A Literature Review of Lateral Protection Devices on Trucks Intended for Reducing Pedestrian and Cyclist Fatalities

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

May 2020

FOREWORD

Lateral protection devices (LPDs) have been required for trucks in Europe since 1989. In the past five years, a few cities in the U.S., under Vision Zero initiatives, are requiring LPDs on city-owned and city-contracted single unit trucks to mitigate pedestrian and cyclist or pedalcyclist fatalities and injuries in impacts with the side of trucks. This report provides data on pedestrian and pedalcyclist fatalities in the U.S. and summarizes a literature review of LPD regulatory and technical standards in other countries and summarizes published effectiveness estimates of LPDs in mitigating injury and death using data from other countries. Potential audiences for this report include Federal, State, or local regulatory agencies, motor carriers, safety advocacy groups, trucking industry associations, and truck or trailer manufacturers.

NOTICE

QUALITY ASSURANCE STATEMENT

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FMCSA-RRR-19-004		
4. Title and Subtitle **A Literature Review of Lateral Protection Devices on Trucks Intended for Reducing Pedestrian and Cyclist Fatalities**		5. Report Date **May 2020** 6. Performing Organization Code
7. Author(s) **Badgley, J., Breck, A., Dawes, M., Epstein, A.K., Welty, K., McNally, A., and Peirce, S.**		8. Performing Organization Report No.
9. Performing Organization Name and Address **John A. Volpe National Transportation Systems Center 55 Broadway Cambridge, MA 02142**		10. Work Unit No. (TRAIS) 11. Contract or Grant No. **SA9PA1**
12. Sponsoring Agency Name and Address **U.S. Department of Transportation Federal Motor Carrier Safety Administration Office of Analysis, Research, and Technology 1200 New Jersey Ave. SE Washington, DC 20590**		13. Type of Report and Period Covered **Final Report** 14. Sponsoring Agency Code **FMCSA**
15. Supplementary Notes **Contracting Officer's Representative: Quon Kwan (retired)**		
16. Abstract **This report provides data on pedestrian and cyclist or pedalcyclist fatalities in the U.S. and summarizes a literature review of lateral protection device (LPD) regulatory and technical standards and specifications in the U.S. and in other countries. The report also summarizes published effectiveness estimates of LPDs in mitigating injury and death to pedestrian and bicyclists from studies conducted in other countries.**		
17. Key Words **trucks, commercial vehicle safety, crash mitigation, vulnerable road user, pedestrians and bicyclist safety, road safety, lateral protection device**	18. Distribution Statement **No restrictions**	
19. Security Classif. (of this report) **Unclassified**	20. Security Classif. (of this page) **Unclassified**	21. No. of Pages **66** 22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized.

TABLE OF CONTENTS

LIST OF APPENDICES

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS, ABBREVIATIONS, AND SYMBOLS

Acronym	Definition
CLOCS	Construction Logistics and Community Safety
FARS	Fatality Analysis Reporting System database
FMCSA	Federal Motor Carrier Safety Administration
FMCSR	Federal Motor Carrier Safety Regulation
FMVSS	Federal Motor Vehicle Safety Standard
FTA	Freight Transport Association (United Kingdom)
GVWR	gross vehicle weight rating
HVCIS	Heavy Vehicle Crash Injury Study
KSI	killed or seriously injured
lb(s).	pound(s)
NTSB	National Transportation Safety Board
TIFA	Trucks in Fatal Accidents database
TRL	Transport Research Laboratory
UK	United Kingdom
UN	United Nations
UNECE	United Nations Economic Commission for Europe
U.S.	United States
USDOT	U.S. Department of Transportation
VIUS	Vehicle Inventory Use Survey
Volpe	John A. Volpe National Transportation Systems Center
VRU(s)	vulnerable road user(s)

EXECUTIVE SUMMARY

In 2017, there were 5,977 pedestrians and 783 cyclists or pedalcyclists killed in motor vehicle traffic crashes in the United States (U.S.). Pedestrian deaths account for 16 percent and pedalcyclist deaths account for 2 percent of all traffic fatalities in 2017. Most of the pedestrian and pedalcyclist fatalities (75 percent) were in collisions with the front of passenger cars and light trucks. On an annual average, there are 26 pedestrian and 22 pedalcyclist fatalities in collisions with the left and right side of large trucks (single unit trucks (SUTs) and truck-trailers) in the U.S.

This report presents a review of lateral protection device (LPD) regulatory and technical standards and specifications in the U.S. and other countries. The report also summarizes published effectiveness estimates of LPDs in mitigating injury and death, obtained from studies conducted in other countries.

Regulations for LPDs have existed since at least 1979, when Japan adopted Safety Regulations for Road Vehicles: Pedestrian Protecting Lateral Protection Devices.[(1)] An international LPD regulation, United Nations (UN) Regulation 73, adopted in 1988, covers 43 countries and the European Union, and has served as a model for other international and industry standards and specifications adopted by some municipalities in the United States.[(2)(i)] So has the specification from the United Kingdom Construction and Road Use Regulations of 1986.[(3)]

No Federal requirements for LPDs on large trucks currently exist in the United States, but city jurisdictions and private fleets have implemented LPDs designed in accordance with specifications developed by Volpe in 2016, resulting in approximately 3,000 installations through mid-2018.

Published field evaluation studies report that LPDs are effective in mitigating fatalities during passing and overtaking maneuvers, in which the truck travels roughly parallel with a vulnerable road user (VRU, i.e. pedestrian or pedalcyclist), with the VRU impacting the passenger side of the vehicle ("nearside," in UK terminology). Field evaluation studies have also shown that LPDs are not effective in preventing fatalities when the VRU impacts the side of a large truck that is turning left or right.

According to the literature review, the effectiveness estimates[ii] of LPDs in preventing fatalities in VRU collisions with the side of large trucks where the VRU and truck are traveling roughly parallel to each other range from 50 to 74 percent for bicyclists and 17 to 27 percent for

---

[i] 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.

[ii] *Effectiveness* of a device is the proportion of fatalities or injuries that would be prevented for specific crash conditions if the device had been present on the vehicle. If e is the effectiveness (in percentage) of LPDs in mitigating bicyclist fatalities in collisions with the side of large trucks, where the bicyclist and truck are traveling roughly parallel to each other, and n is the total number of bicyclist fatalities in similar collisions with large trucks without LPDs, then the number of bicyclist lives that could have been saved if trucks were equipped with LPDs would equal n x e/100.

pedestrians. The effectiveness estimates of LPDs in mitigating serious injury in similar collisions between VRUs and large trucks range from 3 to 9 percent for bicyclists and about zero for pedestrians.

On an annual average, there are 16 pedestrian and 11 pedalcyclist fatalities in collisions with the left or right side of large trucks in the U.S (FARS 2013 – 2017), where the large truck and VRU are traveling roughly parallel to each other (pre-impact maneuvers of the truck for which LPDs have been shown to be effective in mitigating VRU fatalities).

It is unclear whether the effectiveness estimates of LPDs from other countries can be directly applied in the U.S because of differences in VRU exposure and infrastructure designs. Data from the LPD implementation in some cities in the U.S. may provide insight into the performance of LPDs in U.S. applications.

At the time of application of LPD regulations in other countries, advanced technologies such as detection and warning systems and other advanced driver assistance systems were not available. However, with the current availability of advanced technologies, a comprehensive review of all available vehicle technologies and infrastructure designs is needed to determine the most effective and practical approach to mitigating VRU injuries and fatalities in all types of collisions with vehicles. Vehicle technologies include LPDs, cameras and mirrors to improve driver visibility, collision avoidance systems, and pedestrian crash avoidance mitigation systems. Infrastructure designs include bike lanes and sidewalks and improved intersection designs.

1. INTRODUCTION

In 2017, there were 5,977 pedestrians and 783 pedalcyclists (includes unicyclists, bicyclists, tricyclists, and riders of other types of nonmotorized cycles) killed in motor vehicle traffic crashes in the United States (U.S.).[4] [5] Pedestrian deaths account for 16 percent and pedalcyclist deaths account for 2 percent of all traffic fatalities in 2017. While the percentage of pedalcyclist fatalities among all traffic fatalities shows a downward trend since 2012, the percentage of pedestrian fatalities shows an upward trend.

Ninety-one (91) percent (5,363) of the pedestrians killed and 96 percent (753) of pedalcyclists killed in 2017 were involved in single vehicle crashes. Table 1 presents the number of pedestrians and pedalcyclists killed by vehicle type and initial point of impact of the vehicle when it contacted the pedestrian or pedalcyclist in single vehicle crashes in 2017. Among the 6,116 (= 5,363 + 753) pedestrian and pedalcyclists killed, 75 percent involved collisions with the front of passenger cars and light trucks.

Among the 5,363 pedestrian fatalities in single vehicle crashes, only 5.4 percent (290) involved impacts with large trucks, among which 27 (9.3 percent) involved impacts to the left or right side of large trucks. In contrast, 206 of these same 290 pedestrian fatalities (71 percent) involved impacts to the front of the trucks Table 1. Among the 753 pedalcyclist fatalities in single vehicle crashes, only 10 percent (75) involved impacts with large trucks, among which 25 (33.3 percent) involved impacts to the left or right side of large trucks. In contrast, 36 of these same 75 pedalcyclist fatalities (48 percent) involved impacts to the front of the trucks. See Table 1 and Table 2.

Table 1. Pedestrians Killed in Single-vehicle Crashes in 2017, by Vehicle Type Involved and Initial Point of Impact (2017 Fatality Analysis Reporting System).

Vehicle Type	Front Initial Impact No. (%)	Right Initial Impact No. (%)	Left Initial Impact No. (%)	Rear Initial Impact No. (%)	Other/ unknown Initial Impact No. (%)	Total No.
Passenger Car	2,009 (89.6%)	65 (2.9%)	40 (1.8%)	16 (0.7%)	113 (5.0%)	2,243
Light Truck	2,029 (88.6%)	58 (2.5%)	43 (1.9%)	31 (1.4%)	130 (5.7%)	2,291
Large Truck	206 (71.0%)	20 (6.9%)	7 (2.4%)	23 (7.9%)	34 (11.7%)	290
Bus	25 (75.8%)	2 (6.1%)	0 (0.0%)	0 (0.0%)	6 (18.2%)	33
Other/Unknown	260 (51.4%)	7 (1.4%)	5 (1.4%)	0 (0.0%)	234 (46.2%)	506
Total	4,529 (84.4%)	152 (2.8%)	95 (1.8%)	70 (1.3%)	517 (9.6%)	5,363

Table 2. Pedalcyclists Killed in Single-vehicle Crashes in 2017, by Vehicle Type Involved and Initial Point of Impact (2017 Fatality Analysis Reporting System).

Vehicle Type	Front Initial Impact No. (%)	Right Initial Impact No. (%)	Left Initial Impact No. (%)	Rear Initial Impact No. (%)	Other/ unknown Initial Impact No. (%)	Total No.
Passenger Car	249 (88.3%)	11 (3.9%)	7 (2.5%)	3 (1.1%)	12 (4.3%)	282
Light Truck	288 (87.8%)	23 (7.0%)	7 (2.1%)	3 (0.9%)	7 (2.1%)	328
Large Truck	36 (48.0%)	21 (28.0%)	3 (4.0%)	7 (9.3%)	8 (10.7%)	75
Bus	4 (40%)	4 (40%)	1 (10%)	1 (10%)	0 (0.0%)	10
Other/Unknown	37 (63.8%)	2 (3.4%)	0 (0.0%)	0 (0.0%)	19 (32.8%)	58
Total	614	61	18	14	46	753

To better understand pedestrian and pedalcyclist fatalities in the U.S. resulting from impacts with large trucks, the Fatality Analysis Reporting System (FARS)[6] data were analyzed for the five-year period 2013 to 2017. FARS is a census of fatal motor vehicle crashes in the U.S. FARS data were queried for single-vehicle crashes involving single unit trucks (SUTs) or truck-trailers with a gross vehicle weight rating (GVWR) greater than 4,536 kg where the first harmful event in the crash was a collision with a pedestrian or pedalcyclist. The factors considered in the analysis were the pre-crash maneuver of the truck and the initial impact point on the truck-trailer with the pedestrian or pedalcyclist. Average annual fatalities were determined by averaging the five-year data from 2013 to 2017. The summary of the FARS data analysis is discussed below.

