Cambridge Safer Truck Initiative

Vehicle-based strategies to protect pedestrians and bicyclists

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March 2016

DOT-VNTSC-CDPW-16-01

Prepared for:

City of Cambridge, Massachusetts

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

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Acknowledgments

The authors wish to express their appreciation to Mayor Maher, City Manager Rossi, and his administration for their support through the City of Cambridge, and to the following individuals for their invaluable contributions to this report. First and foremost, the authors thank Cambridge DPW Commissioner Owen O'Riordan, Deputy Commissioner John Nardone, and John Fitzgerald for sponsorship of this work and for a rewarding inaugural partnership, and members of the Cambridge City Council for their input and support of the study. The authors are grateful to Alanna Mallon in the Mayor's Office as well as to Christopher Roof at Volpe for making the initial connection that led to this partnership. For their initiative and support of a joint outreach effort, the authors thank Jefferson Smith in the Mayor's Office, Laura Waldon in Volpe Communications, and the US DOT Office of the Secretary, including the Mayor's Challenge initiative. At Volpe, the authors acknowledge the research, finance, and communications support of David Arthur, Susan Dresley, Maria McCarthy, and Kristen Pedroli.

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On average, 2.2 people are killed in traffic crashes in Cambridge each year, based on the decade from 2004 to 2013, greater than the annual homicide rate during the same period. Of the pedestrians and bicyclists, or vulnerable road users (VRUs), killed from 2008 to 2013, 27% were hit by trucks, which represent only 4% of vehicles in the City. While trucks are also disproportionately represented in bicycle and pedestrian fatalities nationally, this over-representation is substantially more pronounced in Cambridge and in other urban areas. Furthermore, truck and bus crashes have been shown to be nearly three times more likely to result in a pedestrian fatality than crashes involving passenger vehicles.

To address the risks posed to life and limb by trucks, the City of Cambridge has partnered with Volpe, The National Transportation Systems Center (Volpe), to inform City actions intended to prevent and mitigate truck-VRU crashes. This partnership builds on Volpe's research and experience with tackling crashes between trucks and VRUs, in particular in urban settings, taking a lead in addressing this critical safety challenge. The City's efforts have the backing of the Cambridge City Council, which has issued a policy order calling "to work with all relevant City Staff, safety experts, and bicycle and pedestrian advocates" to enhance VRU safety (November 10, 2014). The initiative also aligns with other local (e.g. Boston and Harvard University) and national (e.g. US DOT's Mayors' Challenge for Safer People and Safer Streets; and National Transportation Safety Board recommendations) initiatives with similar aims. Lastly, the technologies considered by Cambridge have been shown to improve VRU safety elsewhere, in some cases based on decades of experience in other countries.

A Two-Pronged Strategy

Working with Volpe, Cambridge is examining – and has begun to implement – two types of truck enhancements to increase VRU safety on the city's road network:

> **Truck side guards,** designed to mitigate the outcome of truck-VRU crashes by preventing pedestrians and bicyclists from falling into the space between the axles of passing trucks and being run over by the rear wheels.
>
> **Blind-spot mirrors,** placed strategically to help prevent truck-VRU crashes by reducing or eliminating driver blind spots and improving the situational awareness of truck drivers to VRUs in their vicinity.

Truck Side Guards: Untapped Potential

Of 16 Cambridge crash reports from recent years obtained and reviewed by Volpe, 44% describe scenarios where side guards could have mitigated the outcome in terms of fatalities and injury severity. Such crashes typically occur when a truck initiates a turning maneuver, hits a VRU, and continues to run over the victim with the rear wheels. Truck side guards, physical barriers providing sufficient coverage strength, are designed to push a bicyclist or pedestrian out of the path of the rear wheels. Data from the

UK indicate 61% and 20% reductions in the probability of death in side-impact truck-VRU crashes with bicyclists and pedestrians, respectively, following a national truck side guard mandate phased in between 1983 and 1986. Data on bicycle left-hook (equivalent to U.S. right-hook) truck-bicycle collisions from 2006-2008 indicate a 63% lower fatality rate among cyclists when colliding with side guard-equipped trucks versus trucks exempted from the side guard mandate.

Cambridge's Truck Side Guards: Initial Experience

Cambridge has installed three custom fabricated truck side guard designs as pilot installations, beginning in 2013, on a handful of city-owned trucks to begin testing side guard effectiveness, operability, and any impact on vehicle maintenance. Of the two main types, rail and mesh-panel, the rail guards exhibited greater resilience in terms of their physical condition following one year of operation. Damage to the mesh side guards was likely caused by impact with snow or ice banks during the severe 2014-2015 winter; the rail-style side guards did not experience such damage. Considering this experience and other Cambridge Department of Public Works (DPW) operability priorities, in particular access to equipment and parts underneath the trucks, the City's preferred approach going forward is for installation of rail-style side guards on the remaining city-owned trucks targeted for side guards. Such guards can also be designed to be easily moved out of the way and returned to position via top or side hinge connections.

Recommendations for Further Side Guard Implementation

Volpe has worked with Cambridge to identify city-owned trucks appropriate for side guard installations, currently 52 medium- and heavy-duty vehicles. Based on a review of side guard requirements in other locales, Volpe has developed a set of dimensional and strength specifications for future side guard installations. With Boston's ordinance requiring side guards on such trucks having taken effect in May 2015, Cambridge and other municipalities in metro-Boston could potentially leverage their buying power by tying future City contracts to truck side guard requirements.

A majority of Cambridge truck-VRU crashes involved scenarios that side guards and blind spot mirrors could have mitigated or prevented.

Truck Blind Spot Mitigation: Mirrors and Other Countermeasures

In a medium or heavy duty vehicle, the driver's direct vision around the vehicle is limited. In general, as vehicle size and seat height increase, so does the extent of blind spot areas and consequently the need for countermeasures, such as mirrors. Even light duty vehicles with high seating positions have blind spot areas that are more significant than most drivers realize. A 2006 analysis of national crash data found that 20% of truck crashes occur in configurations where truck driver vision (or lack thereof) may have been an important factor contributing to the crash.

Cambridge DPW fleet vehicles are already equipped with mirror systems that meet or exceed Federal and State requirements, but the City has committed to evaluating potential further measures that could prevent vehicle collisions with VRUs. In partnership with the city, the Volpe Center reviewed available technologies and assessed their potential applicability to city-owned vehicles.

