manufacturers identified were confirmed by NIST MEP to currently have the capability, capacity, and interest** in producing the items being sought. These domestic manufacturers are located in California, Iowa, Kentucky, Louisiana, and West Virginia.
- Additionally, two manufacturers were separately identified by NIST MEP that appear to currently produce a similar item and currently have capability and capacity to produce the side guard items.
- The 19 U.S. manufacturers identified as potential matches indicated that they are interested in pursuing the business opportunity to produce the needed items for supply to the appropriate projects.

As many truck manufacturers are multinational, companies such as Daimler or Volvo already outfit trucks with side guards in many world markets outside of North America (see example in Figure 49). As a result, either the original equipment manufacturer (OEM)[50] or final manufacturer ("body builder")[51] paths to side guard inclusion may be more cost-effective than the aftermarket path, given the efficiency of reduced costs of integration with vehicle layouts that may not otherwise be optimized for inclusion of side guards.

[50] For tractors and trailers
[51] For single-unit trucks

Figure 49: Images of Volvo side guard-equipped vehicles currently manufactured for non-U.S. markets (Source: Alf van Beem and Raymondo166, Wikimedia Commons)

Maintenance cost interview data

- The City of Portland, Oregon, reported no increase in maintenance cost on trucks with side guards installed since 2008 (DePiero & Leader, 2012).
- Boston Public Works reported there were no increases in maintenance costs for the 160 trucks that had side guards installed since 2013 (Carter K. , 2016).
- The New York City director of Fleet Services reported that side guards did not result in any additional maintenance costs on the 2,000 trucks equipped since 2015, but noted that side guard inspection would be added to the maintenance checklist. The estimated maintenance check will require 15 minutes of staff time per truck annually (Graczyk, 2016).

Side guards lack any moving parts and, therefore, like other underride installations like tool boxes, are not expected to increase maintenance costs. However, in line with New York City's director of Fleet Services, this report assumes that there will be some ongoing maintenance cost associated with side guards, specifically that it will take a single mechanic 15 minutes to inspect one side guard per year. Given the current evidence of the potential cost of maintenance from these other sources, this estimate may overstate the maintenance costs by 100 percent, since all claim (per the interviews) that there have been no side guard-associated maintenance costs. The report assumes there is no difference in maintenance cost depending on truck type, cargo body type, or side guard type.

The total annual cost of maintenance is computed by multiplying the number of side guard-equipped trucks and annual maintenance cost per truck.

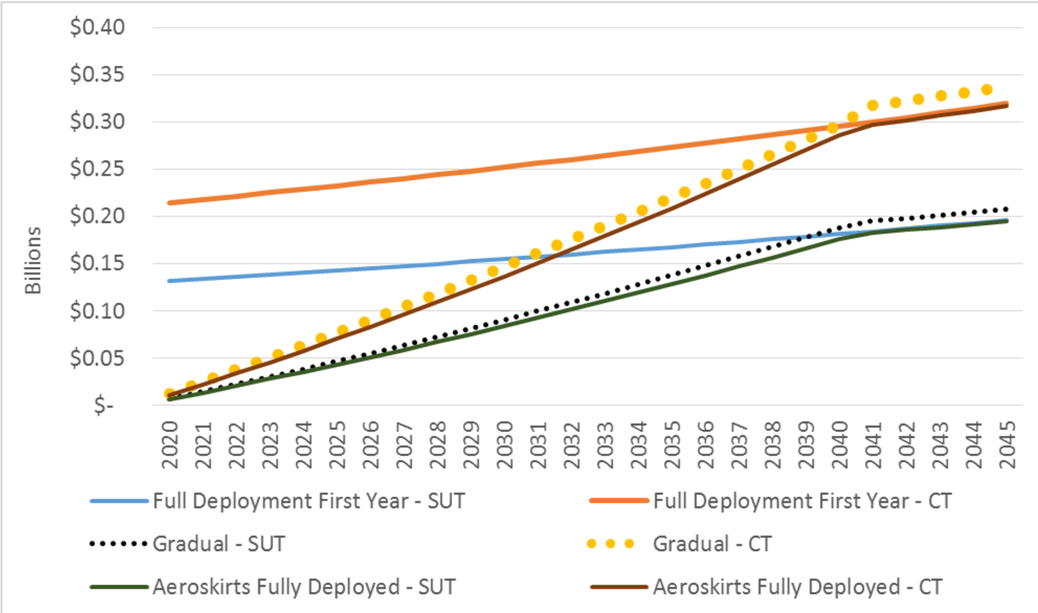

Figure 50: Safety Benefits Each Year by Scenario and Vehicle Type (Low Effectiveness)