1.1 PEDESTRIAN FATALITIES

Data from Table 1:

- There was an average of 255 pedestrian fatalities occurring in crashes with heavy trucks annually.
  - 106 (41.6 percent) were struck by SUTs, and 149 (58.4 percent) were struck by semitrailers.
- Among the 106 pedestrian fatalities in crashes with SUTs,
  - Initial impact
    - 69.8 percent involved initial impacts to the front of the vehicle,
    - 4.2 percent were to the right, and
    - 3.0 percent to the left of the vehicle.
  - Pre-crash vehicle movement
    - 54.5 percent occurred when the SUT was going straight,
    - 10.6 percent when the SUT was turning right, and
    - 11.5 percent when the SUT was turning left.
- Among the 135 pedestrian fatalities in crashes with semitrailers,
  - Initial impact
    - 73.3 percent involved initial impacts to the front of the vehicle,
    - 8.7 percent to the right, and
    - 3.6 percent to the left of the vehicle.
- Pre-crash vehicle movement
  - 76.0 percent occurred when the semitrailer was going straight,
  - 5.6 percent when the semitrailer was turning right, and
  - 2 percent when the semitrailer was turning left.
- In the U.S., there was an annual average of 8 pedestrian fatalities in crashes with SUTs and 18 pedestrian fatalities in crashes with semitrailers where the initial impact was to the left or right side of the vehicle.

1.2 PEDALCYCLIST FATALITIES

Data from Table 2:

- There was an average of 70 pedalcyclist fatalities occurring in crashes with heavy trucks annually.
  - 37 involved crashes with SUTs and 33 involved crashes with semitrailers.
- Among the 37 pedalcyclist fatalities in crashes with SUTs,
  - Initial Impact

    - 52.9 percent involved initial impacts to the front of the vehicle,
    - 26.7 percent were to the right, and
    - 5.3 percent to the left of the vehicle.
  - Pre-crash vehicle movement
    - 51.3 percent occurred when the SUT was going straight,
    - 30.5 percent when the SUT was turning right, and
    - 8.0 percent when the SUT was turning left.
- Among the 33 pedalcyclist fatalities involving crashes with semitrailers,
  - Initial Impact
    - 39.0 percent involved initial impacts to the front of the vehicle,
    - 24.4 percent to the right, and
    - 7.3 percent to the left of the vehicle.
  - Pre-crash movement
    - 59.1 percent occurred when the semitrailer was going straight,
    - 26.8 percent when the semitrailer was turning right, and
    - 6.7 percent when the semitrailer was turning left.
- In the U.S., there was an annual average of 12 pedalcyclist fatalities occurring in crashes with SUTs and 10 pedalcyclist fatalities occurring in crashes with semitrailers, where the initial impact was to the left or right side of the vehicle.

On an annual average, there are 48 pedestrian and pedalcyclist fatalities in collisions with the left and right of large trucks (SUTs and truck-trailers). See Table 3, Table 4, Table 5, and Table 6 below.

Table 3. Pedestrians struck by large trucks in single vehicle fatal crashes when first harmful event in the crash is collision with a pedestrian. Annual averages (FARS 2013–2017).

Initial Point of Impact on Vehicle	Going Straight	Turning Right	Turning Left	Overtaking another vehicle	All Others	Total
Front	49	6.8	10	0.2	8	74
Right	3	1	0	0	0.4	4.4
Left	1	0	1.6	0.2	0.4	3.2
Back	0.8	0.2	0	0	10.4	11.4
Other	4	3.2	0.6	0	5.2	13
Total	57.8	11.2	12.2	0.4	24.4	106

Table 4. Pedestrians struck by truck trailers in single vehicle fatal crashes when first harmful event in the crash is collision with a pedestrian. Annual averages (FARS 2013–2017).

Initial Point of Impact on Vehicle	Going Straight	Turning Right	Turning Left	Overtaking another vehicle	All Others	Total
Front	91.4	3.4	1.8	0.2	12.2	109
Right	7.6	1.6	0.8	0	3	13
Left	4.2	0.2	0.2	0	0.8	5.4
Back	2	1.8	0.4	0	2.4	6.6
Other	7.8	1.4	1.2	0.2	4	14.6
Total	113	8.4	4.4	0.4	22.4	148.6

Table 5. Pedalcyclists struck by large trucks in single vehicle fatal crashes when first harmful event in the crash is collision with a Pedalcyclist. Annual averages (FARS 2013–2017).

Initial Point of Impact on Vehicle	Going Straight	Turning Right	Turning Left	Overtaking another vehicle	All Others	Total
Front	11.6	4.8	1.4	0.2	1.8	19.8
Right	3.6	5.4	0.6	0.2	0.2	10
Left	1.2	0	0.4	0	0.4	2
Back	1.2	0.6	0	0	0.8	2.6
Other	1.6	0.6	0.6	0	0.2	3
Total	19.2	11.4	3	0.4	3.4	37.4

Table 6. Pedalcyclists struck by truck trailers in single vehicle fatal crashes when first harmful event in the crash is collision with a Pedalcyclist. Annual averages (FARS 2013–2017).

Initial Point of Impact on Vehicle	Going Straight	Turning Right	Turning Left	Overtaking another vehicle	All Others	Total
Front	8.6	2.8	1	0	0.4	12.8
Right	4.8	2.6	0	0	0.6	8.0
Left	1.4	0.4	0.2	0	0.4	2.4
Back	1.8	1	0.8	0.2	0.6	4.4
Other	2.8	2	0.2	0	0.2	5.2
Total	19.4	8.8	2.2	0.2	2.2	32.8

1.3 LATERAL PROTECTION DEVICES (LPDS)

LPDs, also referred to as lateral protective devices, are required on certain motor vehicles, trailers, and semi-trailers in at least 32 countries. As shown in Figure 1, LPDs are intended to mitigate pedestrian and pedalcyclist fatalities in crashes where the sides of large trucks is the point of impact by shielding pedestrians and pedalcyclists from entering the open space between the axle groups of large trucks. In recent years, several U.S. cities have required LPDs on heavy SUTs owned, operated, or contracted for operation in the city as part of a Vision Zero[iii] initiative.

Figure 1. Picture. Side-by-side comparison of trucks with and without LPDs, with the unshielded gap between axles marked by a red arrow.

Current Federal regulations require rear impact guards for trailers and semi-trailers. These are intended to reduce the number of deaths and serious injuries resulting from passenger cars rear-ending these vehicles. However, there are currently no Federal regulations in the U.S. concerning LPDs intended to protect pedestrians and bicyclists from falling under the sides of trucks and being caught under the wheels. This review did not find any prior Federal research on truck LPDs or their potential to mitigate collisions with VRUs.

It should be noted that the focus of this study is on LPDs for protecting VRUs, not LPDs designed to protect car occupants by preventing vehicle underride. LPDs for protecting car occupants are more substantial and heavier than LPDs for protecting VRUs. Furthermore, this study does not consider crash avoidance and crash mitigation technologies for addressing truck-VRU fatalities and injuries.

[iii] Vision Zero is a strategy to eliminate all traffic fatalities and severe injuries, while increasing safe, healthy, equitable mobility for all.

2. LITERATURE REVIEW OF CURRENT LPD REGULATIONS AND STANDARDS

LPDs have been studied and selectively implemented for a long time in other countries such as Japan and the United Kingdom. There are references to LPD designs from as early as 1912, while the first legislative requirements in select countries appeared in the 1970s. Japan and the United Kingdom (UK) were among the first in requiring the use of LPDs on large vehicles (in 1979 and 1986, respectively), and the United Nations (UN) and China have maintained LPD regulations since 1988 and 1989, respectively, in various climatic, roadway, and urban conditions. This literature review also identified two countries in South America—Peru and Brazil—with national LPD regulations.

This section reviews LPD regulations and regulatory trends and compares their applicability to different vehicle types. Volpe's partnership with the Massachusetts Institute of Technology Library partnership supported this literature review, which covers international regulations, foreign regulations, requirements in some U.S. cities, and industry standards and recommended specifications. A non-exhaustive review of these sources along with online image searches identified 65 countries where LPDs are used, either because of regulation, or other adoption methods (Table 7).

Table 7. Number of countries where use of LPDs on trucks was identified.

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

Source: Volpe.

*Includes the European Union.

2.1 INTERNATIONAL REGULATIONS

After 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).[iv] 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

[iv] 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 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—was expanded beyond Europe in a 1995 revision.(7) 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, this literature review identified 43 countries that have adopted this regulation (see Appendix A for a full list of countries).(8) Figure 2 provides images of UN Regulation 73 LPDs in France, the Netherlands, and Thailand. Figure 5 in Appendix A provides a schematic of the current UN Regulation 73 dimensional requirements.

Figure 2. Photographs. Images of UN Regulation 73 LPDs in France (top), the Netherlands (middle), and Thailand (bottom).

Sources: Top and middle, Volpe; bottom, Nuttapong Wannavijid, 123rf.com.

Finally, the International Standards Organization maintains a typology to categorize all standards around the world. The International Classification of Standards number relevant to LPDs is 43.040.60—Bodies and body components.(9)

2.2 REGULATIONS IN FOREIGN COUNTRIES

Outside of the international UN Regulation 73, seven countries have taken steps to standardize LPD usage. The earliest national standard that Volpe found was Japan's "Pedestrian Protecting LPDs," which made LPDs a requirement in 1979.(10) The United Kingdom followed with a 1983 amendment to the Road Vehicles (Construction and Use) Regulations to require the fitting of LPDs to some new goods vehicles and some existing semitrailers.(11) This regulation would eventually serve as the model for UN Regulation 73. National LPD regulations have also been implemented in China (1989), Peru (2003), and Brazil (2009) (see Figure 3).

Two nations outside of the United States have also seen LPD programs on a local level, with the implementation of a LPD requirement for large vehicles in Mexico City in 2015, and for city fleet vehicles in two Canadian jurisdictions: Saint-Laurent (Montréal), Quebec in 2013, and St. John's, Newfoundland and Labrador in 2017.(12) (13) (14) Table 13, in Appendix A, details the specifications of each national standard. Schematics and narrative descriptions follow, including the subnational regulations passed in Mexico and Canada. See Figure 3.

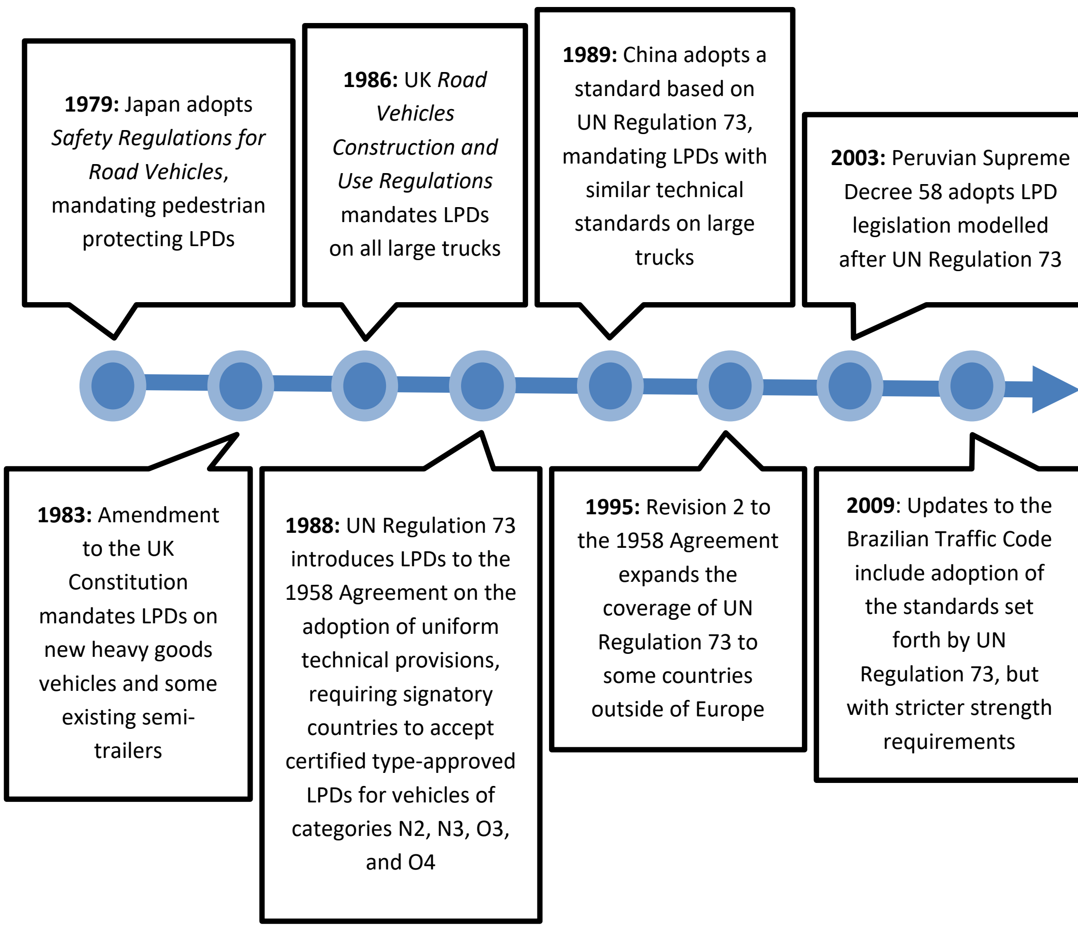


Figure 3. Timeline. National regulations relative to the passage and expansion of UN Regulation 73.