Initial Recommendations for Implementation of Blind Spot Countermeasures

Based on a review of mirror requirements in other locales and discussions with Cambridge DPW, Volpe has developed proposed equipment specifications and performance requirements for mirrors on city-owned and regulated trucks, which would apply to all vehicles with a GVWR over 10,000 lbs. Volpe also recommends considering mirrors for vehicle types with a GVWR below 10,000 lbs. on a case-by-case basis, by testing their blind spots. Training for vehicle operators is important to ensure that they understand how to use mirrors and other blind spot countermeasures appropriately. On-vehicle messaging can help to ensure that vehicle operators, as well as VRUs, are aware of blind spot dangers.

The initial recommendations on blind spot countermeasures are based on the best available knowledge from the current research literature. However, this preliminary review uncovered some important research gaps that warrant further investigation. There is scant information available on the unique role that a look down mirror may play on a truck with a conventional cab configuration. There is also limited information on the rear view that an asymmetric cross over mirror can provide in comparison with that of a hood-mounted rear view convex mirror on a truck with a conventional cab configuration. There is also a host of other rapidly emerging sensor technologies for mitigating blind spots that may warrant future research and consideration.

Safer Truck Program Evaluation

Volpe recommends that Cambridge document, retain installation and performance data, and continuously evaluate its Safer Truck strategy. Such data and evaluation provided the basis for the initial evaluation and recommendations presented in this report.

Along with crash prevention and mitigation, evaluation is important for the long-term success of the City's safety initiatives. Proper evaluation will allow the City to assess whether safety interventions achieve their desired effects and to adjust interventions as necessary, thus reinforcing a robust process of continual, data-driven improvement and, ultimately, saving as many lives and preventing as many serious VRU injuries as possible.

1 Introduction

This report summarizes Volpe, The National Transportation Systems Center's (Volpe's) research and recommendations for the City of Cambridge for implementing a number of proven vehicle safety strategies, including truck side guards, blind spot mirrors, and other vehicle-based safety enhancements on the city-owned truck fleet. The City intends to install these technologies on heavy-duty vehicles to increase safety for pedestrians and bicyclists traveling in Cambridge, leading by example in Massachusetts and encouraging private entities to follow suit.

Volpe's partnership with the City of Cambridge responds to the City Council's policy order adoption of November 10, 2014 "to work with all relevant City Staff, safety experts, and bicycle and pedestrian advocates to consider the possibility of deploying truck side guards across all city-owned and city-leased trucks."[1] Additionally, this partnership dovetails with the U.S. Department of Transportation's Mayors' Challenge for Safer People and Safer Streets, launched on January 22, 2015, by U.S. Transportation Secretary Anthony Foxx.[2]

Volpe has reviewed international best practices and safety data and has considered both operational and human factors issues in developing the recommendations in this report for:

- Installing side guards on large trucks to protect bicyclists and pedestrians from being swept underneath a vehicle in a side-impact crash;
- Installing additional blind spot mirrors, lenses, or cameras intended to increase truck drivers' field of view and situational awareness of bicyclists and pedestrians;
- Posting educational messaging inside and/or outside of large trucks intended to increase awareness of all road users about avoiding blind spots and other specific hazards; and
- Integrating the recommended safety countermeasures into the vehicle bodies and operations of the city's truck fleet, on up to 50 identified vehicles starting in the fall of 2015.

1.1 Safety Challenges

On average, 2.2 Cantabrigians are killed each year in traffic crashes, based on the decade from 2004 to 2013. As one point of reference,[3] this fatality rate is greater than the homicide rate of 1.7 per year during the same time, as shown in Table 1.

Table 1. Traffic fatality rate compared with homicide rate in the City of Cambridge

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	10-year total
Homicides[4]	0	3	2	0	2	2	0	5	1	2	**17**
Traffic deaths[5]	3	4	2	2	3	0	1	2	2	3	**22**

[1] http://www2.cambridgema.gov/cityclerk/PolicyOrder.cfm?item_id=44934
[2] https://www.transportation.gov/fastlane/cambridge-taps-volpe-expertise-for-bike-pedestrian-safety
[3] In 2014, New York City Mayor de Blasio prefaced the adoption of side guards and other vehicle and street safety initiatives by citing that city's nearly equal numbers of deaths due to homicides and traffic crashes: http://www.streetsblog.org/2014/01/15/de-blasio-bratton-trottenberg-vision-zero-action-plan-interagency/
[4] http://www.city-data.com/crime/crime-Cambridge-Massachusetts.html
[5] Volpe analysis based on the NHTSA Fatality Analysis Reporting System

Large trucks are disproportionately represented in bicycle and pedestrian fatalities. Nationally, large trucks comprise 4% of the U.S. vehicle fleet,[6] and are associated with 7% of pedestrian fatalities (297 annually) and 11% of bicyclist fatalities (76 annually).[7,8] In Cambridge, trucks also represent about 4% of vehicles, but accounted for 27% of pedestrian and bicyclist fatalities in 2008-2013.[9] This overrepresentation can be partly attributed to the large blind spots present on most large trucks that limit drivers' visibility of people walking or biking—see Figure 1—and to the greater tendency of people walking or biking to be fatally run over (or suffer underride) in a collision with a large truck compared to a collision with a car. According to a City of New York study, truck and bus crashes are nearly three times more likely to result in a pedestrian fatality than crashes involving passenger vehicles.[10]

Figure 1. The blind spots of typical large truck mirrors, both planar and convex, can cover ten or more bicyclists or pedestrians. The operator can therefore be unaware of these road users when starting a turn.[11]

[6] Bureau of Transportation Statistics, Table 1-11: Number of U.S. Aircraft, Vehicles, Vessels, and Other Conveyances http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_01_11.html

[7] National Transportation Safety Board, "Safety Study NTSB/SS-13/01: Crashes Involving Single-Unit Trucks that Resulted in Injuries and Deaths", pp 69-70 http://www.ntsb.gov/doclib/safetystudies/SS1301.pdf

[8] NTSB Safety Recommendations to NHTSA, April 3, 2014. www.ntsb.gov/doclib/recletters/2014/H-14-001-007.pdf

[9] Based on a query of the NHTSA Fatality Analysis Reporting System

[10] Pedestrian Safety Study & Action Plan, 2010. http://www.nyc.gov/html/dot/downloads/pdf/nyc_ped_safety_study_action_plan.pdf

[11] https://www.youtube.com/watch?v=Y9E1_1M-qhU

Based on Volpe's analysis of the National Highway Traffic Safety Administration (NHTSA) Fatality Analysis Reporting System (FARS), the rate of pedestrians and bicyclists killed by first impacting the side of a truck, an indicator of side underride as a factor in the crash, is slightly higher in Massachusetts than the national average (16.67% vs. 15.73%). The fraction of fatal side impact truck crashes that involve pedestrians or bicyclists is three-fold higher in the state than nationally (28.57% vs. 8.82%), as seen in the orange-colored cells in Table 2. The caveats in this analysis include: national pedestrian and bicyclist fatality side impact rates in FARS are significantly lower than the same rates found in the enriched Trucks in Fatal Accidents (TIFA) database, summarized in Figure 3. Additionally, this analysis does not include nonfatal injuries, which are considered elsewhere in this report.