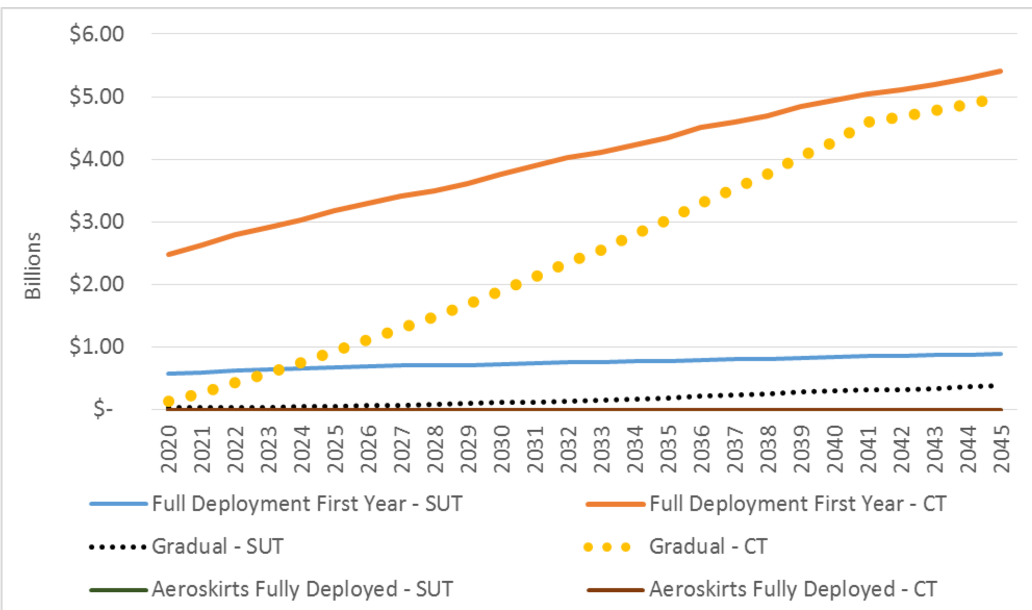

Figure 51: Aerodynamic Benefits Each Year by Scenario and Vehicle Type (Low Effectiveness)

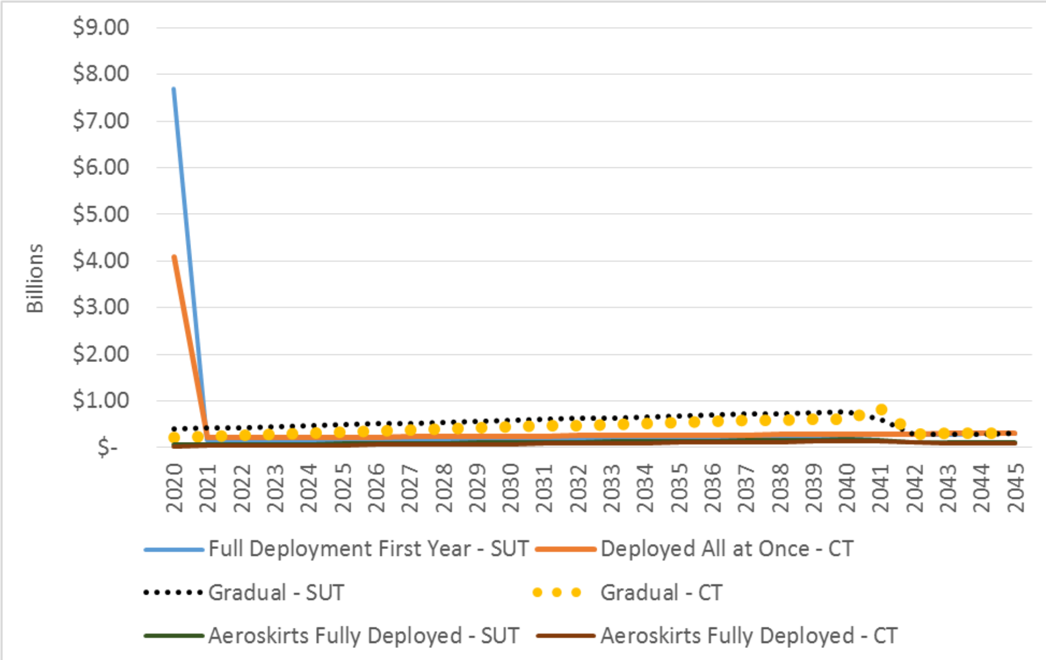

Figure 52: Costs of Side Guards Each Year by Scenario and Vehicle Type (Low Effectiveness)

