Lateral Protective Devices (Side Guards) and Vulnerable Road User Safety

Alexander Epstein, PhD

17 November 2022

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Outline

- Context
- Prevalence and precedents
- Safety effectiveness findings
- Technology demonstration
- Retrofit feasibility
- Types, benefits, costs, and aerodynamic factor

Context


CBS Boston

HOME NEWS SPORTS WEATHER TRAFFIC HEALTH EAT. SEE. PLAY VIDEO AUDIO EVENTS

Bicyclist Dies After Being Struck By Truck In Cambridge

June 23, 2016 8:35 PM

Filed Under: Bicycle Crash, Cambridge, Christina Hager, Inman Square, Lana Jones

A woman on a bicycle was struck and killed in Cambridge (Christina Hager/WBZ-TV)


EYEWITNESS NEWS

SECTIONS TRAFFIC WATCH Los Angeles

NEWS

STUDENT FATALLY STRUCK BY CITY SERVICE TRUCK IN HIGHLAND PARK

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EMBED </> MORE NEWS VIDEOS

A 17-year-old student was fatally struck by a city service truck while walking to school in Highland Park Tuesday morning, police said. (KABC)


Bicyclist killed in crash on Commonwealth Ave. in Allston; fifth biker killed in Boston this year

12/06/2012 12:22 PM

E-mail | Print

David L. Ryan/Globe Staff

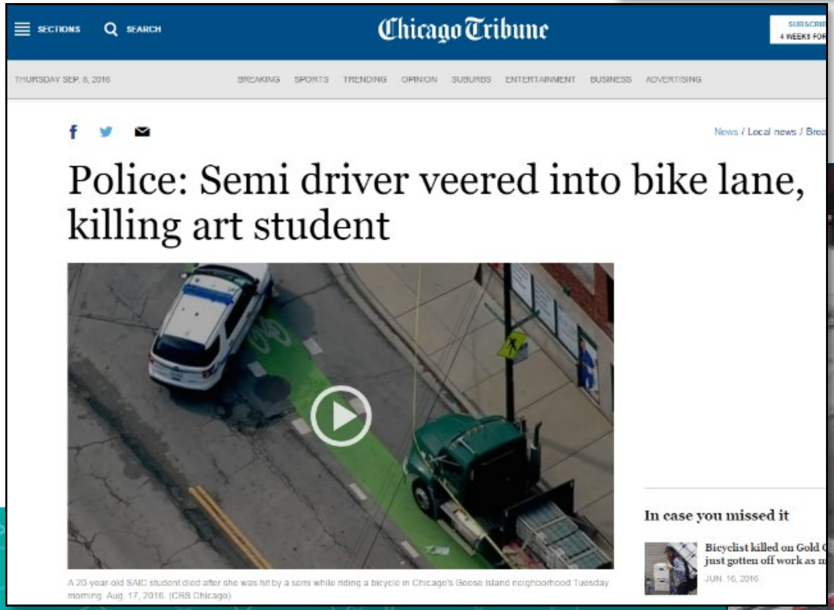

DAILY NEWS | NEW YORK

NYC Crime Bronx Brooklyn Manhattan Queens Education Weather Obituaries

Truck driver arrested after fatally striking cyclist in Brooklyn

BY MEGAN CERULLO THOMAS TRACY GRAHAM RAYMAN

NEW YORK DAILY NEWS Updated: Tuesday, June 7, 2016, 7:05 PM


SECTIONS SEARCH Chicago Tribune

THURSDAY SEP. 8, 2016

BREAKING SPORTS TRENDING OPINION SUBURBS ENTERTAINMENT BUSINESS ADVERTISING

News / Local news

Police: Semi driver veered into bike lane, killing art student

A 20-year-old SAIC student died after she was hit by a semi while riding a bicycle in Chicago's Goose Island neighborhood Tuesday morning. Aug. 17, 2016. (CBS Chicago)

In case you missed it

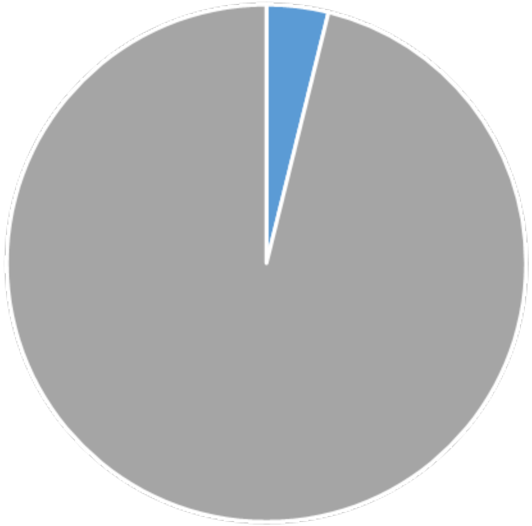
Bicyclist killed on Gold ... just gotten off work as ...

JUN. 16, 2016

Large Truck Safety Context

4%

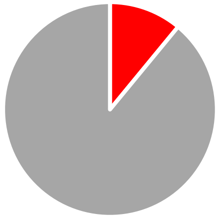
Vehicle Fleet



U.S.