Trucks comprise only about **4%** of vehicles in Cambridge yet accounted for **27%** of pedestrian and bicyclist fatalities.*

* Based on 3 out of 11 traffic fatalities, 2008-2013.

Table 2. Analysis of fatal crashes with trucks for the U.S. and Massachusetts.

Fatal Crashes with Trucks: 2008-2013						
	National	National - side	%	MA	MA - side	%
Truck Crashes	21,644	3,538	16.35%	138	21	15.22%
With P&B	1,983	312	15.73%	36	6	16.67%
With Ped	1,600	198	12.38%	27	3	11.11%
With Bike	383	114	29.77%	9	3	33.33%
With P&B %	9.16%	8.82%		26.09%	28.57%	

Volpe accessed the *Cambridge Open Data* tool (Open Data) from the City of Cambridge to identify crashes involving trucks with bicyclists and pedestrians.[12] Twenty-three crashes reported on Open Data were between trucks or MBTA buses and pedestrians and/or bicyclists.[13] Police reports associated with the respective crashes contained written narratives and diagrams describing the information that officers recorded. A common occurrence, as described in six out of the sixteen crash reports provided by City of Cambridge Police, was a truck in the right lane intending to make a right turn while a bicyclist was on its right, followed by a crash occurring during or after the truck's right turn maneuver. In addition to the narratives, the diagrams further implied impact area as between clock points 2 and 5 per the National Highway Traffic Safety Administration's impact reporting standard for trucks, shown in Figure 2.

[12] Data pertains to motor vehicles, bicycles, and/or pedestrians reported to the City of Cambridge; as of August 2015, the database holds data reported to the City of Cambridge from 2010 to 2013.
[13] Data regarding MBTA buses are not included in Table 3; four out of the 23 reported crashes pertained to MBTA buses.

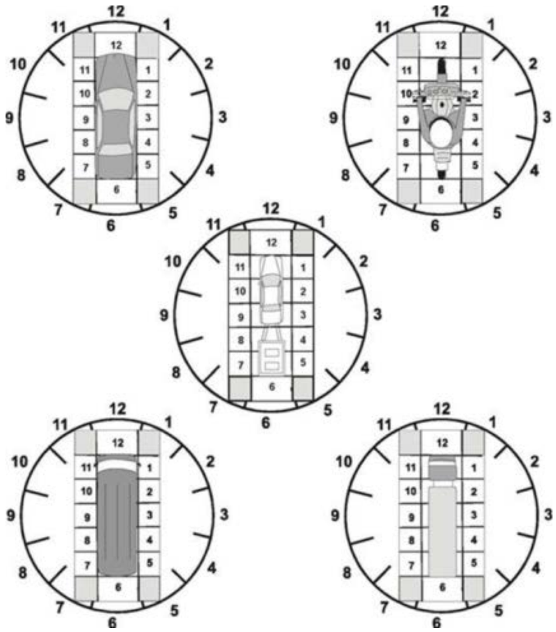

Figure 2. NHTSA's fatal crash reporting system sets impact reporting standard as 12 clock points.

Impacting the trucks' sides indicates that these crashes likely involved side underride and that the presence or absence of a side guard could have been relevant to the crash outcomes. Of the 16 reports that Volpe analyzed, 44% and 19% respectively appeared to be crash types that side guards and crossover mirrors are intended to prevent or mitigate. One crash appeared to be relevant to both safety devices. In total, **9 of the 16 crashes from 2010-2013, or 56%, appeared to be side guard and/or crossover mirror relevant.**

Table 3. The majority of truck-VRU crashes in Cambridge in 2010-2013 were potentially side guard and crossover mirror relevant, respectively

	Total truck-VRU crashes in Cambridge (2010-2013)	Side guard relevant truck-VRU crashes in Cambridge (2010-2013)	Start from stop collisions in Cambridge (2010-2013)
Number	16	**7**	**3**
Percentage	100%	**44%**	**19%**

The Cambridge side-impact rate among fatal truck-VRU crashes is higher than the national average of 32%, as shown in Figure 3.