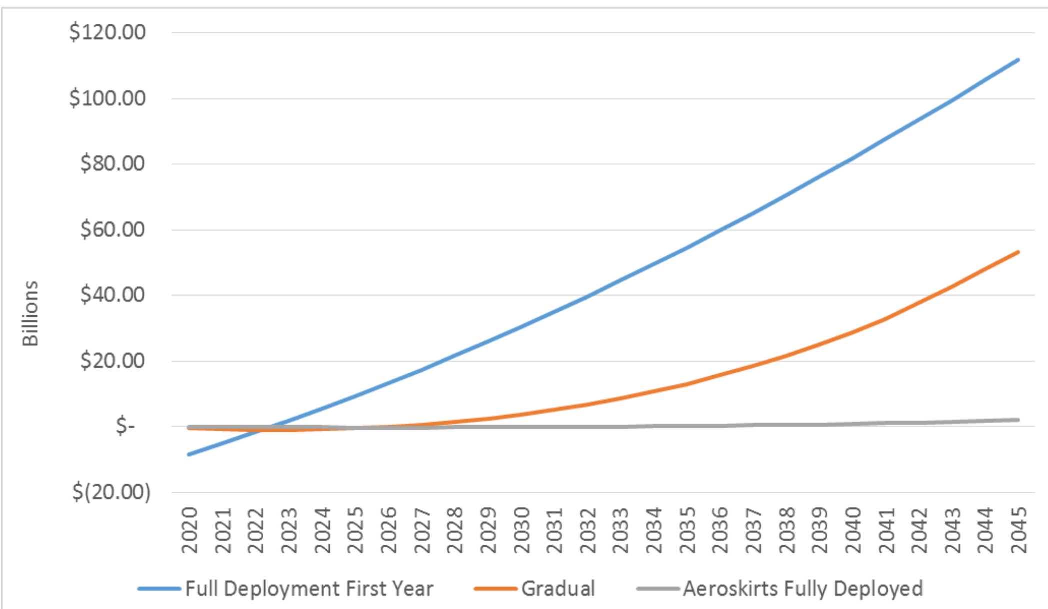

Figure 53: Undiscounted Cumulative Net Benefits of Each Scenario by Year (Low Effectiveness)

Table 31: FMCSA Financial Responsibility Study Total Operating and Insurance Costs Per Truck Per Year (Hymel, Lee, Pearlman, Pritchard, & Rainville, 2012)

Motor Freight Transportation and Warehousing Survey 1994 Trucking, Except Local (SIC 4213)			
Year	Operating Expense per Year per Truck	Insurance Cost per Year per Truck	Share
1990	$70,965	$2,808	4.0%
1991	$70,828	$2,834	4.0%
1992	$75,061	$2,819	3.8%
1993	$78,716	$2,945	3.7%
1994	$87,078	$3,251	3.7%
Transportation Annual Survey 1997 Trucking, Except Local (SIC 4213)			
Year	Operating Expense per Year per Truck	Insurance Cost per Year per Truck	Share
1993	$77,568	$2,932	3.8%
1994	$84,682	$3,214	3.8%
1995	$88,061	$3,286	3.7%
1996	94,390	$3,465	3.7%
1997	$98,570	$3,278	3.3%
ICF/Edwards Study (2003)			
Year	Operating Expense per Year per Truck	Insurance Cost per Year per Truck	Share
2000	$106,482	$4,081	4.1%
2001	$109,672	$6,744	6.0%
Service Annual Survey Trucking (NAICS)			
Year	Operating Expense per Year per Truck	Insurance Cost per Year per Truck	Share
2004	$164,907	$7,226	4.4%
2005	$188,206	$6,688	3.6%
2006	$201,617	$7,207	3.6%
2007	$208,773	$7,242	3.5%
2008	$212,844	$6,778	3.2%
2009	$169,161	$5,789	3.4%
ATRI Update (2011)			
Year	Cost Per Hour	Insurance Premiums	Share
2008	$2.45	$2.22	3.3%
2009	$58.00	$2.15	3.7%
2010	$59.60	$2.06	3.5%
Freight Rate Index			
Year	Cost per Hour	Insurance Premiums	Share
2012	$2.45	$0.12	4.8%

Table 29: ATRI Cost of Trucking Report Operating Expense per VMT (Hooper & Murray, 2017)

Motor Carrier Costs	2008	2009	2010	2011	2012	2013	2014	2015	2016
Vehicle-based									
Fuel Costs	$0.63	$0.41	$0.49	$0.59	$0.64	$0.65	$0.58	$0.40	$0.34
Truck/Trailer Lease or Purchase Payments	$0.21	$0.26	$0.18	$0.19	$0.17	$0.16	$0.22	$0.23	$0.26
Repair & Maintenance	$0.10	$0.12	$0.12	$0.15	$0.14	$0.15	$0.16	$0.16	$0.17
Truck Insurance Premiums	**$0.06**	**$0.05**	**$0.06**	**$0.07**	**$0.06**	**$0.06**	**$0.07**	**$0.07**	**$0.08**
Permits and Licenses	$0.02	$0.03	$0.04	$0.04	$0.02	$0.03	$0.02	$0.02	$0.02
Tires	$0.03	$0.03	$0.04	$0.04	$0.04	$0.04	$0.04	$0.04	$0.04
Tolls	$0.02	$0.02	$0.01	$0.02	$0.02	$0.02	$0.02	$0.02	$0.02
Driver-based									
Driver Wages	$0.44	$0.40	$0.45	$0.46	$0.42	$0.44	$0.46	$0.50	$0.52
Driver Benefits	$0.14	$0.13	$0.16	$0.15	$0.12	$0.13	$0.13	$0.13	$0.16
TOTAL	**$1.65**	**$1.45**	**$1.55**	**$1.71**	**$1.63**	**$1.68**	**$1.70**	**$1.58**	**$1.59**