7%

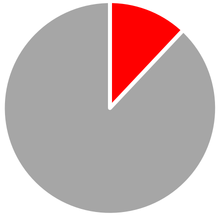
Pedestrian Fatalities



11%

Bicyclist Fatalities

NYC



12%

Pedestrian Fatalities

32%

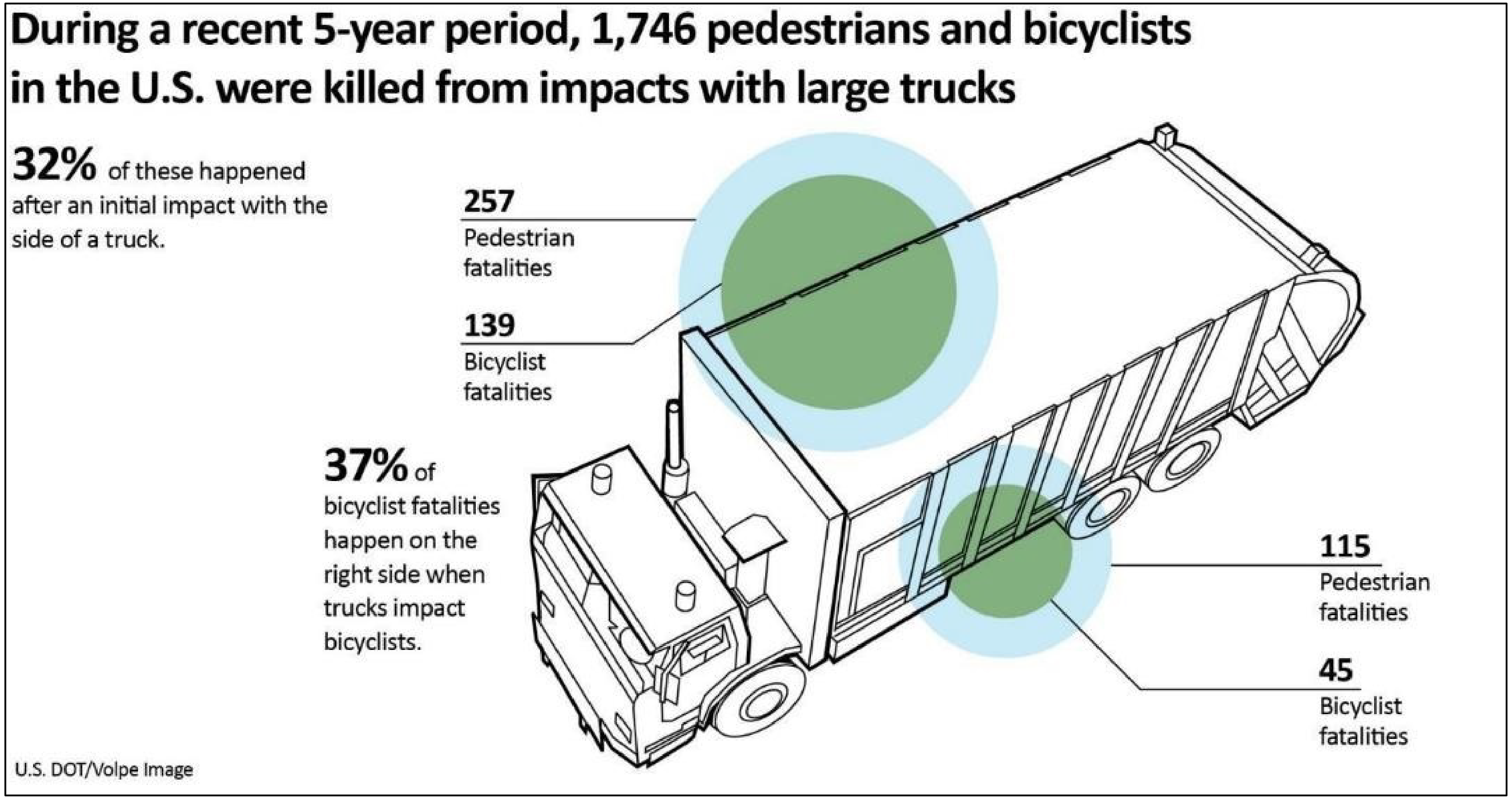
Bicyclist Fatalities

569 truck-VRU fatalities in 2019

https://www.fmcsa.dot.gov/sites/fmcsa.dot.gov/files/2022-01/FMCSA%20Pocket%20Guide%202021.pdf

https://www.nyc.gov/html/dot/downloads/pdf/nyc_ped_safety_study_action_plan.pdf;
https://www.nyc.gov/html/dot/downloads/pdf/bicyclefatalities.pdf

Based on this:



Countermeasure:

Prevalence and precedents of lateral protection devices

*At least **47** countries have adopted LPDs*

1979: Japan adopts *Safety Regulations for Road Vehicles*, mandating pedestrian protecting side guards

1983: Amendment to the UK Constitution mandates side guards on new heavy goods vehicles and some existing semi-trailers

1986: UK *Road Vehicles Construction and Use Regulations* mandates side guards on all large trucks

1988: UN Regulation 73 introduces side guards to the 1958 Agreement on the adoption of uniform technical provisions, requiring signatory countries to accept certified type-approved side guards for vehicles of categories N2, N3, O3, and O4

1989: China adopts a standard based on UN Regulation 73, mandating side guards with similar technical standards on large trucks

1995: Revision 2 to the 1958 Agreement expands the coverage of UN Regulation 73 to some countries outside of Europe

2003: Peruvian Supreme Decree 58 adopts side guard legislation modelled after UN Regulation 73

2009: Updates to the Brazilian Traffic Code include adoption of the standards set forth by UN Regulation 73, but with stricter strength requirements

Prevalence and precedents of VRU side guards

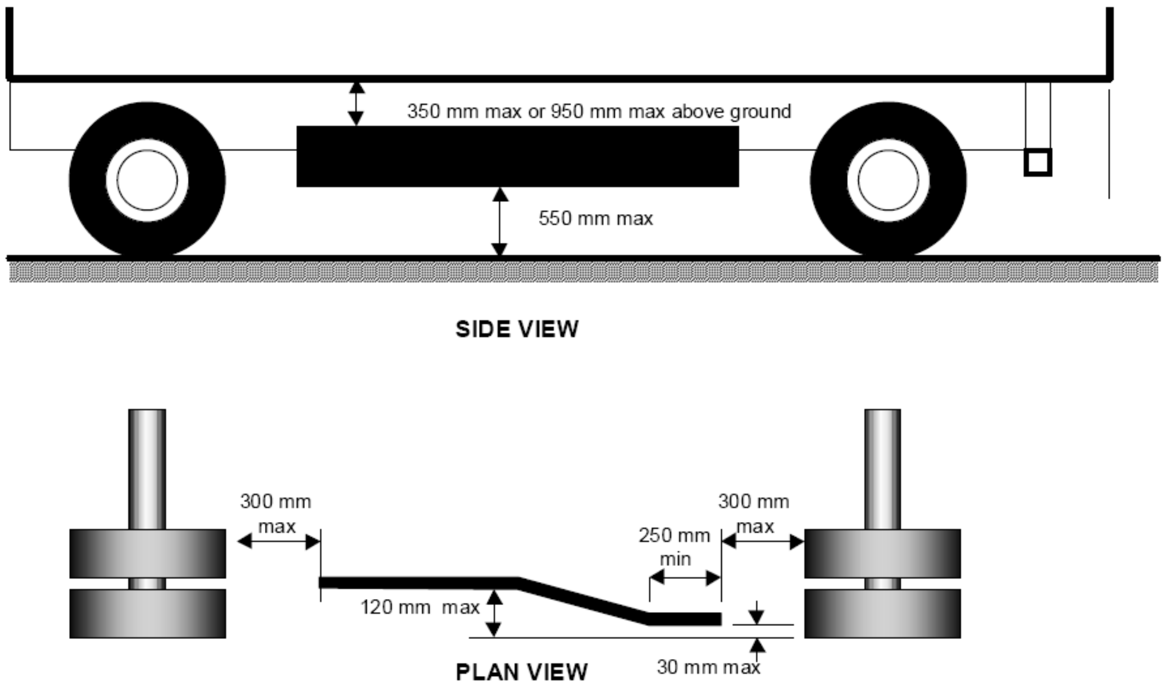
Narrow rails

Wide rails

Panels

Prevalence and precedents of lateral protection devices

- Most widely used standard is UN Regulation 73
- 1 kN static force stiffness test