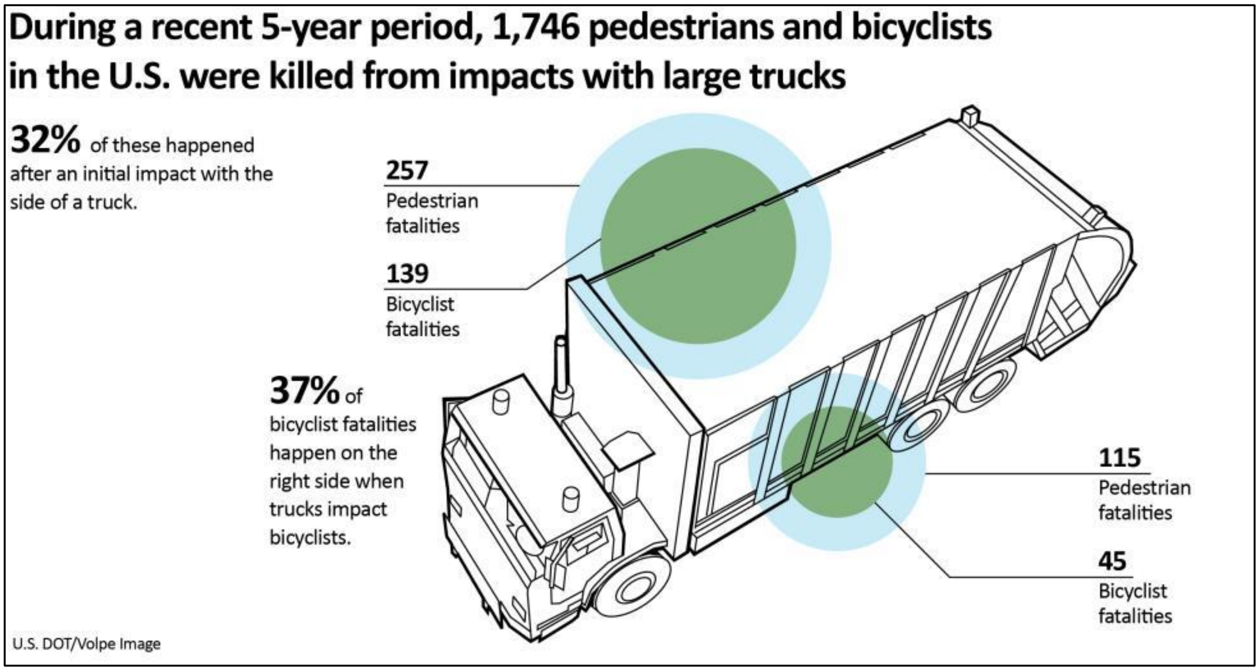

Figure 3. Relative prevalence of side impact collisions between large trucks and vulnerable road users, based on U.S. 2005-2009 TIFA data.

1.2 Urban Truck Safety Strategies

The three principal strategies for achieving a safer urban truck fleet are crash avoidance, mitigation, and evaluation, as depicted in Figure 4.

The first strategy, crash avoidance, broadly includes complete streets infrastructure, such as protected bike facilities, raised crosswalks, and other traffic calming measures. It also includes road user education, e.g., through operator training, the exterior decals recommended in this report, and enforcement. The main focus of crash avoidance in this report, however, is improved situational awareness of the truck operator about VRUs in the vicinity of the vehicle so that the operator is better able to prevent a crash. Situational awareness can be improved by redesigning the cabs of large trucks with taller windows for greater visibility, as is planned in the European Union,[14] as well as by the addition of blind spot mirrors, Fresnel lenses, or cameras.

The second strategy, crash mitigation, represents the last line of defense when a crash has not been avoided through infrastructure, education, enforcement, or visibility measures such as the blind spot mirrors recommended in this report. Side guards are the principal form of crash mitigation tool considered in this report. Other possible vehicle redesign strategies for protecting VRUs in collisions include lower, rounded front bumper designs for trucks and wheel guards on buses.

The third strategy is evaluation, which is important for the long-term success of any safety program. Evaluation involves assessing whether safety interventions or enhancements that have been

[14] BBC article

implemented are achieving the desired effects, adjusting these interventions as necessary, and reinforcing a process of continual, data-driven improvement.

The Safer Truck initiative is an opportunity for the City of Cambridge to lead among U.S. municipalities on truck safety for bicyclists and pedestrians. Rolling out multiple safety technologies--different side guard, mirror, and messaging designs--with limited domestic experience but with international precedence places the City at the leading edge of urban truck safety in the U.S. Through the partnership with Volpe, the City can also launch innovative public awareness and education programming, while Volpe helps transfer key findings statewide or nationally to other cities via the USDOT. The findings of this initial rollout on the City-owned truck fleet will potentially inform future regulatory, procurement, and/or voluntary safety programs for all truck fleets that operate on Cambridge streets to promote the most effective safety technologies.

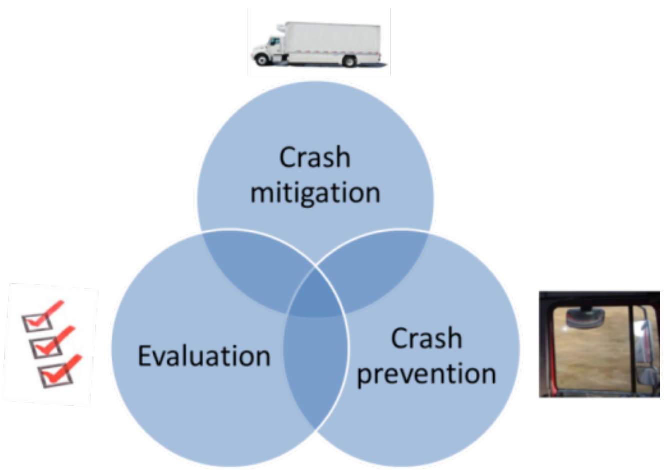

Figure 4. Three pillars of vehicle-based technology for VRU safety.

Cambridge currently owns 54 municipal fleet Class 3 or above (over 10,000 lbs.) trucks in the Department of Public Works (DPW), including garbage trucks, the truck type most commonly involved in recent bicyclist/pedestrian crashes in Cambridge and Boston.

This report highlights regulatory and voluntary precedents for truck side guard deployment, available safety data, and recommends technical specifications for City truck safety enhancements in partnership with the Cambridge Department of Public Works. In this report, Volpe’s findings are synthesized into recommendations for side guard, mirror, and educational decal deployment on City-owned vehicles to lead by example and to encourage private fleets to adopt similar practices.

2 Truck Side Guards

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

Current Federal regulations require rear impact guards for the wheels of trailers and semi-trailer trucks to reduce the number of deaths and serious injuries occurring when passenger vehicles crash into the back end of a truck. However, there are currently no national regulations concerning side underride protection or side guards to protect pedestrians and bicyclists from the risk of falling under the sides of trucks and being caught under the wheels. A large truck typically has an exposed space, often exceeding four feet in height, between its axles. During a crash with the truck, VRUs can fall into the exposed space and be crushed as the rear wheels roll.

As shown in Figure 5, side guards, also referred to as "lateral underrun protection" and "side underride protection" devices, work by shielding pedestrians and cyclists, and if designed to a higher strength standard, motorcyclists, from the open space between the axles of most types of large trucks.

Figure 5. A large truck without side guards (left) and with side guards (right).

Side guards are currently required on certain motor vehicles, trailers and semi-trailers in Japan, in European Union countries, the United Kingdom, and Brazil. Some side guard variants also provide environmental benefit in the form of improved fuel efficiency by reducing aerodynamic drag under certain types of driving conditions.

2.1 Review of side guard deployment safety impacts and costs

2.1.1 Evidence of effectiveness

Volpe performed a high level review of existing data on the safety impacts of truck side guard deployment for pedestrians and bicyclists in crashes with large trucks. The scan drew primarily on international crash data, with the goal of establishing a benchmark for future data collection on the safety impacts of U.S. truck side guard deployment.