2.3 LPD SPECIFICATIONS IN THE U.S.

2.3.1 Federal

Large trucks sold in the United States are required to comply with applicable Federal Motor Vehicle Safety Standards (FMVSSs) and operation and maintenance of these vehicles are regulated by the Federal Motor Carrier Safety Regulations (FMCSRs). FMVSS No. 223 applies to rear impact guards, which are intended to arrest light-duty vehicles crashing into the rear of a tractor trailer. No FMVSS or FMCSR currently requires or references LPDs. At the time of publication, no Federal regulation or guidance focusing on VRU injury mitigation appears to exist or to have been considered in past Federal rulemakings.

2.3.2 State and Local

Although no national LPD regulations currently exist in the United States, there are at least seven municipal requirements that have been implemented or planned since 2008. Washington, D.C.; New York, NY; the adjoining cities of Boston, Cambridge, and Somerville, MA; Seattle; San Francisco; Chicago; and Philadelphia have required LPDs on a combination of municipal heavy-duty vehicles, city-regulated trucks, or all registered trucks in the municipality. In 2008, the Council of the District of Columbia passed a law requiring District-owned heavy-duty vehicles to be equipped with side-underrun guards, but no funds were appropriated for the District to meet these requirements until 2014. Also in 2008, Portland, OR implemented a pilot program on its municipal truck fleet which resulted in about 12 vehicles being fitted with LPDs. [(15)]

In 2013, Boston began retrofitting city vehicles with LPDs, and in October 2014 it enacted the Nation's first ordinance requiring LPDs on city-contracted trucks, followed by similar ordinances in Somerville, MA and Chicago.[(16)] In 2015, the New York City Council enacted a local law requiring LPDs 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, potentially making it the broadest LPD requirement in the United States.[(17)] It is estimated that approximately 3,000 trucks have been equipped with LPDs through mid-2018 collectively under these local laws.

With the exception of Boston's laws, these local laws have referenced and adopted the 2016 LPD specifications developed by Volpe (see Section 2.4) and are therefore generally similar (see Figure 4 and Table 7). The Boston ordinance preceded the Volpe developed specifications and was instead modeled on the UN Regulation 73 specifications. See Figure 4 and Table 8.

Figure 4. Photographs. Images of LPD-equipped trucks in Cambridge (top left), Boston (top right), New York City (middle left, middle right, and bottom left), and Chicago (bottom right).

Sources: Chicago: Rosanne Ferrugia; Boston: Kristopher Carter; others: Volpe.

Table 8. Summary of local LPD requirements and specifications, for trucks with a gross vehicle weight rating (GVWR) of 10,000 pounds or more.

City	Date Enacted	Vehicles Exempted	Strength Rqmt.	Maximum Ground Clearance	Maximum Gap between Guard and Wheels
Boston, MA	2014	Agricultural trailers, Fire engines, and Trucks used exclusively for snow removal.	2 kN (440 lbs.)	21.5 in.	11.8 in.
New York, NY	2015	Street sweepers, Fire engines, Car carriers, and Off-road construction vehicle types on which LPD installation is deemed impractical by the department.	2 kN (440 lbs.)	350 mm (13.8 in.)	11.8 in.
Washington, DC	2016	None	2 kN (440 lbs.)	350 mm (13.8 in.)	11.8 in.
Somerville, MA	2017	Ambulance; Fire apparatus; Low-speed vehicle with maximum speed under 15 mi/hr; Agricultural tractor.	2 kN (440 lbs.)	350 mm (13.8 in.)	11.8 in.
Chicago, IL	2017	Ambulance; Fire apparatus; Low-speed vehicle with maximum speed under 15 mi/hr; Agricultural tractor.	2 kN (440 lbs.)	350 mm (13.8 in.)	11.8 in.

2.4 INDUSTRY STANDARDS AND RECOMMENDED SPECIFICATIONS

The Australian Trucking Association standard in Australia, the Construction Logistics and Community Safety (CLOCS) Standard and Fleet Operator Recognition Scheme (FORS) in U.K are industry standards with specifications for LPD on large trucks. The specifications developed by Volpe for LPDs are more stringent than other standards and regulations adopted outside the U.S., with a strength requirement of 2 kilonewtons (kN) and a maximum ground clearance of 350 millimeters (mm). The Australian Trucking Association's standard ("Side Under Run Protection Technical Advisory Procedure") is the most lenient, with a strength requirement of 1 kN and a maximum ground clearance of 550 mm.[18] The CLOCS, FORS, and Australian Trucking Association standards are adopted mostly by industry members, while the specifications developed by Volpe have been adopted by a mix of domestic private fleets and U.S. cities (see Table 9).

Table 9. Summary of Industry LPD standards in Australia and the United Kingdom, and LPD specifications Developed by Volpe.

Standard	Year Published	Adopters	Vehicles Covered	Strength Rqmt.	Maximum Ground Clearance	Maximum Gap Between Wheels and Guard
Australian Trucking Association 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
CLOCS Standard for Construction Logistics; 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 LPD, 300 mm (11.8 in.) between the back of the LPD and the back tire
Volpe developed specifications — 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 [v]	350 mm (13.8 inch) clearance	Should not exceed 300 mm (11.8 inches)

2.4.1 Adopters of LPD Specifications Developed by Volpe

LPD specifications developed by Volpe have been adopted by some local jurisdictions in the United States and Canada. Additionally, Mexico City's 2015 LPD regulation is based on the specifications developed by Volpe. Table 10 summarizes known adoption of LPDs in accordance

[v] The specifications developed by Volpe are published in Imperial units; however, it is summarized here in metric units for consistency with the other standards.

with Volpe developed specifications among North American jurisdictions, insurers, and institutions.

Table 10. Jurisdictions and other entities that have adopted LPDs with Volpe-developed specifications.

Adopting Entity	Year of Adoption
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

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 LPDs or may require LPD modifications. The existing vehicle exemptions in UN Regulation 73 and the UK Road Vehicles (Construction and Use) Regulations are provided in Appendix A.

2.6 SUMMARY OF LPD REGULATIONS AND STANDARDS

A comparison of the key attributes of the national standards and the multinational UN Regulation 73 shows a wide variety of standards First, the UK standard applies to trucks of a lower GVWR than the Japan standard: 3,500 kg or 7,716 lbs. compared to 8 tons or 16,000 lbs. But the UK standard exempts more vehicle types and allows a higher ground clearance: 550 mm or 21.7 in. compared to 450 mm or 17.7 in. The UN regulation requires a minimum ground clearance of 550 mm (21.7 in.) and a minimum strength requirement of 1 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 LPDs to withstand forces of 5 kN.(19)

LPD regulations passed by municipalities tend to be modeled on UN Regulation 73, or on standards adopted by peer municipalities. For example, Mexico City enacted a law based on one passed in New York City, which was based on the specifications developed by Volpe.

[This page left intentionally blank]

3. LITERATURE REVIEW OF EFFECTIVENESS ESTIMATES OF LPDS

Section 3.1 describes the nature of the 11 publications that contained data specifically on the effectiveness of LPDs in mitigating fatalities and injuries to VRUs impacting the side of a large trucks. Section 3.2 summarizes the data that these studies provide on VRU collisions with the side of trucks, and the estimated effectiveness of LPDs in mitigating VRU fatalities and injuries in such collisions. All publications studied LPD implementation outside the United States.

3.1 OVERVIEW OF STUDIES

Field evaluation studies report that LPDs are effective during passing and overtaking maneuvers, in which the truck travels roughly parallel with the VRU, with VRU impacts on the passenger side of the vehicle ("nearside," in UK terminology) but not in VRU impacts to the side of large trucks when the truck is turning.

Some publications had multiple study components and are therefore 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 ESTIMATES

The introduction of LPDs globally over the past three decades was intended to prevent bicyclists and pedestrians from falling into the space between the axles of a large truck and being run over by the wheels. Field data studies from the United Kingdom show that LPDs have some level of effectiveness in mitigating VRU fatalities in collisions with the side of trucks (passenger-side of truck) in glancing collisions where the truck and VRU are traveling straight ahead roughly parallel to each other. However, the same field data indicates that LPDs have little or no effectiveness in mitigating fatalities in VRU collisions with the side of large trucks when the truck is turning left or right. There are some preliminary simulation studies indicating that LPDs with lower ground clearance may have some effectiveness in mitigating fatalities in VRU impacts to the side of large truck when the large truck is turning. However, these studies are inconclusive and need further verification.

Effectiveness of a device is the proportion of fatalities or injuries that would be prevented for specific crash conditions if the device had been present on the vehicle. If "e" is the effectiveness (in percentage) of LPDs in mitigating bicyclist fatalities in collisions with the side of large trucks, where the bicyclist and truck are traveling roughly parallel to each other, and "n" is the total number of bicyclist fatalities in similar collisions with large trucks without LPDs, then the number of bicyclist lives that could have been saved if trucks were equipped with LPDs would equal n x e/100.

3.2.1 Summary of Tables

Overall, there is much more information available for bicyclist fatalities than for any other category of VRU collisions with large trucks (bicyclist serious injuries, pedestrian fatalities, and pedestrian serious injuries).

In its 2005 study, Transportation Research Laboratory (TRL) analyzed the STATS19 road accident dataset[20] for the years 1980–1982 (before the original introduction of LPDs) and 1990–1992 (10 years later when LPDs were standard in the U.K. truck fleet). The study compared the percentage of bicyclist fatalities and serious injuries among all bicyclist collisions into the side of large trucks (passenger-side) for the two three-year periods 1980–1982 and 1990–1992 to estimate effectiveness of LPDs. In bicyclist collisions into the side of trucks (passenger-side), where the truck and the bicyclist were traveling straight ahead, there was a 61 percent reduction in the percentage of fatalities and 13 percent reduction in the percentage of serious injuries after the implementation of LPDs. However, in bicyclist crashes into the side of trucks in other pre-crash vehicle maneuvers, such as the vehicle turning right or left, the proportion of killed or seriously injured cyclists was similar before and after LPDs were introduced. TRL noted that this suggests LPDs are only effective in collisions to the side of trucks where the bicyclist and truck are traveling straight ahead roughly parallel to each other before the crash. TRL also found that in crashes involving pedestrians colliding with the side of a truck (passenger-side) that was moving straight ahead, there was a 20 percent reduction in the proportion of pedestrian fatalities after LPDs were required but no reduction in serious or minor injuries. The STAT19 data also showed that there was no reduction in pedestrian fatalities in other pre-crash vehicle maneuvers (vehicle turning left or right).

TRL also conducted an in-depth study which suggested that crashes between cyclists and trucks turning left (a left turn in U.K. is equivalent to a right turn in the U.S.) often involve a collision with the vehicle side toward the front of the vehicle which knocks the cyclist to the ground.[44] As the truck progresses with its turn, the rear of the vehicle cuts into the corner, and the LPD passes over the top of the prone cyclist who then gets run-over by the rear wheels of the truck.

A follow up study was conducted by TRL in 2010 comparing STATS19 accident data of bicyclist collisions into the side of large trucks, where the truck and the bicyclist were traveling straight ahead roughly parallel to each other, for the years 2006–2008 and 1980–1982. This 2010 study showed that after LPDs became a standard feature in the U.K. truck fleet, the percentage of bicyclist fatalities decreased by 56 percent and the percentage of serious injuries decreased by 3 percent in bicyclist collisions with the side of trucks (passenger-side of truck) when both the truck and cyclist were traveling straight ahead, roughly parallel to each other. However, this study also showed that LPDs had no effectiveness in preventing bicyclist fatalities and injuries for other pre-crash vehicle maneuvers such as when the truck is turning left or right. TRL suggested that a lower ground clearance than the required 550 mm could improve the effectiveness of LPDs in left turn crashes but noted that further research is needed.