LPD best practice specification

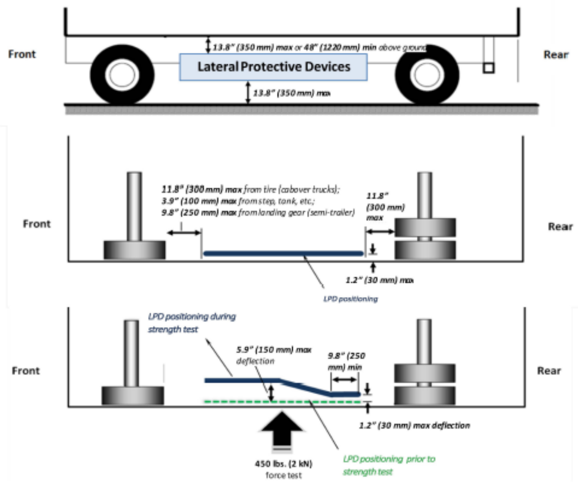
Volpe *The National Transportation Systems Center*

Lateral Protective Device Best Practice Specification

DOT-VNTSC-OSTR-16-05

This document is intended to be used by (1) public or private medium/heavy-duty truck fleets considering adding lateral protective devices (LPDs), also known as side guards; (2) jurisdictions or customers that require LPDs through policy or procurement; (3) manufacturers of LPDs; and (4) truck manufacturers and dealers.[1] The best practice specifications below are based on previously published Volpe reports (Reports DOT-VNTSC-DCAS-14-01 and DOT-VNTSC-SFMTA-16-01) and may be referred to as the "Volpe LPD best practice specification." This document can be used as a basis for design, production, testing, review, and procurement of LPDs and LPD-equipped vehicles.

1. Dimensional and strength criteria

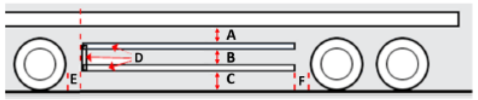


U.S. Department of Transportation
John A. Volpe National Transportation Systems Center

Revised April 2021

An LPD meets the strength requirement if it is capable of withstanding 450 pounds (2 kilonewtons) of force applied perpendicularly to any part of its surface by the center of a flat, circular plate of diameter no greater than 8.7 inches (220 mm), such that the deflection of the loaded side guard measured at the center of the plate does not exceed (1) 5.9 inches (150 mm) anywhere, or (2) 1.2 inches (30 mm) in the rearmost 9.8 inches (250 mm). A manufacturer may also demonstrate compliance using a valid engineering calculation, such as finite element analysis.[2]

2. Additional dimensional criteria for rail-style LPDs



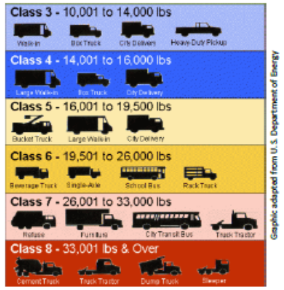
A	13.8 inches (350 mm) max
B	11.8 inches (300 mm) max
C	13.8 inches (350 mm) max
D	3.9 inches (100 mm) min
E	11.8/3.9 inches (300/100 mm) max*
F	11.8 inches (300 mm) max

*The gap between the LPD's leading edge and the wheel, wheel arch, or other permanent vehicle structure should not exceed 11.8 inches (300 mm). A turned-in vertical bar connecting the forward ends of the horizontal rails should be incorporated if the forward gap exceeds 3.9 inches (100 mm). The bar need not be turned in or can be omitted if the distance is less than 3.9 inches (100 mm).

3. Vehicle weight threshold and flexibility of design

LPDs can be installed on Class 3 and above vehicles, which have a gross vehicle weight rating (GVWR) of 10,000 pounds (4,536 kg) and higher.

Acceptable LPD protection can be provided by any combination of vehicle body, fuel tanks, tag axles, tool boxes, or purpose-built side guards comprising a smooth surface flush with the vehicle sidewall, meeting the dimensional and strength specifications set forth above.



[1] This document was prepared for the Office of the Assistant Secretary of Research and Technology.

[2] A third option for demonstrating strength compliance may be type approval by the United Kingdom Department for Transport Vehicle Certification Agency or other recognized side guard homologation with equal or greater stringency. An LPD with such type approval that also meets the Volpe dimensional criteria may be considered to meet the Volpe best practice specification.

www.volpe.dot.gov/LPDs

Volpe

https://rosap.ntl.bts.gov/view/dot/55683

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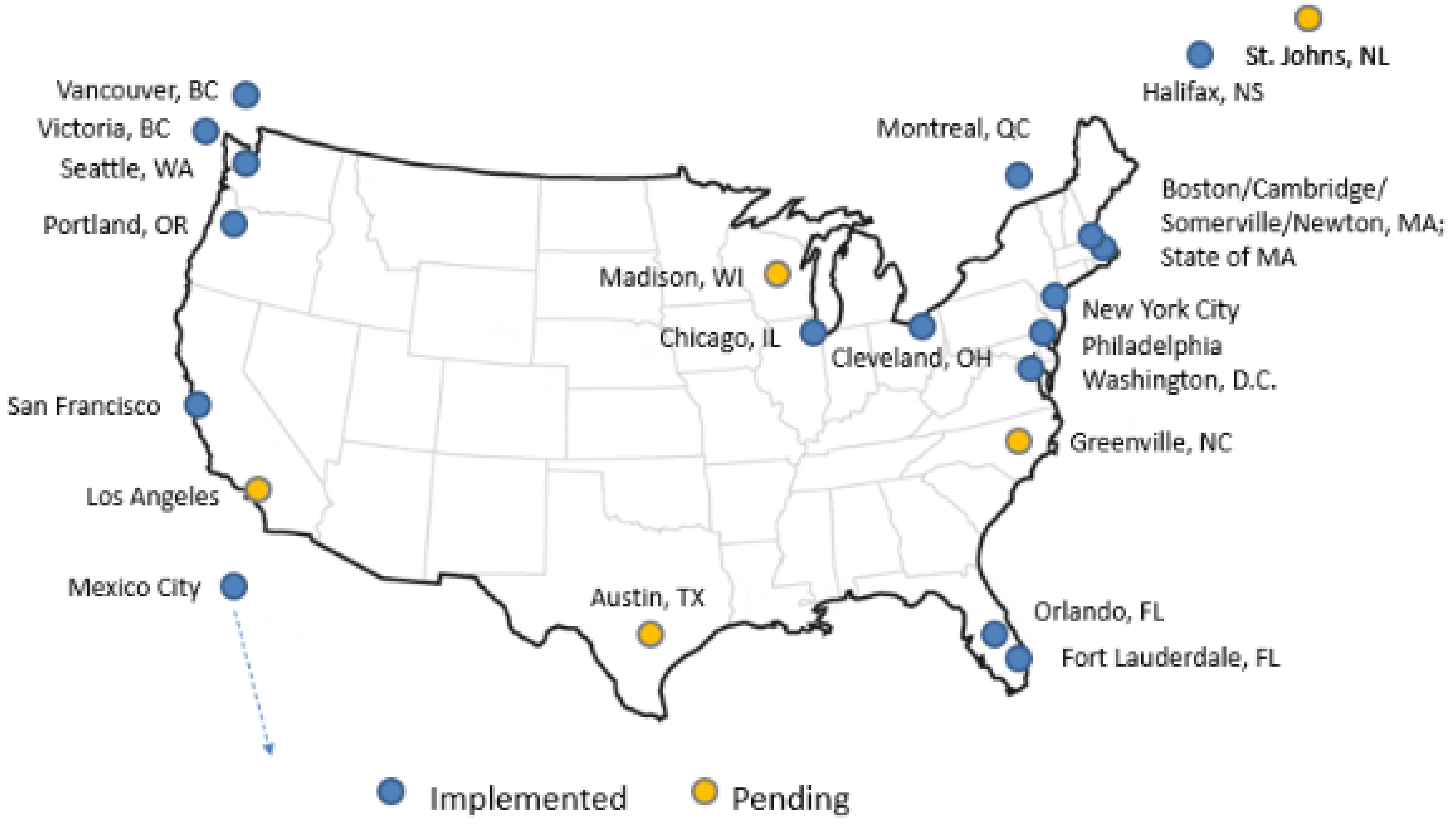
Truck Side Guard Adoption in North America