The introduction of side guards in the UK, European Union, and Japan over the past three decades was intended to prevent bicyclists and pedestrians from falling into the space between the axles of a passing large truck and being run over by the rear wheels. Side guards are primarily designed to be effective in overtaking or glancing side impact crash types, for example, during turns. According to the National

Transportation Safety Board, the prevalence of these types of crashes ranges as high as 25% for pedestrians with single-unit trucks to 55% for bicyclists with tractor-trailers.[15]

The safety effectiveness of side guards on large trucks was demonstrated by a UK study, which showed significant reductions in the number of bicyclist fatalities for the relevant crash types from before the side guards were introduced to after the side guards were introduced.[16]

The injury severity distribution for bicyclists and pedestrians colliding with the side of a truck changed substantially, with 61% and 20% reductions in fatalities, as shown in Figure 6. This conclusion was reported in a 2005 UK Transport Research Laboratory (TRL) analysis[17] and cited by the National Research Council Canada in a 2010 report.[18]

Figure 6. A variety of side guard designs are found globally, including a subset of aerodynamic side skirt models that also function as side guards. Right: Changes in the fatality rates of relevant side-impact crashes between VRUs and large trucks following the United Kingdom's passage of a national side guard law in 1986.

In addition to comparing the before-and-after crash outcomes with regard to the side guard phase-in between 1983 and 1986, a 2010 UK Transport Research Laboratory (TRL) report[19] compared the crash outcomes involving British trucks that are exempt and non-exempt from the side guard regulation.[20] The fatality rates in bicycle left-hook collisions during 2006-2008 in the UK (equivalent to right-hook collisions in the US) when side guard-equipped and side guard-exempt trucks were involved are presented in Table 4. **Whereas only one in four bicyclists was killed or seriously injured in crashes**

[15] NTSB, Crashes Involving Single-Unit Trucks that Resulted in Injuries and Deaths, 2013 http://www.ntsb.gov/doclib/safetystudies/SS1301.pdf

[16] National Research Council Canada, Side Guards for Trucks and Trailers Phase 1: Background Investigation, 2010.

[17] Knight, I., Dodd, M., Bowes, D., Donaldson W. et al, Integrated safety guards and spray suppression – final summary report, 2005. http://www.trl.co.uk/reports-publications/report/?reportid=5450

[18] National Research Council Canada, Side Guards for Trucks and Trailers Phase 1: Background Investigation, 2010.

[19] R Cookson and I Knight, Side guards on heavy goods vehicles: assessing the effects on pedal cyclists injured by trucks overtaking or turning left. 2010.

[20] An advantage of this comparison is that it considers crashes over the same time period, eliminating potential confounding factors that may have occurred between 1982 and 1990. A different confounding factor could exist if exempt vehicles were inherently more fatal in side-impact crashes for unknown reasons that are not related to the presence of side guards. However, both the time-series and the exempt/not exempt safety analyses are qualitatively consistent and show reduced fatality rates among side guard-equipped large trucks.

when the truck was equipped with a side guard, two out of three bicyclists were killed or seriously injured when the truck was exempt and not equipped with a side guard.

Table 4. Crash severity distribution in truck-bicycle left turn collisions in the UK when the truck was either exempt or not exempt from side guard installation. (KSI = killed or seriously injured)

	Fatal	Serious	Slight	% fatal	% KSI
Exempt	9	21	15	**20%**	**67%**
Not exempt	7	8	44	**12%**	**25%**

2.1.2 Custom fabricated versus commercial off-the-shelf (COTS)

Side guard retrofits for existing large trucks can be procured as custom fabrication jobs at metal shops and dealers, or they may be purchased and installed as commercial off-the-shelf aftermarket products. The City of Boston's pilot program used both approaches (Figure 7), while Cambridge has used two types of custom fabricated designs since the pilot installation began in 2013 (Figure 8). Recent Volpe research has focused on expanding the aftermarket product availability by identifying both local fabricators and aerodynamic trailer skirt manufacturers that have the engineering capacity to validate their products and to supply side guards at large scale.

In European, Asian, and South American markets, truck original equipment manufacturers incorporate side guards during design and assembly; in the long term, such integration is clearly the preferred solution to avoid the need for retrofitting, but the timeline for availability of OEM side guards in North America is unclear. Additionally, retrofit COTS side guards are readily available from United Kingdom vendors, and these are generally already tested and certified to the European lateral underride EEC Regulation no. 73 and EEC Directive 89/297.[21] These may provide a ready solution for the City of Cambridge if international procurement through a local distributor is possible and cost-effective, or they may be acquired to use as a template for local fabricators to copy their compliant, certified designs.

Figure 7. Boston's side guard pilot designs were purchased off-the-shelf (left) as well as custom fabricated

[21] British off-the-shelf side guard systems appear to be tested and pre-certified by the UK's Vehicle Certification Agency to meet the 2 kN strength requirement as well as the other Volpe-recommended specifications. For example: http://www.eurotransman.co.uk/euro_transport_side_guards.html and http://www.eurotransman.co.uk/pdf/side_guards_legal_requirements.pdf

(center and right).

Figure 8. Cambridge side guard pilot designs were custom fabricated.[22]

2.1.3 Operability of major side guard types

Based on discussion with the City of Cambridge as well as with Boston, New York City, and private fleets, Volpe considered a number of operability concerns related to side guard use.

- Winter performance
  - Globally, side guards are used on trucks in harsher and snowier environments than Cambridge, including in northern Scandinavia, so are generally compatible with winter operation, even on snow plow trucks. Based on the Boston pilot that began in 2013, the rail-style side guards have performed well through the last two winters. Both Boston and Cambridge's expanded mesh style guards performed reasonably well in the extreme winter of 2014-2015, but a limited number of them also suffered considerable damage, shown in Figure 9. On one truck, the bottom angle iron of the metal frame was bent inward (possibly after hitting an icy snow bank), and the mesh detached from the angle irons, requiring repair.
- Removable or stowable designs
  - Occasional access to undercarriage components is facilitated by a removable panel design. One supplier, Airflow, produces a panel that can be snapped on and off without tools. Other designs employ a flip-up or sideways hinged rail.
- Weight and implication for how many staff needed to remove/replace
  - Panel-style fiberglass or aluminum panels are generally light and can be handled by a single operator.
- Integration of toolboxes and control panels
  - Toolboxes or other storage/job boxes should be aligned to be flush with the vehicle sidewall to function as part of the side guard; the remaining, smaller purpose-built side guard can then be fitted around the boxes to cover the remaining open space.
- Alignment of gaps in rail side guards to provide access
  - It is desirable to align and locally modify the spaces between horizontal rails in rail-style side guards with hydraulic levers, tank caps, and other frequent access points.