Table 10 summarizes four UK studies that relied on “before and after” comparisons of national data (Knight, 2005), (Smith, 2005), (Cookson, 2010), (Robinson, 2014). Among all bicyclist collisions with large trucks across the three observation periods from 1980–1982, 1990–1992, and 2006–2008, fatal collisions with the sides of trucks when the truck and bicyclist are traveling roughly parallel to each other range from 6 to 15 percent, and similar collisions resulting in serious injury to the bicyclist range from 28.5 to 33 percent. The effectiveness estimates of LPDs in mitigating bicyclist fatalities in such collisions with the side of trucks ranged from 50 to 74 percent and estimates of LPD effectiveness in mitigating serious injury to bicyclist in similar collisions ranged from 3 to 9 percent.

The UK study (Knight, 2005) estimated that in pedestrian collisions with the side of large trucks when truck and pedestrian are traveling straight ahead, the effectiveness of LPDs in mitigating pedestrian fatalities is 17–27 percent. This study found that LPDs had no effectiveness in mitigating serious injury to pedestrians involved in similar collisions with large trucks. Table 11 summarizes the key information from these studies.

Table 11: Summary table of four UK studies comparing nationwide data from 1980 to 2008. Effectiveness Estimates of LPDs in Collisions of VRUs with the Side of Large Trucks where the truck and VRU are traveling roughly parallel to each other.

Safety impact	Effectiveness estimates (reduction in fatality or serious injury as a proportion of all injuries)
Bicyclist fatalities	50–74%
Bicyclist serious injuries	3–9%
Pedestrian fatalities	17–27%
Pedestrian serious injuries	0%

Table 12 summarizes other studies from Australia and the Netherlands that show effectiveness estimates of LPDs for pedestrians and bicyclists (Australia) or combined effectiveness estimates for pedestrians and bicyclists (the Netherlands). Table 12 also includes a UK study that provides a single combined effectiveness estimate for motorcycles, bicyclists, and pedestrians.

Table 12. Effectiveness Estimates of LPDs in Collisions of VRUs with the Side of Large Trucks (studies from Australia, the Netherlands, and the UK).

Publication	Guard implementation	Crash set	Effectiveness (reduction in fatality or serious injury as a proportion of all injuries)
Rechnitzer, 1993	Not specified	All fatal crashes	20.0%
Rechnitzer, 1993	Not specified	All serious injury crashes	25.0%
VanKampen, 1999	Bus as proxy for low-clearance guard condition	All passenger side turning maneuvers (rail-style LPD)	25.0%
VanKampen, 1999	Bus as proxy for low-clearance guard condition	All passenger side turning maneuvers (smooth-style LPD)	35.0%
Riley, 1981	Not specified	Side impacts for motorcyclists, bicyclists, and pedestrians	24.0%

3.3 SUMMARY OF FINDINGS ON EFFECTIVENESS ESTIMATES

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. Most studies focused on bicyclist fatalities, although there were several studies that addressed safety effectiveness for pedestrians and motorcyclists. According to the literature review, the effectiveness estimates of LPDs in preventing fatalities in VRU collisions with the side of large trucks (passenger-side of trucks), where the VRU and truck are traveling straight ahead, roughly parallel to each other, range from 50 to 74 percent for bicyclists and 17 to 27 percent for pedestrians. The effectiveness estimates of LPDs in mitigating serious injury in similar collisions between VRUs and large trucks range from 3 to 9 percent for bicyclists and about zero for pedestrians. The literature review also indicated that LPDs are not effective in mitigating VRU fatalities and injuries in VRU collisions with the side of trucks when the truck is turning left or right.

4. SUMMARY

4.1 U.S. VRU FATALITY DATA RELEVANT TO LPDS

In 2017, there were 5,977 pedestrians and 783 pedalcyclists killed in motor vehicle traffic crashes in the United States (U.S.). Among these fatalities, about 0.5 percent (27) of the pedestrian fatalities and 3.3 percent of the pedalcyclist fatalities involved impacts to the left or right side of large trucks. Seventy-five (75) percent of the pedestrian and pedalcyclist fatalities were in collisions with the front of passenger cars and light trucks.

On an annual average, there are 26 pedestrian and 22 pedalcyclist fatalities in collisions with the left and right of large trucks (SUTs and truck-trailers) in the U.S (FARS 2013–2017). Among these fatalities, an annual average of 16 pedestrian and 11 bicyclist fatalities involve large truck pre-impact maneuvers for which LPDs have been shown to be effective in mitigating VRU fatalities (truck and VRU travelling straight ahead, roughly parallel to each other). Therefore, LPD technology may be relevant to about 0.3 percent of all pedestrian fatalities and 1.4 percent of all pedalcyclist fatalities in the US annually.

4.2 EXISTING LPD REGULATIONS

There is global precedent for VRU-protecting LPD or lateral protective device adoption, as demonstrated by overseas national regulations over the past 40 years, the multinational UN regulation adopted by 43 countries and the European Union.

Specifications vary among the regulations and standards reviewed, but the approximate geometry and strength requirements remain relatively consistent. Most LPD 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. Maximum ground clearances range from 350 mm (13.8 in.) to 550 mm (21.7 in.).

In contrast to the VRU-protecting LPDs 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 LPD technology aims to protect, and to apply the proper context in any potential future U.S. standards or regulations.

4.3 EFFECTIVENESS STUDIES

Most studies focused on bicyclist fatalities, although there were several studies that addressed safety effectiveness for pedestrians and motorcyclists. Field evaluation studies in other countries report that LPDs are effective during passing and overtaking maneuvers, in which the truck travels roughly parallel with the VRU, with VRU impacts on the passenger side of the vehicle (“nearside,” in UK terminology) but not in VRU impacts to the side of large trucks when the truck is turning.

According to the literature review, the effectiveness estimates of LPDs in preventing fatalities in VRU collisions with the side of large trucks (passenger-side of trucks), where the VRU and truck are traveling roughly parallel to each other, range from 50 to 74 percent for bicyclists and 17 to 27 percent for pedestrians. The effectiveness estimates of LPDs in mitigating serious injury in similar collisions between VRUs and large trucks range from 3 to 9 percent for bicyclists and about zero for pedestrians. The literature review also indicated that LPDs are not effective in mitigating VRU fatalities and injuries in VRU collisions with the side of trucks when the truck is turning left or right.

4.4 APPROACHES TO VRU SAFETY IN THE U.S.

The literature review compiled studies of effectiveness estimates of LPDs in other countries. It is unclear whether these effectiveness estimates can be directly applied in the U.S because of differences in VRU exposure and infrastructure designs. Data from the LPD implementation in some cities in the U.S. may provide insight into the performance of LPDs in U.S. application.

At the time of application of LPD regulations in other countries, advanced technologies such as detection and warning systems and other advanced driver assistance systems were not available. However, with the current availability of advanced technologies, a comprehensive review of all available vehicle technologies and infrastructure designs is needed to determine the most effective and practical approach to mitigating VRU injuries and fatalities in all types of collisions with vehicles. Vehicle technologies include LPDs, cameras and mirrors to improve driver visibility, collision avoidance systems, and pedestrian crash avoidance mitigation systems. Infrastructure designs include bike lanes and sidewalks and improved intersection designs.

APPENDIX A – LPD REGULATIONS AND STANDARDS

NATIONAL STANDARDS AND SPECIFICATIONS

Table 13 summarizes national standards and their specifications. UN Regulation 73 is included for comparison purposes.

Table 13. Summary table of national standards and their specifications.

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.[vi]	Not available	450 mm (17.7 in.)[vii]	Not available

[vi] This definition typically exempts buses.

[vii] 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).

Country	Year Passed	Vehicles Covered	Vehicles Exempted	Strength	Maximum Ground Clearance	Maximum Gap Between Wheels and Guard
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 mi/hr; 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.)

Country	Year Passed	Vehicles Covered	Vehicles Exempted	Strength	Maximum Ground Clearance	Maximum Gap Between Wheels and Guard
United Nations [b]	1988; updated in 2007, 2010, and 2016	Vehicles of categories N_2, N_3, O_3, and O_4.[viii]	Tractors for semi-trailers, and Vehicles designed and constructed for special purposes where it is not possible, for practical reasons, to fit such lateral protection.	1 kN (225 lbs.)	550 mm (21.7 in.)	300 mm (11.8 in.)
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 LPDs due to objective reasons.	1 kN (225 lbs.)	550 mm (21.7 in.)	300 mm (11.8 in.)

[viii] 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.

Country	Year Passed	Vehicles Covered	Vehicles Exempted	Strength	Maximum Ground Clearance	Maximum Gap Between Wheels and Guard
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

Below is a list of the 44 parties that have approved UN Regulation 73 (43 countries and the European Union):

- Albania
- Austria
- Belarus
- Belgium
- Bulgaria
- Croatia
- Cyprus
- Czech Republic
- Denmark
- Egypt
- Estonia
- European Union
- Finland
- France
- Georgia
- Germany
- Greece
- Hungary
- Ireland
- Italy
- Latvia
- Lithuania
- Luxembourg
- Macedonia, Republic of
- Malaysia
- Malta
- Moldova, Republic of

- Montenegro
- Netherlands
- Norway
- Poland
- Portugal
- Romania
- Russian Federation
- San Marino
- Serbia
- Slovakia
- Slovenia
- Spain
- Sweden
- Switzerland
- Turkey
- Ukraine
- United Kingdom

Figure 5 provides a schematic of the existing UN Regulation 73 LPD dimensional requirements.

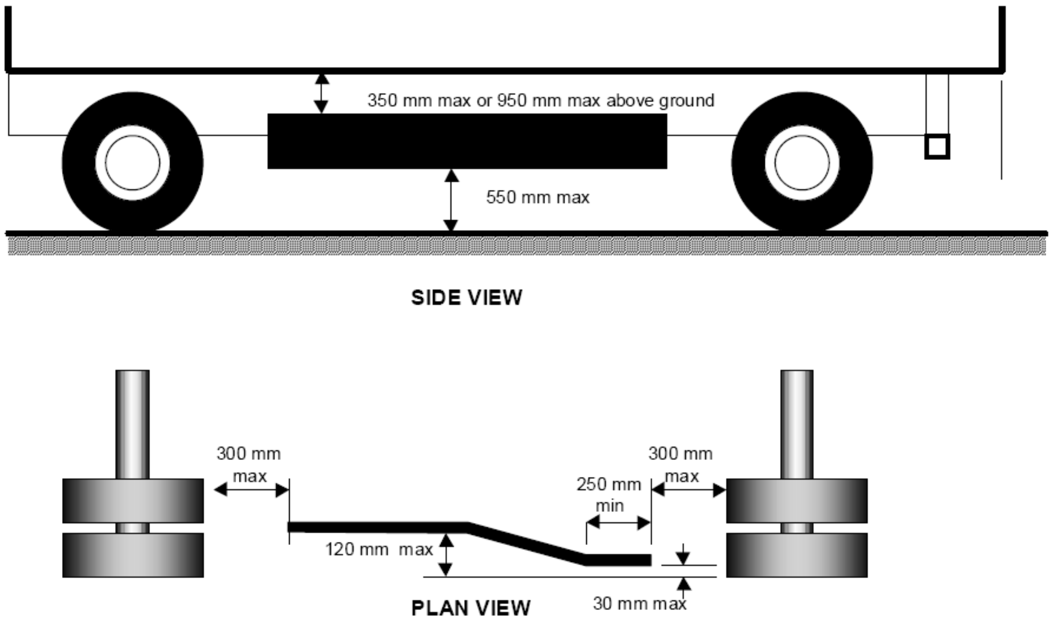


Figure 5. Schematic. UN Regulation 73 LPD dimensional requirements.

Source: UN Regulation 73.

JAPAN

LPDs became required in Japan in 1979, making Japan appear the first country to mandate the use of LPDs on heavy vehicles (Figure 6).(21) The maximum ground clearance permitted by 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 aligned with the UN standard (see Figure 5). On the largest articulated vehicles this clearance is typically even lower: 380 mm to 400 mm (15 to 15.75 in.).(22)

Figure 6. Photograph. A rail-style LPD on a truck in Japan.

Image source: Hirohito Takada, 123rf.com.

UNITED KINGDOM

LPDs 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.”[23] In 1986, LPDs were mandated on all large trucks by an Act of Parliament.[24] In 1988, the UK also agreed to be bound to UN Regulation 73, which had a lower strength requirement and fewer specific exemptions (see Figure 7).