Seattle
New York City
Chicago
Portland, OR
New York City
Cambridge, MA
Washington, DC
Boston, MA

Safety effectiveness

Safety effectiveness findings

- ~50 publications accessed and reviewed
- **11 studies presenting specific data generally indicate side guard effectiveness at mitigating crashes with VRUs**
  - Effective for passing/overtaking maneuvers, improving with reduced ground clearance
  - Three studies† and Volpe demonstration indicate effective for crashes in which the truck turns

Four UK field studies (before vs. after) showed exposure and effectiveness 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 x 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%

† Keigan, 2009; Van Kampen 1999; and Cookson 2010, which presents both affirmative and contradictory findings

***45%** of bicycle crashes are driver- or passenger-side, roughly parallel crashes across all severities; however, an effectiveness value was not reported.

**Pedestrian crashes only reflect passenger- and not driver-side impacts.

(Knight, 2005), (Smith, 2005), (Cookson, 2010), and (Robinson, 2014)

Safety effectiveness findings

Total truck-VRU fatality and injury reductions reported in connection with implementation of LPDs, across all studies reviewed:

- **Fatalities:**
  - Studies specific to <u>bicycle</u> fatalities: **5 – 30%**.
  - Studies specific to <u>pedestrian</u> fatalities: **2 – 4%**
  - Studies that <u>did not differentiate</u> by VRU category: up to **20%**
- **Serious injuries:**
  - Studies specific to <u>bicycle</u> serious injuries: **<1 – 6%**
  - One study specific to <u>pedestrian</u> serious injuries: **<1%**
  - Studies that <u>did not differentiate</u> by VRU category: up to **25%**

Volpe analysis; see also: https://rosap.ntl.bts.gov/view/dot/49250

Safety effectiveness findings: Exempt/non-exempt

Finding: LPD-equipped truck-bicycle passing/overtaking crashes in the UK were ~70% less likely to result in a fatality than crashes involving SG-exempt trucks

Crash severity distribution in truck-bicycle passing/overtaking crashes

		Fatal	Serious	Slight	% fatal	% KSI
1990-1992	Exempt (no SG)	6	18	22	**13%**	**52%**
	Not exempt (equipped with SG)	5	34	103	**4%**	**27%**
2006-2008	Exempt (no SG)	4	11	15	**14%**	**52%**
	Not exempt (equipped with SG)	3	23	43	**4%**	**37%**

(Knight, et al., 2005; Cookson & Knight, 2010)

Finding: LPD-equipped truck-bicycle turning crashes in the UK were 40% less likely to result in a fatality than crashes involving SG-exempt trucks

		Fatal	Serious	Slight	% fatal	% KSI
2006-2008	Exempt (no SG)	9	21	15	**20%**	**67%**
	Not exempt (equipped with SG)	7	8	44	**12%**	**25%**

(Cookson & Knight, 2010)

Safety effectiveness findings

Finding: UK field studies based on detailed investigations of individual fatal bicyclist crashes show various, sometimes higher effectiveness numbers, including for turning crashes

Study	LPD implementation	Crash set	Effectiveness (reduction in fatality or serious injury as a proportion of all injuries)
Keigan09	UK regulatory requirement	Heavy vehicle changing lanes or **turning left**	**93.8%**
Keigan09	UK regulatory requirement	Cyclist lost control alongside vehicle	**45.5%**
Keigan09	UK regulatory requirement	Total of the two above	**74.1%**
Talbot14	UK regulatory requirement	Side crashes	**11.5%**
Talbot14	More stringent side guard dimensions to close gaps	Side crashes	**26.9%**

Safety effectiveness findings

Finding: certain studies from Australia, the Netherlands, and the UK report high combined effectiveness for pedestrians and bicyclists, including for turning crashes

Publication	LPD 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)
Rechnitzer93	Not specified	All fatal crashes	100.0%	**20.0%**
Rechnitzer93	Not specified	All serious injury crashes	100.0%	**25.0%**
VanKampen99	Bus as proxy for low-clearance guard condition	All passenger side **turning maneuvers** (rail-style side guard)	Not specified	**25.0%**
VanKampen99	Bus as proxy for low-clearance guard condition	All passenger side **turning maneuvers** (smooth-style side guard)	Not specified	**35.0%**
Riley81	Not specified	Side impacts for motorcyclists, bicyclists, and pedestrians	66.0%	**24.0%**

Safety effectiveness findings

Finding: Lower side guard height increases effectiveness

Study	Guard implementation	Crash set	Effectiveness (reduction in fatality or serious injury as a proportion of all injuries)
Hogstrom86	Not specified	Not specified	**35.0%**
Riley85	Maximum allowable gaps and inset under UK regulation, including **550mm** ground clearance	Cyclist lost control alongside vehicle	**60.0%**
Riley85	Improved guard, **450mm** ground clearance	Cyclist lost control alongside vehicle	**80.0%**
Riley85	Improved guard, **400mm** ground clearance	Cyclist lost control alongside vehicle	**100.0%**
Riley85	Improved guard, **300mm** ground clearance	Cyclist lost control alongside vehicle	**100.0%**

Finding: Improved side guard design increases potential VRU fatality mitigation

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

(Knight, et al., 2005)

Safety effectiveness findings

Prior findings may have underestimated effectiveness or exposure

- Effectiveness was based on partial real-world implementation (Robinson14)
- Did not consider improved LPD design (Riley85, Knight05)
- Limited crash scenarios considered, e.g., no driver side (Knight05, Cookson10, Smith05)

Safety effectiveness findings


Safe Fleet Transition Plan: Private Vehicle Crashes and Vehicle Safety Technology

Preliminary Report: Expanding the NYC Safe Fleet Transition Plan to Trade Waste Industry and Private Truck Fleets

Alexander K Epstein, Ph.D., Michael Chang, Lucy Liu, and Rahi Patel

December 2021

Prepared for:
Business Integrity Commission and Department of Citywide Administrative Services
City of New York

U.S. Department of Transportation
Volpe Center

	Fatality	Injury
No side guard	17.2%	82.8%
Yes side guard	12.9%	87.1%
Unknown	15.0%	85.0%
Total	15.7%	84.3%