[22] Left photo © City of Cambridge, right photo © Alex Epstein

- Diesel particulate filters (DPFs)
    - No evidence has been identified of side guard-DPF incompatibility from Boston's experience, as well as based on recent European emissions control standards, which have required DPFs since MY2011/2012.

Figure 9. Challenges of the expanded metal mesh design.

Two expanded mesh-style guard piloted by Cambridge experienced considerable winter damage, as seen in Figure 9. The damage is visible at the rear of these side guards where impact with icy snowbanks likely occurred.

Separate from the winter damage, exposed mesh edges are present where the rear access hole (circled in Figure 9) has been cut. These are sharp and could injure an operator who reaches through it. The forward hole has been lined with rubber for this reason. Any holes in the expanded mesh guards should be similarly lined to prevent cuts when operator reach through them; however, Volpe also recommends minimizing the number of access holes through the side guard by installing underbody components in such a way that eliminates the need for punching holes through the guard, to the extent possible.

2.1.4 Costs

The total cost of a side guard includes materials and installation labor, both of which decrease with economies of scale and the learning curve of larger volume installation.

As reference points, Boston's 2013-2014 pilot installations cost $1,800 per vehicle; NYC's pilot installations cost about $3,000 per vehicle, including $1,350 in materials, expected to decrease in price with scaling up; and Portland's installations, which were among the first in the U.S. and involved a combination of custom panels and toolboxes, cost an average of $2,500 per vehicle.

Table 5. Example North American side guard retrofit reported costs.

U.S. city	Reported approximate cost per vehicle	Side guard type
Boston[23]	$1,800	Steel rail; fiberglass panel
New York City[24]	$3,000	Fiberglass panel
Portland[25]	~$1,000 small trucks - $4,000 trailers; $200-$250 per toolbox	Metal panel and toolbox

Based on a review of side guard costs from three suppliers that could be identified, as well as input from City of New York, City of Portland, OR, and City of Boston installations, the estimated costs for fitting a single-unit truck with side guards can range from $600 to $3,000. The lower end of this range is comparable to the $847 average implementation cost per single-unit truck or trailer using off-the-shelf components in Europe[26], and the $1,200 estimated cost for the City of Cambridge mesh-style side

[23] http://www.cityofboston.gov/news/default.aspx?id=20121
[24] http://www1.nyc.gov/office-of-the-mayor/news/101-15/city-begins-installing-truck-side guards-protect-pedestrians-cyclists
[25] Interview with Don DePiero and Donny Leader, City of Portland City Fleet, Bureau of Internal Business Services, November 30, 2012.
[26] National Research Council Canada, Side Guards for Trucks and Trailers Phase 1: Background Investigation, 2010.

guards also falls within this range. The cost of the City's rail-style guard was unavailable, since the dealer bundled the only such guard with a recent truck order and did not itemize costs.

If feasible, acquiring pre-certified side guard kits from UK suppliers may be a cost effective strategy. For example, a pair of twin-rail 10-foot side guards, including mounting hardware, can be purchased for about $300 plus shipping costs.[27] One challenge that may arise is arranging for shipping of the horizontal rails due to their long length. If shipping can be arranged, standard UK side guards are available with either vertical legs to the body,[28] similar to Cambridge's mesh-style design, or bolted to the frame rail,[29] similar to Airflow.

2.1.5 Installation and maintainability issues

Volpe considered the installation and maintainability issues that could arise with side guards on the City's truck fleet.

Installation can either be frame-mounted, body-mounted, or both. The Cambridge pilot installations have used both, though without penetrating the frame rail. Some frame rail installations, such as Airflow Deflector, require drilling holes through the frame rails to install the mounting hardware; frame rail installations can be very labor intensive unless a magnetic drill press is purchased to drill the holes more efficiently. Overall, installation of aftermarket products such as Airflow requires between 8 and 16 staff hours per vehicle. Body-mounted side guards that attach using vertical struts and do not require drilling the frame rail are likely to require less installation time.

Another consideration for choosing a side guard system is the expected degradation of the side guard material over time. Degradation could potentially weaken the structure and decrease its impact-resisting safety function over time. With road salt, winter corrosion can be a significant issue for aluminum side guards, unless they are properly powder coated, anodized, or otherwise treated. With aluminum side guards, it is critical to ensure that all fasters and other hardware in contact with the guard are either aluminum as well or, if the fasteners are steel, are isolated by rubber bushings, washers, etc. to prevent galvanic corrosion between the dissimilar metals. Fiberglass or composite side guards, as used by Airflow and by aerodynamic skirt manufacturers entering the side guard market, will generally not be susceptible to such corrosion.

Regardless of the side guard type, it must be secure in order not to loosen or detach over time. If bolts or similar fasteners are used rather than permanent welds to attach the guard, Volpe advises that the bolts should generally be grade 8 and should be inspected for proper torque over time to detect possible loosening. If loosening occurs, consider eliminating all washers and adding rubber bushings to help isolate road vibration and slow or stop the bolt loosening.

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[27] For example: http://www.nationwide-trailer-parts.co.uk/collections/side-guard-systems-hgv-trailer
[28] For example: http://www.nationwide-trailer-parts.co.uk/collections/side-guard-systems-hgv-trailer/products/sideguard-legs
[29] For example: http://www.nationwide-trailer-parts.co.uk/collections/side-guard-systems-hgv-trailer/products/chassis-mounted-sideguard-support-beam

Figure 10. Top left: Frame-mounted installation of a side guard. Top right: Body-mounted side guard. Bottom: Cambridge's expanded mesh side guards are both frame mounted and body-mounted.

2.2 Recommendations for City of Cambridge vehicles

2.2.1 Recommended design and specifications

In this section, Volpe synthesizes the above findings to provide a set of side guard implementation recommendations for the City of Cambridge on its municipal truck fleet. Side guards should be designed with the aim of safety, strength, weight and ease of operations and maintenance.