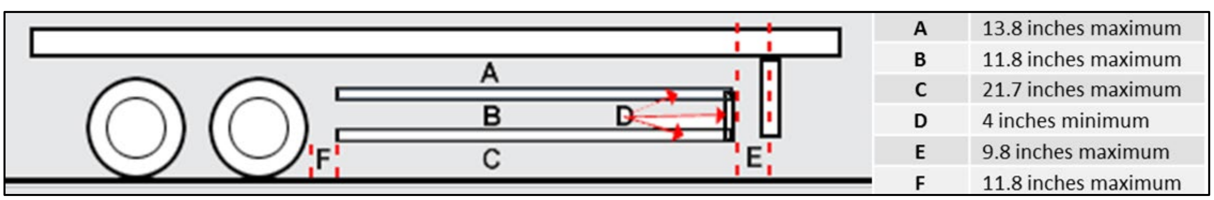


Figure 7. Technical specifications of the UK dimensional requirements for LPDs on trailers.

Adapted from Transports' Friend, n.d.

CHINA

LPDs first became mandatory in China in 1989 with the implementation of Standard GB 11567, a requirement largely aligned with the UN LPD regulation formulated the year before (see Figure 8). 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.[25]

[ix] The standard is applicable for vehicles in categories N_2, N_3, O_3, or O_4, with exemptions for tractors and vehicles designed for a special purpose that precludes LPDs. A notable example of this exemption is logging vehicles; the configuration to hold timber does not permit the installation of a guard. The regulation specifies a maximum ground clearance of 550 mm (21.7 in.) and a strength requirement of 1 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 like the one put forward by the UN in its strength requirement and applicability to vehicle types.

Figure 8. Photograph. Abandoned Chinese dump trucks with LPDs.

Source: Novyy Urengov, 123rf.com

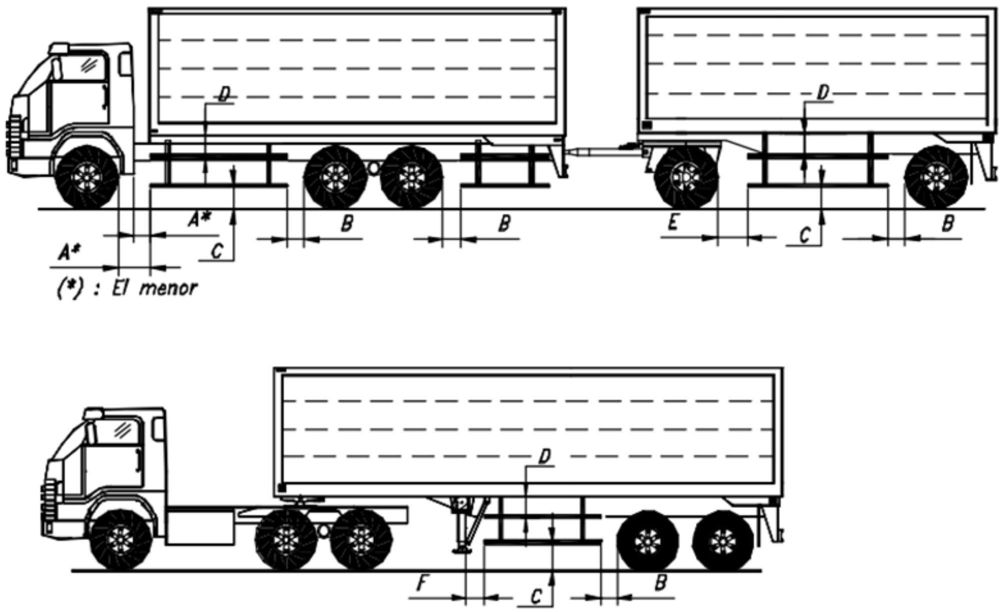
PERU

LPDs have been mandatory in Peru since the 2003 passage of Supreme Decree 58, which mandated that vehicles in categories N_2, N_3, O_3, or O_4 have lateral defenses for the protection of bicyclists, pedestrians, and motorcyclists.[26] 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 9 and Figure 10). The guards must be a maximum of 120 mm (4.7 in.) from the outer edge of the wheels or friction rail of the vehicle. Additionally, the regulation specifies that the LPD should have a smooth exterior surface and no sharp edges.

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

Unlike many of the other national regulations, there is no strength requirement specified for the guard.

Figure 9. Photographs. Single-unit and combination tractor trailers equipped with LPDs 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 10. Schematic. Technical specifications of the Peru standard.(27)

BRAZIL

With the passage of Resolution 323 to the Brazilian Traffic Code in 2009, trucks in Brazil are required to install LPDs (see Figure 11), with the goal of protecting Brazil's large population of motorcyclists, in addition to bicyclists and other operators of small vehicles.(28) The regulation requires LPDs to withstand a load of 5 kN—the UK and UN regulations require LPDs to withstand a load of only 2 and 1 kN, respectively. The regulation requires trucks, trailers, and semi-trailers with a total gross weight of more than 3,500 kg and imported or made after 2011 to install LPDs to be legally registered.

The maximum ground clearance allowed is 550 mm (21.7 in.), and LPDs must not extend beyond the plane corresponding to the width of the vehicle (see Figure 12). The upper bound of the LPD 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 11. Photograph. A LPD on a truck in Brazil.

Source: Sergio Shumoff, 123rf.com.

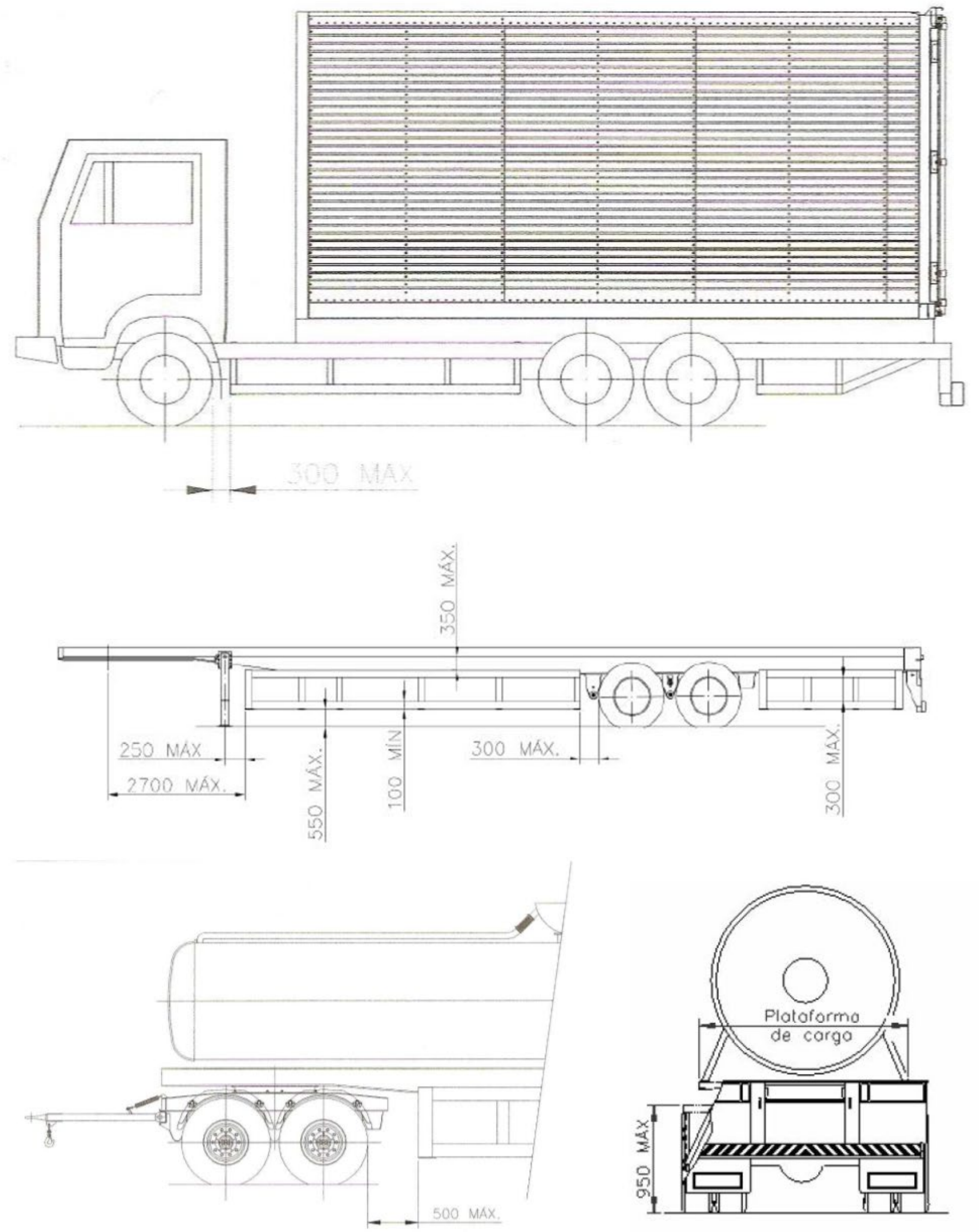


Figure 12. Schematic. Technical specifications of the Brazil standard (all figures are in millimeters).

Source: 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 LPDs in Canada. The Borough of Saint-Laurent in Montréal, Quebec began testing LPDs in 2010, passed a resolution in 2012 to equip all new eligible fleet vehicles with LPDs, and by 2014 had equipped 25 of the 33 eligible fleet trucks, with plans to fit all 33 by the end of 2015.[29] As of 2017, the city of St. John's, Newfoundland and Labrador has also implemented LPDs on 43 fleet vehicles. This addition is not prescribed by any law or regulation, but has instead been implemented voluntarily following several VRU deaths. In a similar manner, the city of Westmount, an enclave of Montréal, has begun adding LPDs to it snow plows.[30]

LPDs 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 LPDs in Canada.[31]

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.[32] The regulation requirements were modeled on the New York City LPD standard, which is consistent with the specifications developed by Volpe.[33]

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 LPD must be able to withstand a force of 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 13). This 2 kN strength specification is consistent with the UK standard, higher than UN Regulation 73, and lower than the Brazil standard.

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 LPD instead of horizontal rails or bars. Finally, the regulation specifies that the LPD must be made of stainless steel.

From secondary sources, Volpe found that a national Mexican LPD 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.[34]

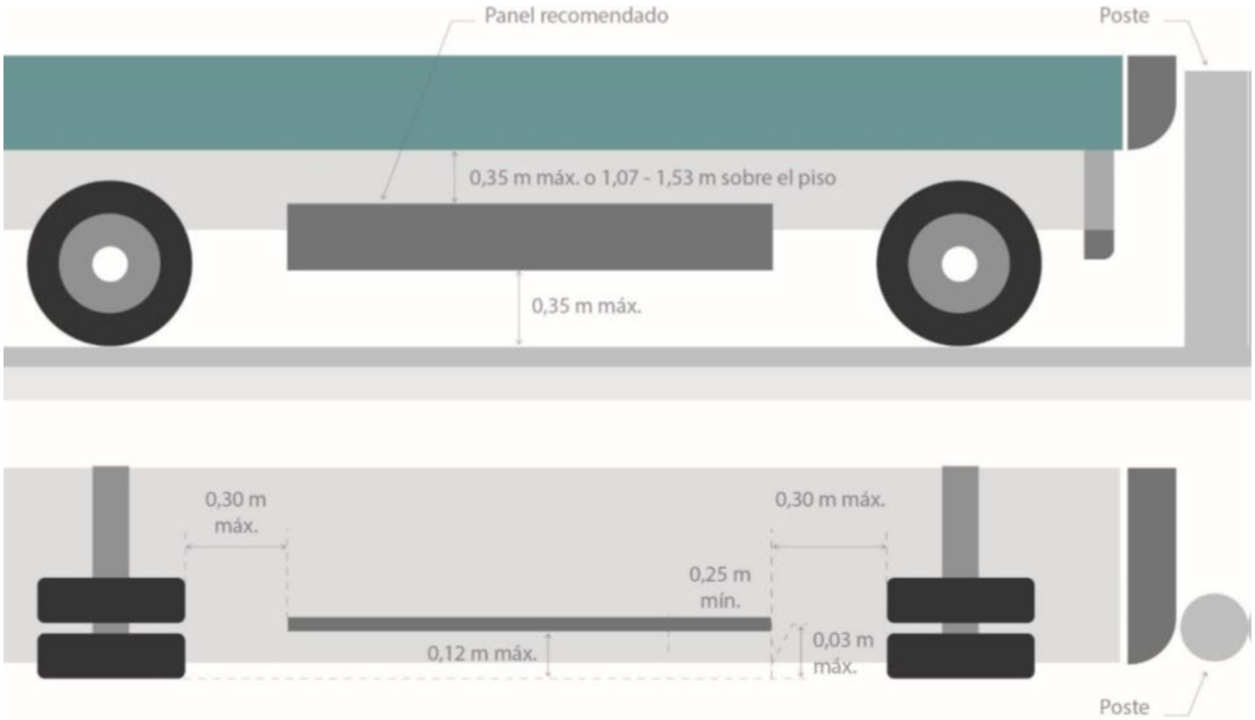


Figure 13. Schematic. Specifications of the Mexico City standard.[35]

OTHER POTENTIAL LPD ADOPTION IN FOREIGN COUNTRIES

A non-exhaustive review of vehicle images indicates that at least 14 additional countries likely see relatively widespread adoption of LPDs and may have implemented their own requirements or guidance.[x] When added to the 43 countries that abide by UN Regulation 73, the 4 unique countries already identified as having national LPD regulations, and the 4 countries with sub-jurisdiction regulations or industry standards, at least 65 countries appear to have widespread LPD usage, whether or not actually required. While some of these countries may have implemented LPD standards and requirements, additional research would be needed to confirm the existence and details of any regulations.