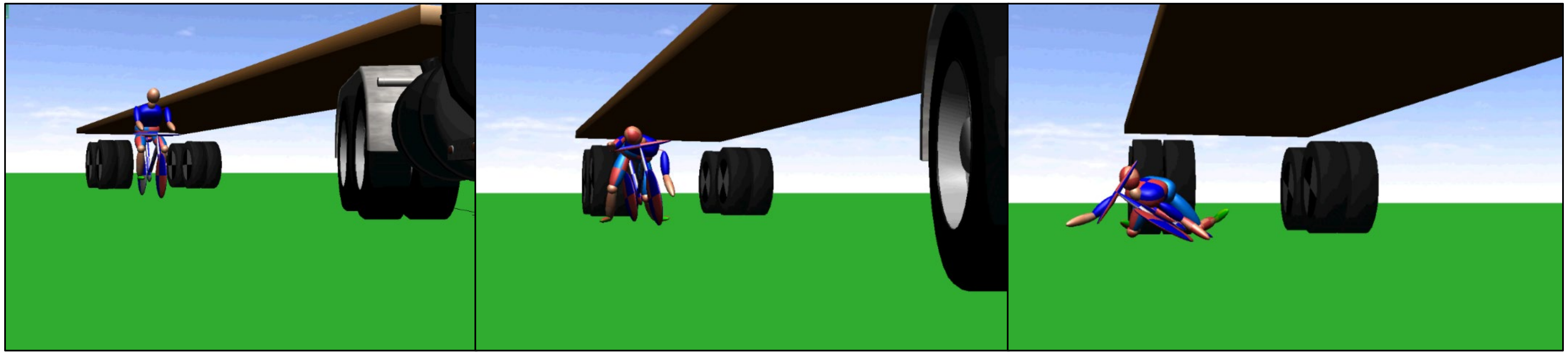
25% fatality rate decrease

https://www1.nyc.gov/assets/dcas/downloads/pdf/fleet/Safe-Fleet-Transition-Plan-Private-Vehicle-Crashes-and-Safety-Technology-December-2021.pdf; n = 18 fatalities, 97 injuries, 115 total
Note: This has not been exhaustively studied to confirm and has not been examined within USDOT beyond Volpe's analysis.