The recommended side guard specifications for Cambridge-owned and contracted large trucks are depicted in Figure 11. Note that these are more stringent than the requirement in the City of Boston's ordinance (see Appendix A) and consistent with the recently enacted City of New York requirements.[30]

[30] http://legistar.council.nyc.gov/LegislationDetail.aspx?ID=1687945&GUID=9621FABE-B038-4D87-BD30-54547AD24E3F

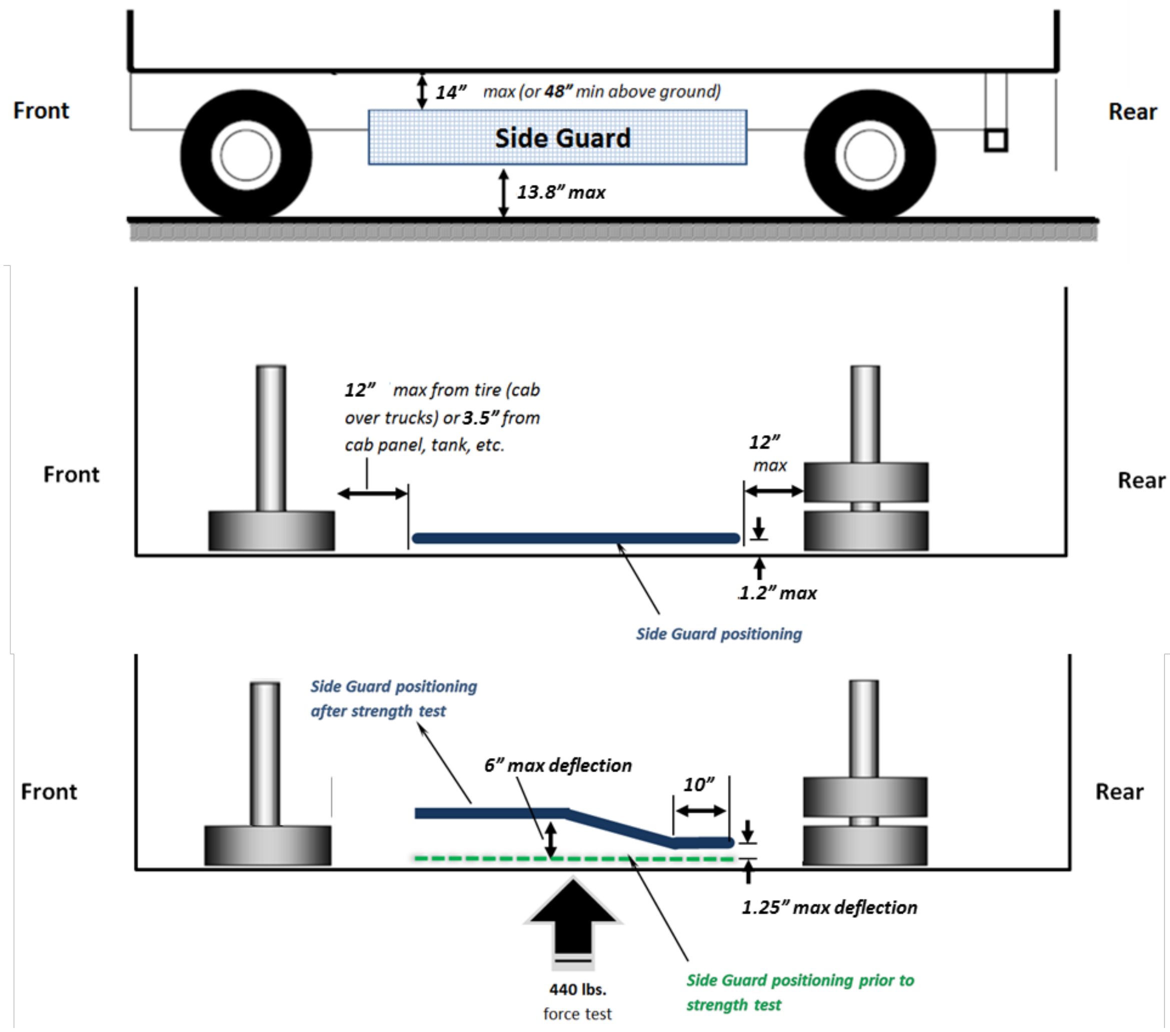

Figure 11. Recommended side guard requirements for the City of Cambridge rollout.

If a side guard regulation were adopted in Cambridge, it should stipulate maximum ground clearance, minimum strength requirement, and define the areas of installation as shown in Figure 11 on medium- and heavy-duty vehicles above a certain gross vehicle weight rating (GVWR). Consistent with the Boston and New York City laws and with the National Transportation Safety Board's safety recommendations, **Volpe recommends 10,000 lbs. as the GVWR threshold.**

2.2.1.1 Geometric (e.g., size, clearance, construction type)

Following both published recommendations by Monash University and UK guidance on the effectiveness of improved side guards, [31] as well as based on input from fleets, **Volpe recommends implementing a maximum 13.8 inch (350 mm) ground clearance.** This maximum clearance, which is lower than the 21.5 inch ground clearance permitted by the Boston Truck Side Guard Ordinance,[32] is recommended for

[31] R Cookson and I Knight, Side guards on heavy goods vehicles: assessing the effects on pedal cyclists injured by trucks overtaking or turning left. 2010.
[32] http://www.cityofboston.gov/isd/weightsandmeasures/sideguards/default.aspx

Cambridge because it provides greater protection[33] for vulnerable road users while not impeding on-road truck operations. Additionally, the maximum inboard distance is recommended to be 1.2 inches throughout the length of the side guard rather than only in the rearmost section. Volpe's recommended dimensional requirements are otherwise generally consistent with the Boston ordinance.

Figure 12. Some objects may be located further than 1 inch inboard from the truck's side.

As noted in Figure 11, the side guard should be positioned no more than 1.2 inches inboard from the truck's side. Figure 12 shows that in some cases, a toolbox or tank that could otherwise act as a side guard may be located further inboard than 1.2 inches. In that event, Volpe recommends the following options to address the issue:

1. If the toolboxes and tanks are used as part of the side guard surface, they should be re-positioned to be no further than 1.2 inches inboard to be considered flush with the side guard. In many cases this is a simple task of loosening bolts and moving the toolbox/tank along a track on the underside.
2. If moving them is not possible and they are 3-4 inches inboard, the side guard can stack outboard of them (2-4 inches is enough to fit the depth of a side guard). The hinged or removable design will be recommended if access to the toolbox or tank is needed.
3. If neither of the above options is possible and the toolbox or tank is not located near the rear wheel, then DPW could consider allowing flexibility on a vehicle-by-vehicle basis. The maximum 1.2 inch inboard distance is most important for safety near the rear wheels and less important away from the rear wheels.