INDUSTRY STANDARDS

Australian Trucking Association Standard

The Australian Trucking Association standard was developed with the goal of providing guidelines and instructions to help truck and trailer manufacturers and truck operators in Australia comply with UN Regulation 73 LPD standards.[36] The standard is in the form of a Technical Advisory Procedure developed by the Australian Trucking Association Industry

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

Technical Council and endorsed by the Australian Trucking Association General Council. The procedure 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 comply with UN Regulation 73, for which it maps European and Australian vehicle category designations. The designs 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."[37]

The technical specifications are equivalent to those in UN Regulation 73, with two exceptions that make them more stringent: first, the Australian Trucking Association standard specifies additional LPDs rearward of the axle group; second, it recommends (but does not require) a lower maximum ground clearance of 525 mm (20.7 in.) (see Figure 14). In Australia, the Melbourne Metro Rail Authority is requiring that all trucks involved in the construction of a metro system project starting in 2017 be fitted with LPDs, and the Australian Trucking Association standard was at least partially adopted.[38] [39]

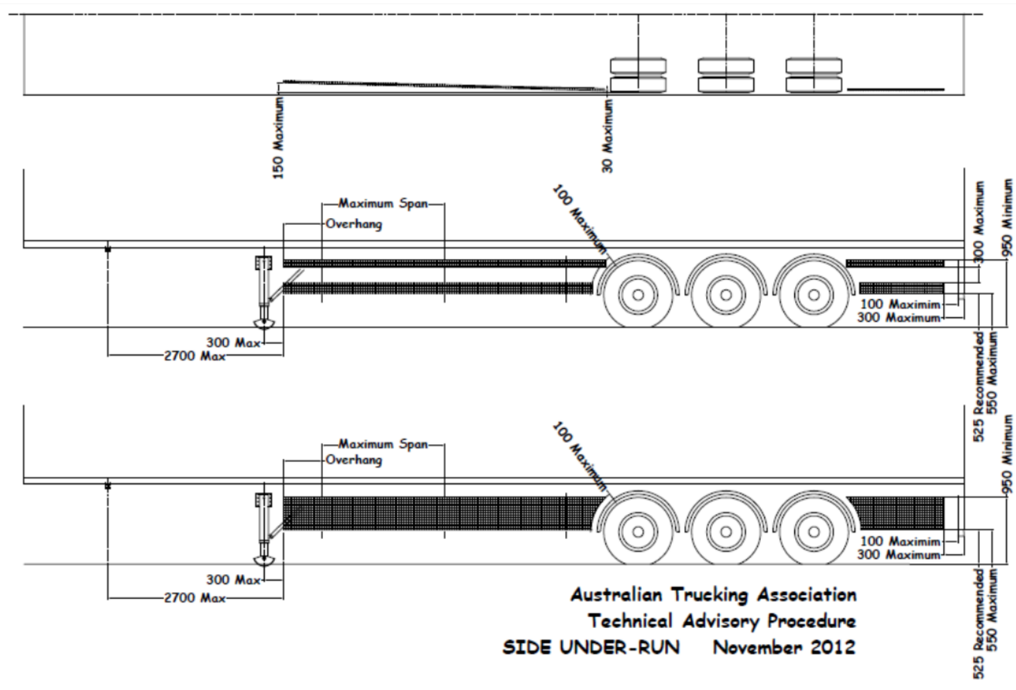


Figure 14. Schematic. Technical specifications of the Australian Trucking Association standard.

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

The Construction Logistics and Cyclist Safety (CLOCS) Standard for Construction Logistics and the Fleet Operator Recognition Scheme (FORS) are industry standards used initially in London and more recently throughout the UK.[xi] 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).[40] To comply with CLOCS, clients must fit LPDs to all vehicles that are currently exempt from LPD 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").[41]

Volpe LPD Specifications

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-VNTSC-OSTR-16-05." The origin and basis of the specifications included Volpe's initial review of international precedents, published recommendations from the (TRL and Monash University, and fleet feedback from LPD operational pilots in the cities of Boston, Cambridge, New York, and San Francisco. The Volpe specifications was published in U.S. customary units based on the 350 mm maximum ground clearance recommended by TRL and the 2 kN force test criteria (see Figure 15). Volpe recommended the stronger 2 kN standard (identical to the UK standard) to provide a larger safety margin and account for the greater average weight of people today compared to when the first LPD requirements were developed more than 30 years ago.[42]

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

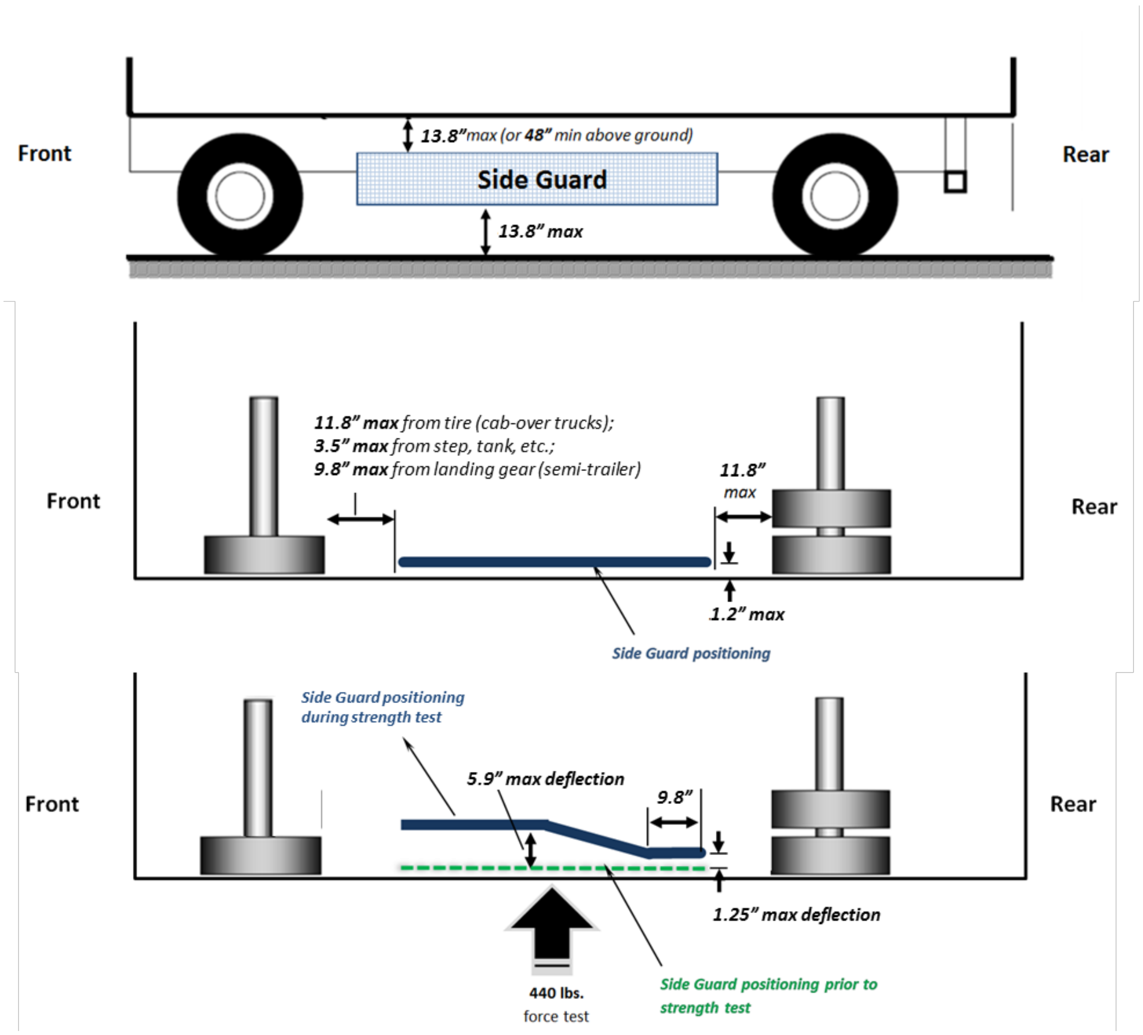


Figure 15. Schematic. Technical criteria of the specifications developed by Volpe.

Source: Volpe.

Figure 16. Photographs. Private sector rail and panel style LPDs in the Boston and New York City metro areas.

Source: Volpe

Private Sector Installations

Whether complying with local laws or acting voluntarily, some private sector U.S. fleets operating in urban areas are installing LPDs (Figure 16). In the Boston area, these include Save That Stuff, Sunrise Scavenger, Capitol Waste, EarthWorm, and Harvard University; in New York City, FreshDirect, Action Carting, New York Post, and Coca-Cola; and in Seattle, the University of Washington.

EXISTING EXEMPTIONS

The UN Regulation 73 LPD 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 that preclude installing 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, but when the trailer is extended, the gap between the LPDs and the forward or rear tire can be greater than normal.
- Cargo tank trucks equipped with hose or pipe connections for loading or unloading must be fitted with LPDs "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 (such as a crane) to provide additional stability during loading, unloading, or other operations, the LPD 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 LPD 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 LPDs, they are regarded as replacing the LPDs. UN ECE R.73 also exempts low speed vehicles from LPD requirements.

The UK Road Vehicles (Construction and Use) Regulations for LPDs excludes street sweepers, refuse collection trucks, tipping dump trucks, military vehicles, fire engines, and car carriers from complying with the regulation.

APPENDIX B – REVIEW OF EFFECTIVENESS STUDIES

FIELD EVALUATION STUDIES

Several UK studies have demonstrated the safety effectiveness of LPDs on large trucks, showing decreases in pedestrian and bicyclist injury severity for the most LPD-relevant crash types after the UK mandated LPDs for most heavy duty vehicles (see Figure 17 and Figure 18).[(43)] A 2005 UK TRL study compared 1980–1982 ("before") data with 1990–92 ("after") data, and a 2010 TRL study compared 1980–82 ("before") data with 2006–08 ("after") data.[(44)] [(45)] According to both studies, the most relevant crashes for LPDs are passenger side ("nearside") impacts in which the heavy vehicle is 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) or "overtaking moving vehicle" (2010 TRL study).