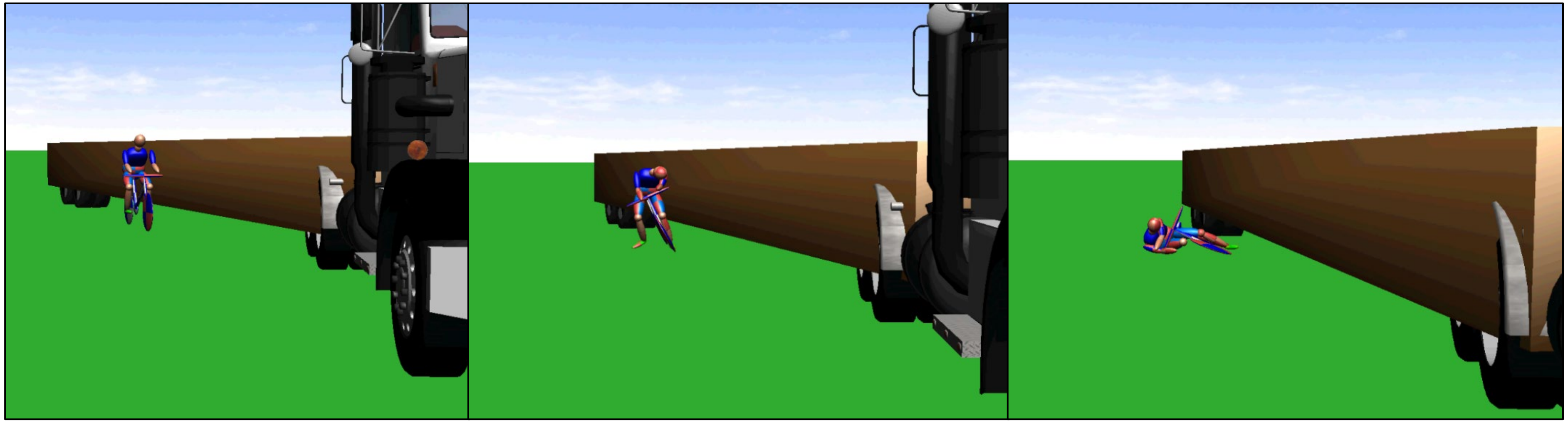
Technology demonstration

Notional turning crash simulation

No LPD



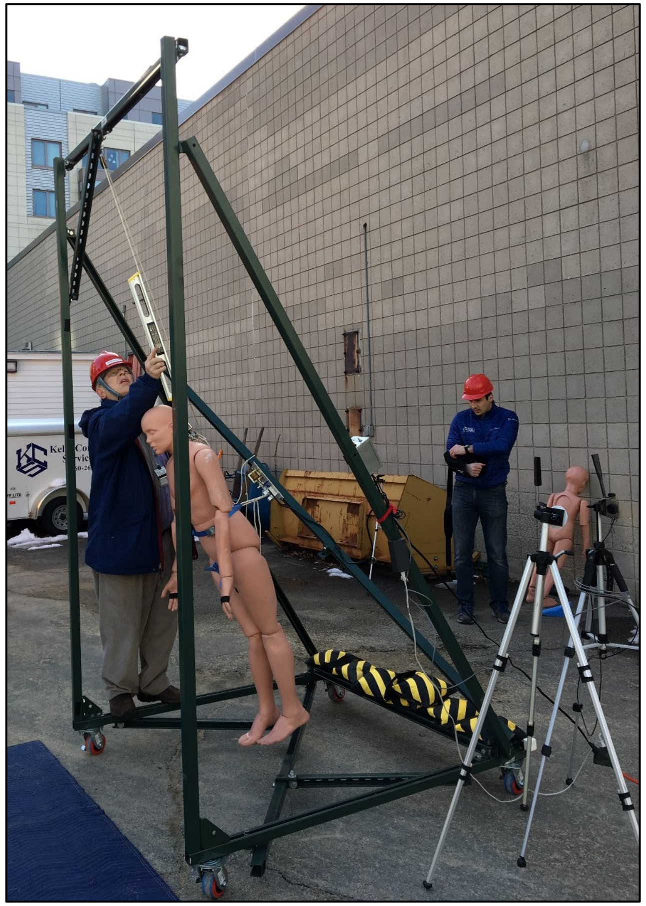
Aerodynamic LPD



Source: Seven Hills Engineering

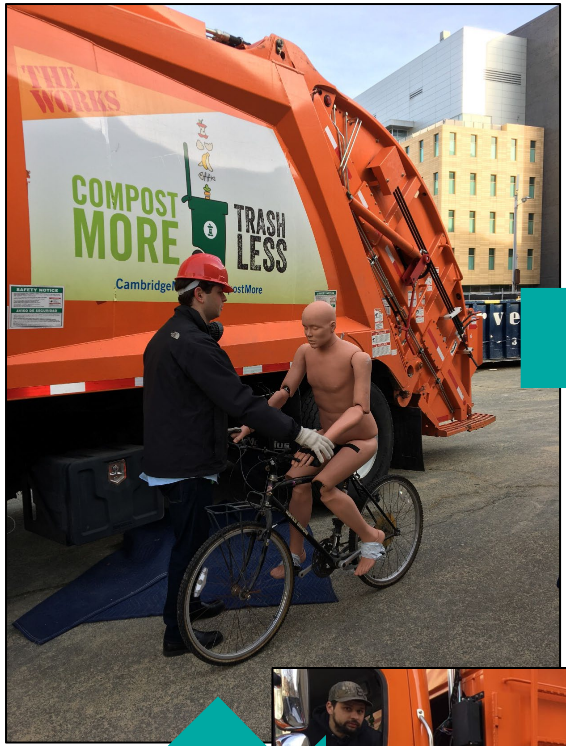
LPD technology demonstration results

- Collaboration between Volpe, Tufts University and City of Cambridge Public Works
- Methodology: anatomically jointed manikins, controlled release into SUT with photo-sensors
- Multiple crash scenarios and targets
- Video: https://youtu.be/FREj0hKJOFg



Technology demonstration results: person walking

Technology demonstration results: person biking



Retrofit feasibility

Retrofit feasibility assessment

- Considered potential installation and operational interactions between the U.S. truck fleet's most common cargo body types, almost 50 vehicle components, and the installation of aftermarket side guards.
  - **No truck parts or accessories were identified as incompatible with LPDs.**
- Considered potential interactions between side guards—whether aftermarket or premarket—and FMCSA commercial vehicle safety inspections.
  - **Several existing solutions were identified for continuing to perform Level 1 safety inspections on trucks with LPDs.**

Credit: FMCSA

Retrofit feasibility assessment

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
Premarket	• 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

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Benefits, costs, and aerodynamic factor

Types, costs, and aerodynamic factor

SUT / Non-aerodynamic (rail-style)

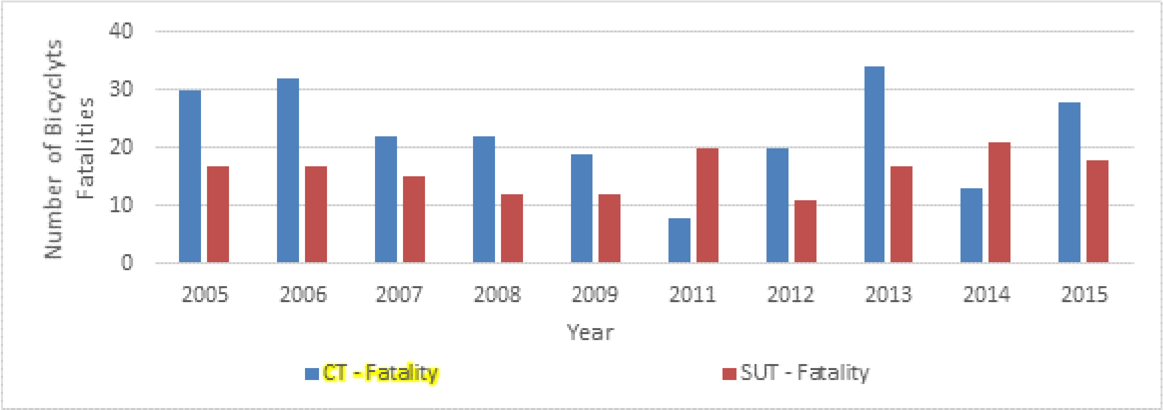
SUT / Aerodynamic (panel-style)

Note: aerodynamic savings only become significant when the vehicle travels at higher speed.

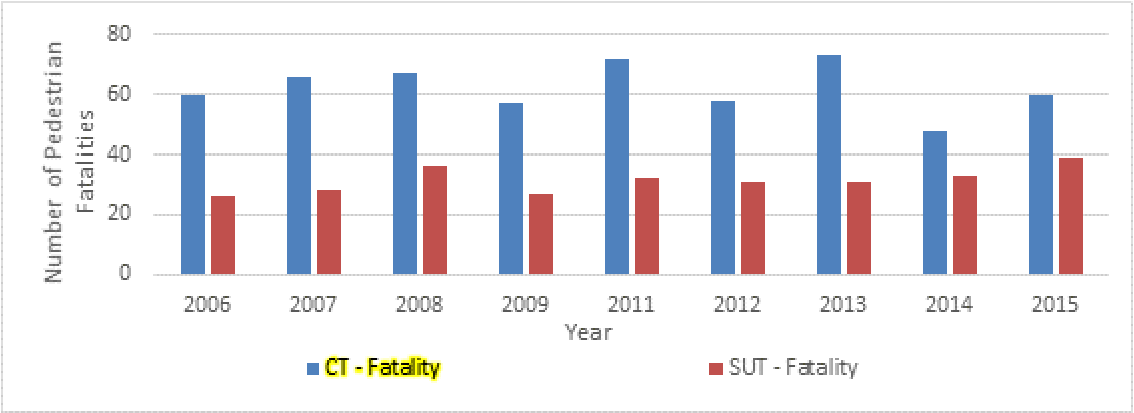
CT / Non-aerodynamic (rail-style)

CT / Aerodynamic (panel-style)

Counterintuitive finding #1: Tractor-trailers crashed with VRUs in relevant scenarios at least as often as SUTs



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



Side Guard-Relevant Pedestrian Fatalities by Truck Category from 2006 to 2015

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Volpe analysis

Counterintuitive finding #2: SUTs drive at least 40% on highways (where aerodynamics matter)

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%

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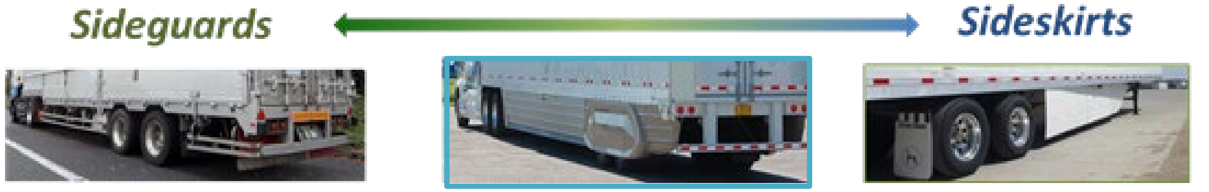
Volpe analysis

Types, costs, and aerodynamic factor

Source type	Reported approximate cost per vehicle	Side guard type
European suppliers, e.g., Takler…	~$300-$1,500; **~$700 average**	Typically rail
Certain trailer skirt makers, e.g., Transtex, WABCO, PHSS…	**~$1,000+** plus installation	Rigid panel



<------Aerodynamic fuel consumption savings----->

- Above costs are OEM. Cost of retrofitting ranges $700-$1,800 for rail design and $1,000-$2,700 for full panel designs
- Benefit-cost analysis used the median figures: **$1,250 for rail retrofit and $1,850 for full panel retrofit.**