The TRL 2005 study results show that the bicyclist injury distributions for the passing/overtaking crash category changed substantially and favorably after the nationwide installation of LPDs.[(46)] In contrast, the before and after data did not show any appreciable change in the injury distribution for "passenger side turning maneuver" crashes, nor for any other crash categories. Based on this, the authors conclude that the primary safety impact of LPDs is in passing/overtaking crashes, in which the heavy vehicle is moving straight ahead. Figure 18 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 and cited by National Research Council Canada in a 2010 study.[(47)]

The 2010 TRL report comparing crash data from 2006–2008 also showed lower bicyclist fatality and serious injury rates for LPD-relevant crashes when compared to the pre-LPD 1980–1982 period.[(48)]

The 2005 TRL study revealed 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 by 20 percent, compared to the 61 percent observed for bicyclists. More detail is available in a companion TRL report.[(49)] Case studies from the Heavy Vehicle Crash Injury Study (HVCIS) and the Truck Crash Injury Study (TCIS) databases in the UK suggested that different crash mechanisms might account for this variation in effectiveness; according to these data sources, more pedestrians walked into the sides of vehicles than fell against them.[(50)]

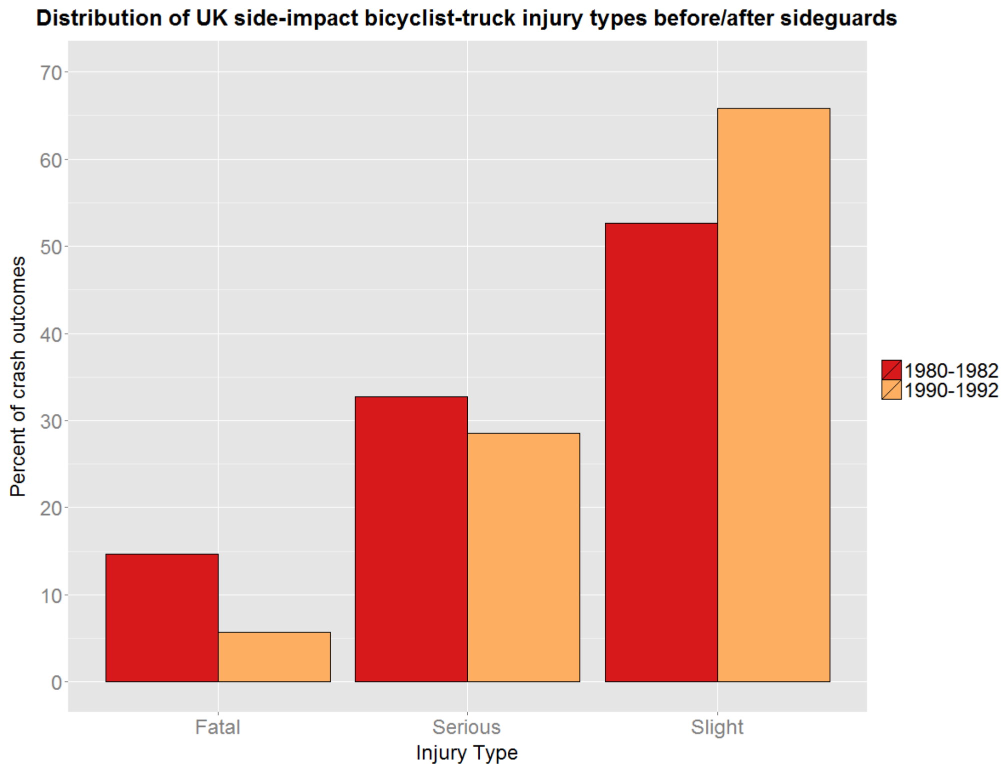


Figure 17. Bar graph. Fatality and injury distribution of bicyclists in passing/overtaking side impacts with trucks 4–6 years before and 4–6 years after the mandatory introduction of LPDs in the UK (74 crashes in 1980–82 and 66 crashes in 1990–92).

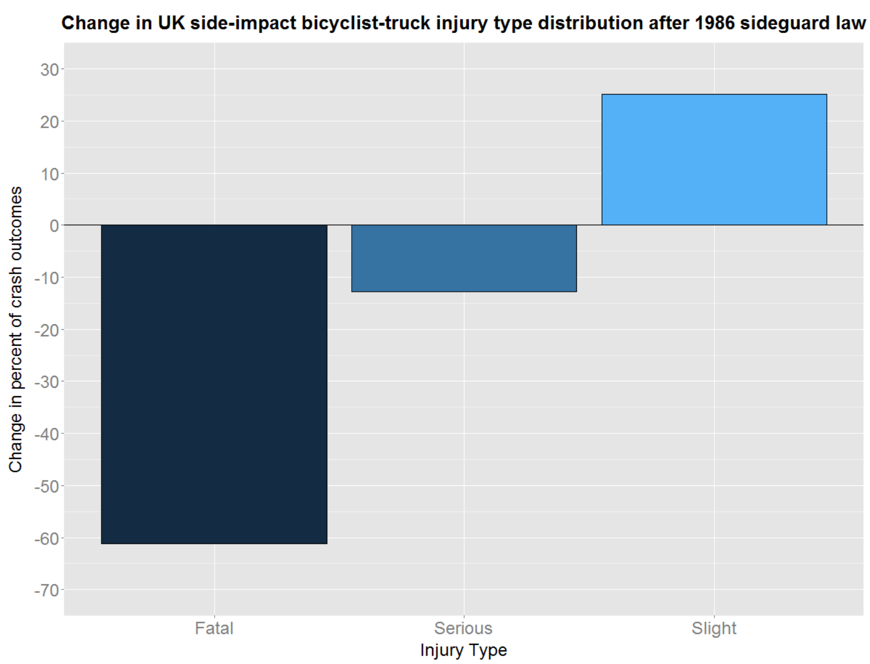


Figure 18. Bar graph. Decrease in fatality and serious injury rates for bicyclists in passing/overtaking crashes following LPD implementation in the UK (74 crashes in 1980-82 and 66 crashes in 1990-92).

It is possible that other confounding factors may have changed between the before and after measurement periods, and some may question the extent to which these uncontrolled factors, may have distorted the apparent LPD effectiveness. While confounding factors can never be ruled out entirely in real-world experiments, the knowledge available suggests that any confounding factors would have influenced only the frequency of crashes (e.g. preventative countermeasures such as mirrors, safety education campaigns, etc.), and would not have influenced the severity of crashes in the way that a mitigating countermeasure like a LPD 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 LPD-relevant categories. However, according to the 2005 TRL report, "in the non-LPD-relevant crash types the proportion of killed or seriously injured (KSI) cyclists and pedestrians were broadly similar before and after LPD introduction, or even increased slightly." This further supports the hypothesis that LPDs 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 LPD phase-in), the 2005 TRL report also compared post-phase-in crash outcomes for exempt and non-exempt trucks.[(xii)] The results were consistent with the before and after results, again suggesting that LPDs effectively mitigated crash severity in the passing/overtaking crash category. Exempt vehicles had a higher proportion of the most severe crashes (VRUs killed or seriously injured) and were overrepresented in those serious crashes when compared to non-exempt vehicles. The differences were statistically significant. Table 14 compares exempt and non-exempt vehicle crash outcomes for 1990–92.

The 2010 TRL report performed a similar comparison of exempt and non-exempt vehicles in 2006–08, and Table 15 shows that the results for the passing/overtaking crashes were consistent with both the 2005 exempt/non-exempt comparison and the before and after comparisons for both studies. All these results support the hypothesis that LPDs helped reduce the severity of crashes. The 2010 TRL report added a separate comparison of exempt and non-exempt crash data for passenger side turning maneuvers. These results were unexpected; they show that exempt vehicles were more likely to have crashes in these maneuvers, and they had a higher proportion of severe crashes. The before and after data, by contrast, only showed a minor, statistically insignificant change in the injury distribution for this crash type. The authors note that several factors could explain these conflicting results, such as the use of exempt vehicles in different environments, driver behavior, or field of view (e.g. close proximity mirrors required as of 2006).

[xii] This comparison considers crashes over the same 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 more fatal in side-impact crashes for unknown reasons unrelated to the presence of LPDs. However, both the time-series and the exempt/not exempt safety analyses are consistent and show reduced fatality rates among LPD-equipped large trucks.

Table 14. 1990–1992 crash severity distribution in truck-bicycle passing/overtaking crashes in the UK when the truck was either exempt or not exempt from LPD installation.

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

Source: Knight, et al., 2005.

Table 15. 2006–2008 crash severity distribution in truck-bicycle passing/overtaking crashes in the UK when the truck was either exempt or not exempt from LPD installation.

Truck Type	Fatal	Serious	Slight	% fatal	% KSI
Exempt (no LPDs)	4	11	15	14%	52%
Not exempt (equipped with LPDs)	3	23	43	4%	37%

Source: Cookson & Knight, 2010.

A 2014 TRL report revisited the data from the prior TRL reports, and suggested extrapolating from the results. The authors of the 2014 TRL report pointed out that the before and after comparisons from the prior studies likely underestimated the effectiveness of LPDs because the "after" period did not have universal LPD fitment. The 2014 report estimated 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 to estimate the actual effectiveness of LPDs. That is, they proposed dividing the observed efficacy by the percentage of vehicles actually equipped with LPDs. Using the effectiveness estimates from the 2005 and 2010 TRL studies, the 2014 TRL study(51) estimated effectiveness of LPDs in VRU crashes into the side of trucks where the truck and VRU are traveling straight ahead, roughly parallel to each other as follows:

- Effectiveness in mitigating pedalcyclist fatalities: 50% to 74 percent.
- Effectiveness in mitigation serious injuries to pedalcyclists: 3% to 9 percent.
- Effectiveness in mitigating pedestrian fatalities: 17% to 27 percent.
- Effectiveness in mitigating serious injuries to pedalcyclists: 0 percent.

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 LPDs. The study used buses as a proxy for LPD-equipped trucks, since the side of a bus presents a smooth surface that extends close to the ground (often lower than most LPDs). The study compares the severity of VRU crashes for buses turning right (passenger side) and trucks turning right for 1989–97, noting that serious injuries were 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.(xiii) 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 drew a distinction between "open" LPDs (i.e., rail-style) versus "closed" LPDs (i.e., smooth-style), and assigned a different effectiveness to each. The study assigned an effectiveness of 35 percent to smooth-style LPDs, based on the above analysis, and a slightly lower effectiveness of 25 percent to rail-style LPDs. The study listed four scenarios of LPD adoption and assigned cost-benefit estimates to each in terms of lives saved per guilders invested.(52)

Some studies used a hybrid qualitative/quantitative approach to assess the relevance of LPDs. 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, transcripts of interviews with drivers and witnesses, and detailed injury and trauma assessments. Unfortunately, because the data sets for these case studies were limited to fatal crashes, the studies were not able to analyze the instances when a LPD prevented a fatality. Instead, for vehicles that did not have LPDs fitted, they judged whether a LPD would have potentially mitigated the fatal injuries, based on the data and expert input available. For fatal crashes in which the vehicle had LPDs fitted, they noted how the LPD performed, and why it did not save the VRU.

- One study with a sample size of over 300 fatal crashes estimated that LPDs would have prevented fatal injuries to more than 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—that is, LPDs could have prevented 24 percent of fatalities in crashes they are designed to mitigate.(53)
- Another study had a sample size of n=27 relevant fatal crashes, including 16 "type A" crashes, in which the vehicle made contact with the cyclist by turning left or changing lanes, and 11 "type B" crashes, in which the cyclist lost control or wobbled while alongside the vehicle. Researchers determined that 20 of the 27 fatalities could have been prevented had the vehicle been fitted with a LPD (or a LPD with more rigorous technical specifications). This included 15 of the 16 "type A" crashes and 5 of the 11 "type B" crashes.(54)

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

- Another study had a sample size of 24 fatal crashes, including front and side fatal crashes of all types (not limited to LPD-relevant crashes). It found that all the fatally injured cyclists were on the ground before any LPD interaction could have occurred. The UK LPD requirement allows a gap of up to 550 mm from the bottom of the LPD to the road surface. A guard set this high can pass over a person already completely prone on the ground, and this sample did not show LPDs to be effective. The authors note that this does not prove that LPDs are ineffective; the data from the study were insufficient to prove or disprove their effectiveness given the circumstances of the crashes in this sample.[(55)]
- Another study had a sample size of four fatal rear wheel run-over crashes with LPDs fitted, and eight fatal rear wheel run-over crashes without LPDs fitted. In the four cases where LPD 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 LPD near the fuel tank, and (2) in the remaining two cases, the cyclist was already on the ground and went underneath the LPD, as described in the study above. For the crashes in which the vehicle was not fitted with a LPD, the researchers estimated that a LPD may have prevented the bicyclist from going under the vehicle in three out of eight cases.[(56)]

An Australian study estimated that LPDs 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 LPD-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.[(57)] The European estimates are from two other studies cited in this section.[(58) (59)]

EMPIRICAL STUDIES

A 1985 UK study used a crash dummy on a bicycle to test the effectiveness of a LPD for the typical LPD-relevant crash, in which 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 LPD with the maximum allowable gaps and inset under the UK regulation, and then tested improved LPDs with smaller horizontal and vertical gaps and reduced inset (i.e., surpassing contemporary UK regulatory requirements). The minimum legal LPD 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, reduced inset, and a smaller gap between the guard and the rear wheels reduced the incidence to near zero. Based on the tests, researchers recommended changes to LPD 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).[(60)]

A 1986 Swedish study by the Volvo truck manufacturing company carried out several tests and experiments with a crash dummy on a moped to assess the effectiveness of a LPD for protecting a motorcyclist or bicyclist. The study concluded that a LPD would have a positive (mitigating) influence in 35 percent of accidents.[61]

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 LPD rather than a rail-style LPD. In the simulated experiment, both LPD designs were effective at preventing the upper body of the VRU from being run over by the rear wheels, but the smooth LPD was more effective at reducing overall injury risk, especially for head impacts. Replacing rail with smooth style LPDs would result in an 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 LPDs) 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." The author concludes also that a pedestrian falling against the side of a vehicle is more likely to be protected by a LPD than a bicyclist falling against the side of a vehicle, but pedestrians have less exposure to this type of accident, so the overall benefit is smaller. The author posits that more pedestrians walk into the sides of vehicles than fall against them.[62

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to Quon Kwan and Martin Walker of FMCSA for sponsorship of this report and to several individuals for their valuable input. The authors thank Coralie Cooper and Ryan Keefe at the 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; and Volpe's Office of Communication and Knowledge Management for assistance with obtaining images.