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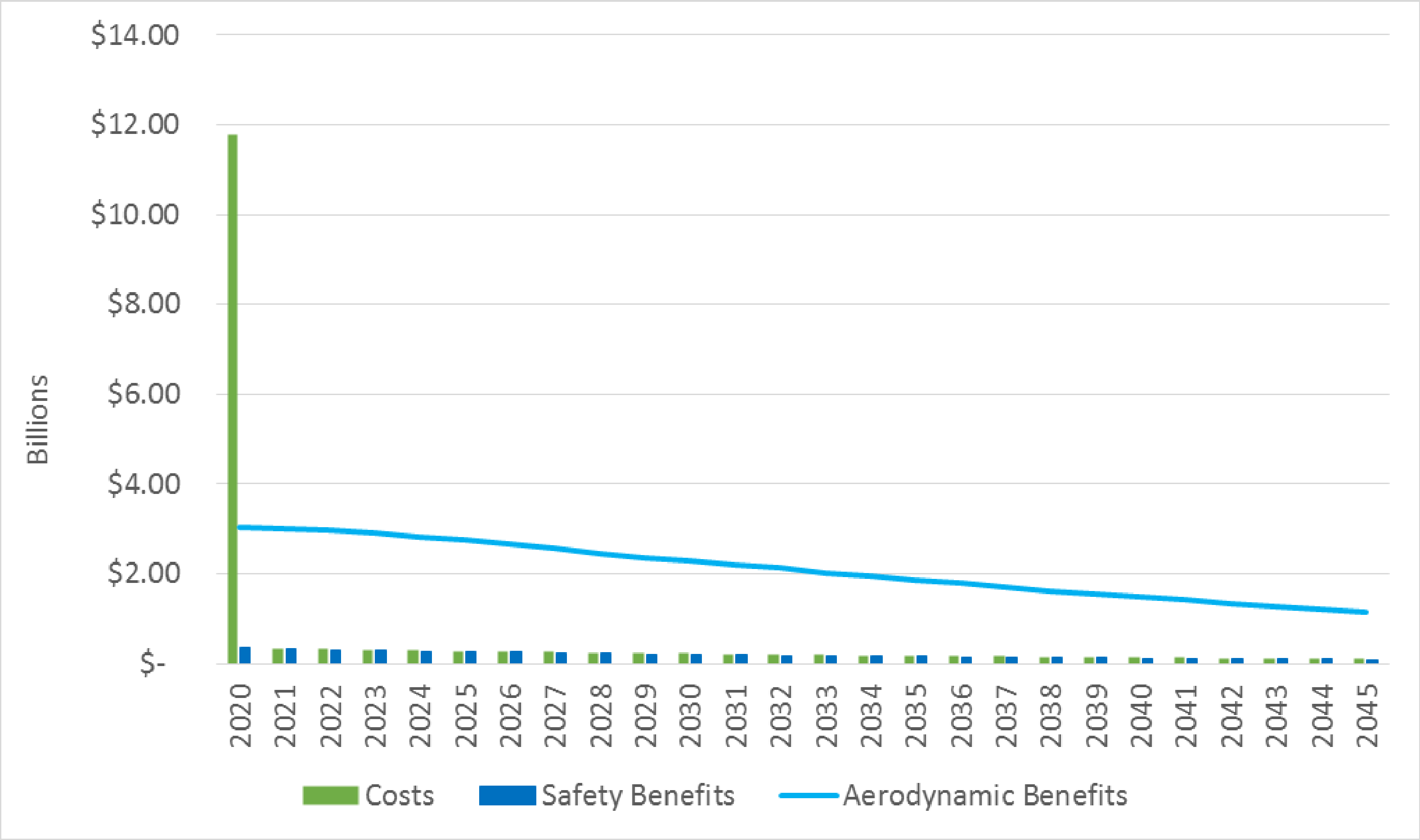
Benefit-cost analysis for notional adoption scenarios

- Considered the *safety benefits* for all side guards as well as *aerodynamic benefits* for aerodynamic type side guards, which are dual-function
- Crashes included in the analysis were limited to only those whose crash cost could conceivably be reduced if a side guard had been on the truck
- Current aerodynamic underbody skirts were assumed to require reinforcement to provide equivalent safety benefit
- 7% discount rate

Volpe analysis

Benefit-cost analysis for notional adoption scenarios

Scenario 1: **Full Deployment First Year (all trucks equipped at once)**



Volpe analysis

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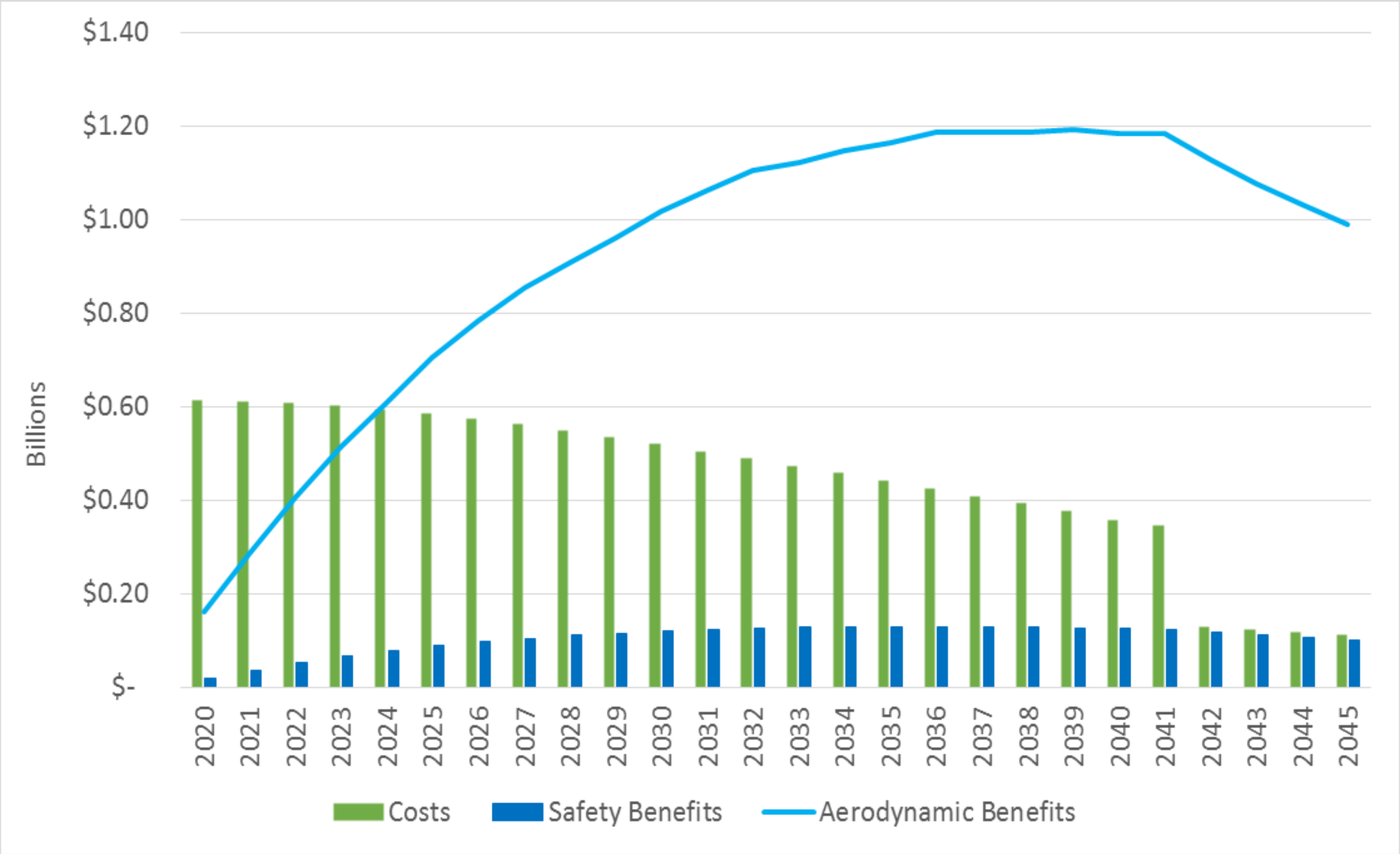
Benefit-cost analysis for adoption scenarios

Scenario 2: **Gradual Deployment (5% of fleet equipped per year)**



Volpe analysis

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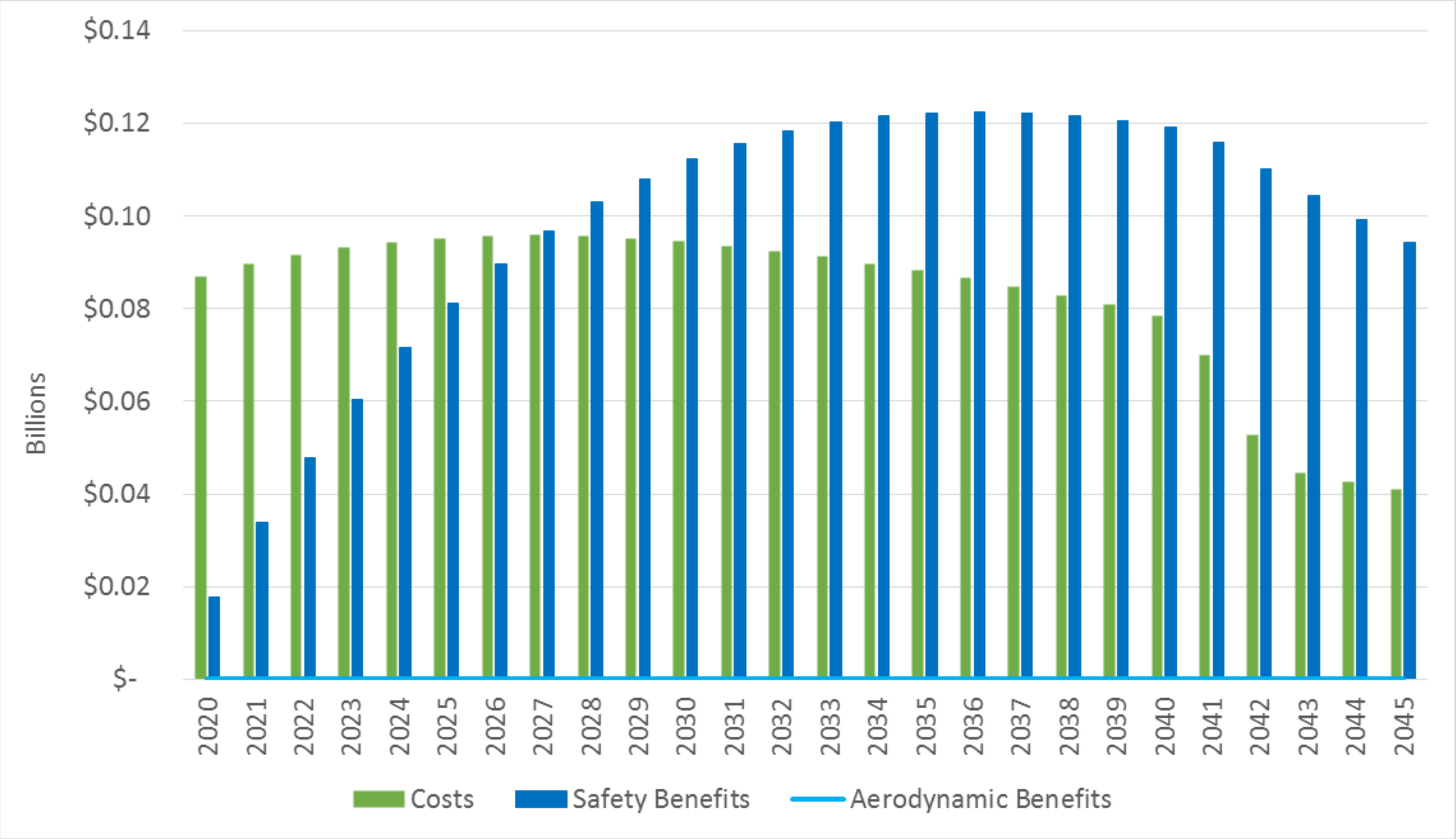
Benefit-cost analysis for notional adoption scenarios

Scenario 3: **Aero Skirts Fully Deployed** (assumes all trucks are equipped with aero skirts by 2020 so that no aero benefits are realized)



Volpe analysis

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Benefit-cost analysis for notional adoption scenarios

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**

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**

Payback Period for Each Scenario and Discount Rate, Assuming Low or High Benefits Level

	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

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Volpe analysis

Benefit-cost analysis for notional adoption scenarios

- **All three scenarios show net benefits of U.S.-wide side guard deployment**. Aerodynamics comprise a significant share of total benefits, except in Scenario 3.

- Potential benefits not considered:
  - Improving **wind stability** and related crash costs
  - Reducing **road spray** and related crash costs
  - Mitigating **low-speed or glancing automobile-truck** collisions and associated costs
  - Improving **automatic emergency braking system detection** of the truck such as in the Tesla "Autopilot" 2016 Florida fatality, and reducing such crashes

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Volpe analysis

Conclusions

- Growing interest and local/state policies in U.S. to address truck-VRU collisions with LPDs or side guards
- LPDs are a globally implemented safety countermeasure for truck-VRU collisions
- International studies have demonstrated effectiveness
- No incompatibilities identified with common truck types and components or with Level 1 safety inspections
- Benefit-cost ratios >1 under three bounding notional implementation scenarios

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Truck Lateral Protective Device (LPD) Resources

Note: the term "side guard" is used colloquially throughout this webpage and related materials, but refers to "lateral protective devices" and not to "underride" guards.

Truck lateral protective devices are vehicle-based safety devices designed to keep pedestrians, bicyclists, and motorcyclists from being run over by a large truck's rear wheels in a side-impact collision.

The U.S. DOT Volpe Center is monitoring this technology's adoption in the United States, and has conducted research and partnered with public- and private-sector fleets to help deploy lateral protective devices and other technologies that address the **deadliest road crashes**: those between large trucks and pedestrians or bicyclists.

Questions?

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