[This page intentionally left blank.]

REFERENCES

[1] Ministry of Land, Infrastructure, Transport, and Tourism. (1979). Pedestrian Protecting Side Guards (Article 18-2). *Safety Regulations for Road Vehicles*. Japan: Ministry of Land, Infrastructure, Transport, and Tourism.[2] United Nations Economic Commission for Europe. (1995). Regulation No 73 of the Economic Commission for Europe of the United Nations (UNECE) - Uniform provisions concerning the approval of goods vehicles, trailers and semi-trailers with regard to their lateral protection. *Official Journal of the European Union*. United Nations Economic Commission for Europe.

[3] The Parliament of the United Kingdom. (June 25, 1986). The Road Vehicles (Construction and Use) Regulations 1986. *Statutory Instruments, 1986 No. 1078, Road Traffic*. United Kingdom: The Parliament of the United Kingdom.

[4] National Highway Traffic Safety Administration (March 2019) Pedestrians Traffic Safety Facts 2017 Data, DOT HS 812 681, https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812681.

[5] National Highway Traffic Safety Administration (June 2019) Bicyclists and Other Cyclists Traffic Safety Facts 2017 Data, DOT HS 812 765, https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812765.

[6] Fatality Analysis Reporting System, https://www.nhtsa.gov/research-data/fatality-analysis-reporting-system-fars.

[7] GlobalAutoRegs. (2017). *About UN Regulations*. Retrieved from GlobalAutoRegs.com: https://globalautoregs.com/rules?t=UNR.

[8] UNECE Inland Transport Committee. (February 28, 2017). *Status of the Agreement, of the annexed UN Regulations and of amendments thereto.* Retrieved from World Forum for Harmonization of Vehicle Regulations: https://www.unece.org/fileadmin/DAM/trans/main/wp29/wp29regs/2017/ECE-TRANS-WP.29-343-Rev.25.pdf.

[9] International Organization for Standardization. (n.d.). *43.040.60 - Bodies and body components*. Retrieved June 2017, from Standards catalogue: https://www.iso.org/ics/43.040.60/x/.

[10] Pedestrian Protecting Side Guards, Article 18-2. (1979). *Safety Regulations for Road Vehicles*. Japan.

[11] The Parliament of the United Kingdom. (June 25, 1986). The Road Vehicles (Construction and Use) Regulations 1986. *Statutory Instruments, 1986 No. 1078, Road Traffic*. United Kingdom: The Parliament of the United Kingdom.

[12] Salvaguardas para Camiones Urbanos. (August 17, 2015). *Reglamento de Tránsito del Distrito Federal*. Mexico City, Mexico: GACETA OFICIAL DEL DISTRITO FEDERAL.

[13] The Jessica Campaign. (June 10, 2016). Side Guards Resolution to Federation of Canadian Municipalities, Saint Laurent, Montréal, QC. Saint Laurent, Montréal, Quebec, Canada. Retrieved from http://thejessicacampaign.ca/2016/09/26/side-guards-resolution-to-federation-of-municipalities-by-city-of-saint-laurent-montreal-qc/.

[14] Macdonald, B. (June 30, 2016). Municipal Fleet Manager, City of St. John's. (K. Welty, Interviewer).

[15] DePiero, D., & Leader, D. (November 30, 2012). City of Portland City Fleet, Bureasu of Internal Business Services Employees. (A. Epstein, Interviewer)

[16] City of Boston Mayor's Office. (October 29, 2014). *City Council Passes Truck Side Guard Ordinance.* Retrieved from CityofBoston.gov: https://www.cityofboston.gov/news/default.aspx?id=14853.

[17] Council of the District of Columbia. (July 25, 2016). Bicycle and Pedestrian Safety Amendment Act of 2016. Washington, D.C., United States: Council of the District of Columbia.

[18] Australian Trucking Association. (2012). Technical Advisory Procedure: Side Under Run Protection. ATA Industry Technical Council.

[19] Ministerio de Transportes y Comunicaciones. (October 2003). Decreto Supremo No. 058-2003-MTC. *Reglamento Nacional de Vehículos*. Peru: Ministerio de Transportes y Comunicaciones.

[20] STATS19 road accident dataset consists of road accidents on the public highway in Great Britain, reported to the police and which involve human injury or death. http://www.adls.ac.uk/department-for-transport/stats19-road-accident-dataset/?detail#top.

[21] Pedestrian Protecting Side Guards, Article 18-2. (1979). *Safety Regulations for Road Vehicles*. Japan.

[22] Riley, B., Penoyre, S., & Bates, H. (1985). Protecting Car Occupants, Pedestrians, and Cyclists in Accidents Involving Heavy Goods Vehicles by Using Front Underrun Bumpers and Sideguards. *10th International Technical Conference on Enhanced Safety of Vehicles*, (pp. 883-896). Oxford.

[23] Riley, B., Penoyre, S., & Bates, H. (1985). Protecting Car Occupants, Pedestrians, and Cyclists in Accidents Involving Heavy Goods Vehicles by Using Front Underrun Bumpers and Sideguards. *10th International Technical Conference on Enhanced Safety of Vehicles*, (pp. 883-896). Oxford.

[24] The Parliament of the United Kingdom. (June 25, 1986). The Road Vehicles (Construction and Use) Regulations 1986. *Statutory Instruments, 1986 No. 1078, Road Traffic*. United Kingdom: The Parliament of the United Kingdom.

[25] Car and Trailer Side Protection. (2001). *GB 11567-2001*. China: National Standards of People's Republic of China.

[26] Ministerio de Transportes y Comunicaciones. (October 2003). Decreto Supremo No. 058-2003-MTC. *Reglamento Nacional de Vehículos*. Peru: Ministerio de Transportes y Comunicaciones.

[27] Ministerio de Transportes y Comunicaciones. (October 2003). Decreto Supremo No. 058-2003-MTC. *Reglamento Nacional de Vehículos*. Peru: Ministerio de Transportes y Comunicaciones.

[28] National Traffic Council. (September 2009). Resolution No. 323. *Brazilian Traffic Code*. Brazil.

[29] Buteau, F. (March 18, 2014). Road safety in Saint-Laurent: Putting Citizens First! Saint Laurent, Montréal, Canada. Retrieved from http://conf.tac-atc.ca/english/annualconference/tac2014/s-2/bateau.pdf

[30] Macdonald, B. (June 30, 2016). Municipal Fleet Manager, City of St. John's. (K. Welty, Interviewer)

[31] The Jessica Campaign. (June 10, 2016). Side Guards Resolution to Federation of Canadian Municipalities, Saint Laurent, Montréal, QC. Saint Laurent, Montréal, Quebec, Canada. Retrieved from http://thejessicacampaign.ca/2016/09/26/side-guards-resolution-to-federation-of-municipalities-by-city-of-saint-laurent-montreal-qc/

[32] Salvaguardas para Camiones Urbanos. (August 17, 2016). *Reglamento de Tránsito del Distrito Federal*. Mexico City, Mexico: Gaceta Oficial del Distrito Federal.

[33] Santillan, O. (December 9, 2015). Barras protectoras de peatones y ciclistas en trailers, un pendiente del Reglamento de Tránsito. *El Big Data*.

[34] Santillan, O. (December 9, 2015). Barras protectoras de peatones y ciclistas en trailers, un pendiente del Reglamento de Tránsito. *El Big Data*.

[35] Salvaguardas para Camiones Urbanos. (August 17, 2015). *Reglamento de Tránsito del Distrito Federal*. Mexico City, Mexico: GACETA OFICIAL DEL DISTRITO FEDERAL.

[36] Australian Trucking Association. (2012). *Technical Advisory Procedure: Side Under Run Protection.* ATA Industry Technical Council.

[37] Australian Trucking Association. (2012). *Technical Advisory Procedure: Side Under Run Protection.* ATA Industry Technical Council.

[38] Carey, A. (March 21, 2017). Sideguards for Metro tunnel trucks in bid to save cyclists' lives. *The Age*.

[39] *Bikes and Trucks*. (May 23, 2017). Retrieved from Bicycle Network: https://www.bicyclenetwork.com.au/general/policy-and-campaigns/3267/.

[40] Construction Logistics and Community Safety (CLOCS). (December 2015). CLOCS Standard for construction logistics: Managing work related road risk. London, United Kingdom.

[41] London Cycling Campaign. (March 16, 2017). Camden CLOCS up another first. London, United Kingdom.

[42] Volpe National Transportation Systems Center. (2014). *Truck Sideguards for Vision Zero* . New York City : NYC City Administrative Services.

[43] Patten, J., & Tabra, C. (2010). *Side Guards for Trucks and Trailers Phase 1: Background Investigation.* Ottawa: National Research Council Canada.

[44] Knight, I., Dodd, M., Bowes, D., Donaldson, W., Smith, T., Neale, M., . . . Couper, G. (2005). *Integrated Safety Guards and Spray Suppression- Final Summary Report.* TRL Limited.

[45] Cookson, R., & Knight, I. (2010). *Sideguards on heavy goods vehicles: assessing the effects on pedal cyclists injured by trucks overtaking or turning left.* Transport Research Laboratory.

[46] Knight, I., Dodd, M., Bowes, D., Donaldson, W., Smith, T., Neale, M., . . . Couper, G. (2005). *Integrated Safety Guards and Spray Suppression- Final Summary Report.* TRL Limited.

[47] Patten, J., & Tabra, C. (2010). *Side Guards for Trucks and Trailers Phase 1: Background Investigation.* Ottawa: National Research Council Canada.

[48] Cookson, R., & Knight, I. (2010). *Sideguards on heavy goods vehicles: assessing the effects on pedal cyclists injured by trucks overtaking or turning left.* Transport Research Laboratory.

[49] Smith, T., Neale, M., & Knight, I. (2005). *Identifying the Safety Benefits of Smooth Side Guards and Ending Exemptions.* TRL Limited.

[50] Knight, I., Dodd, M., Bowes, D., Donaldson, W., Smith, T., Neale, M., . . . Couper, G. (2005). *Integrated Safety Guards and Spray Suppression- Final Summary Report.* TRL Limited.

[51] Robinson, T., & Cuerden, R. (2014). *Safer lorries in London: identifying the casualties associated with side guard rails and minor exemptions.*

[52] Van Kampen, L., & Schoon, C. (1999). *The safety of lorries: An accident and measure analysis* . Transport and Logistics Netherlands.

[53] Riley, B., Chinn, B., & Bates, H. (1981). *An analysis of fatalities in heavy goods vehicle accidents.*

[54] Keigan, M., Cuerden, R., & Wheeler, A. (2009). *Analysis of police collision files for pedal cyclist fatalities in London, 2001-2006.* London.

[55] Thomas, P., Talbot, R., Reed, S., Barnes, J., & Christie, N. (2015). *Fatal urban cyclist collisions with lorries: an in-depth study of causation factors and countermeasures using a system-based approach.*

[56] Talbot, R., Reed, S., Barnes, J., & Thomas, P. (n.d.). *Pedal Cyclist Fatalities in London: Analysis of Police Collision Files (2007-2011).*

[57] Rechnitzer, G. (1993). *Truck Involved Crash Study: Fatal and Injury Crashes of Cars and Other Road Users with the Front and Sides of Heavy Vehicles.*

[58] Hogstrom, K., & Swensson, L. (1986). *Accident analysis: front, side, and rear protection of trucks.* International Journal of Vehicle Design, Special Issue on Vehicle Safety.

[59] Riley, B., Chinn, B., & Bates, H. (1981). *An analysis of fatalities in heavy goods vehicle accidents.*

[60] Riley, B., Penoyre, S., & Bates, H. (1985). Protecting Car Occupants, Pedestrians, and Cyclists in Accidents Involving Heavy Goods Vehicles by Using Front Underrun Bumpers and Sideguards. *10th International Technical Conference on Enhanced Safety of Vehicles*, (pp. 883-896). Oxford.

[61] Hogstrom, K., & Swensson, L. (1986). *Accident analysis: front, side, and rear protection of trucks.* International Journal of Vehicle Design, Special Issue on Vehicle Safety.

[62] Smith, T., Neale, M., & Knight, I. (2005). *Identifying the Safety Benefits of Smooth Side Guards and Ending Exemptions.* TRL Limited.