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[33] Ibid: "Test work has suggested that side-guards that just met the minimum requirements of [UK] legislation [550 mm/21.7" ground clearance] reduced the incidence of pedal cyclists being run over to 40% of the total. The incidence could however, be eliminated by reducing the ground clearance to 300 mm [11.8"]. Survey work has shown that typical side guards fall approximately half way between the two in terms of ground clearance [i.e., about 425 mm/16.7"]" Also, per the Monash University 2002 side guard study recommendations: "…a clearance under the barrier of 550 mm [21.7"] is much too high to ensure unprotected road users are not run over by the wheels of the heavy vehicle. Hence it is recommended the ECE [side guard] standard be adopted with…Underrun clearance 350 mm [13.8"]." http://www.monash.edu/__data/assets/pdf_file/0017/217124/muarc194.pdf

Specifications

A	14 inches max
B	11.8 inches max
C	13.8 inches max
D	4.0 inches min
E	12 / 3.5 inches max*
F	12 inches max

*The gap between the side guard's leading edge and the wheel, wheel arch, or other permanent vehicle structure should not exceed 12 inches. A turned-in vertical bar connecting the forward ends of the horizontal rails should be incorporated if the forward gap exceeds 3.5 inches. The bar need not be rounded or can be omitted if the distance is less than 3.5 inches.

Figure 13. Recommended dimensional requirements for rail-style side guards, based on the European standards with the exception of the ground clearance Dimension C, which is more stringent for additional safety. Rounded figures are provided for ease of fabrication.

To minimize the risk of impaling or entangling a person during a crash, the forward edge of the side guard should either be installed a maximum of 3.5 inches behind a permanent vehicle structure, such as a wheel arch or the cab (Figure 14); or if there is a gap greater than 3.5 inches, the forward vertical bar edge should be turned inward with a rounded, continuous outer surface, as shown in Figure 15. The forward gap should not exceed 12 inches.

Additionally, any gap between the cab and the top of the side guard exceeding 14 inches, as seen in Figure 14, should be filled with an additional rail or panel of equal strength to the side guard.

Figure 14. When the forward edge of the side guard falls under the cab, any gap between the cab and the top of the side guard exceeding 350 mm (13.8 in.) should be filled with an additional rail or panel of equal strength.[34]

Figure 15. The forward edge of the side guard should have a continuous surface that turns inwards. This surface and turn-in is optional when the front edge of the side guard is within 100 mm (3.5 in.) of a permanent structure of the vehicle, e.g., cab or wheel arch.[35]

Volpe recommends adopting either a smooth panel-style side guard or a wide rail style over the narrow rail style. There is evidence for the increased safety of smooth, panel-style guards, or of guards in which the "rails" are broad and the gaps narrow. These recommended side guard types also offer improved visibility, ease of cleaning, and arguably offer better aesthetics. From the Cambridge Department of Public Works' standpoint, wide rails are the preferred design. These allow easier access to some of the undercarriage equipment when necessary, and based on the 2014 and 2015 winters, the wide rail style proved more durable during winter operations than the expanded mesh panels. For any rail-style guards, the dimensional minimum and maximum figures shown in Figure 13 should be observed to ensure the smoothness and spacing of the rails.[36]

[34] Images from Freight Transport Association (UK) Sideguards Compliance Guide, 2010.
[35] Image from Freight Transport Association (UK) Sideguards Compliance Guide, 2010.
[36] For example, the steel tube, cage-style side guards in the Boston pilot program would be unlikely to meet these recommended specifications.

Figure 16. Either wide-rail or panel style side guards are recommended for maximum coverage and longitudinal (front to back) smoothness, and they are found globally on both tractor-trailers and straight trucks.

Figure 17. Wide, closely spaced rails on rail-style side guards (Left: UK example; right: Cambridge prototype) are the preferred design for the City of Cambridge DPW.

Volpe performed a site visit and reviewed the City's pilot installations at the DPW Yard at 147 Hampshire Street, including both the expanded steel mesh and the wide rail designs. In addition to the winter damage, access cutouts, and other operability issues, Volpe reviewed the installations from a safety perspective. Volpe's review did not include mechanical measurements and relied on visual inspection.

While most installations appeared to provide sufficient coverage of the open space between the axles, on certain vehicles, large gaps remained uncovered by the guards or by other undercarriage equipment (see Figure 19 and Figure 20). One solution in these cases would be to adjust the positioning of the equipment to make it flush with the vehicle sidewall and to act as part of the side guard, as the fuel tank at the right in Figure 18 illustrates. This approach, when practical, offers unrestricted access to the equipment and decreases the side guard size that must be installed. However, DPW has indicated that moving factory installed tanks or other large pieces of equipment may not be practical. The side guards in these two figures were not extended over the tanks and other undercarriage equipment so as not to preclude access. The result is that impact coverage is reduced and no longer meets the recommended specifications. In these cases, the following options are advised:

- Use of a rail-style side guard with rails positioned to provide openings where needed that are large enough for routine access; or
- A hinged or easily removable guard (see Figure 18) for maintenance access.

Figure 18. Top Left: United Kingdom cement truck with flip-up truck side guard. Others: Cambridge's prototype flip-up, rail-style side guard by McNeilus combines good gap coverage with easy undercarriage access.

Figure 19. Large gap in coverage and lack of a smooth impact surface. The side guard, whether purpose built or a combination of storage boxes and tanks, should present a continuous, smooth surface from the cab to the rear wheel so as to help sweep aside a VRU in a side impact.

Figure 20.The fuel tank at left does not provide a continuous longitudinal surface, and the fuel tank leaves gaps above and below it. Two solutions include: (1) extending the side guard forward to cover the tank, as shown in Figure 17 Left; or (2) changing the tank to a rectangular model that presents a smooth, flat surface flush with the existing side guard, as shown at right.

2.2.1.2 Strength and Material choice

One of the few significant differences between the UK and EU standards, which were the starting points for the current recommendation, is that the UK minimum strength requirement is based on an applied 2 kN (440 lbs.) test force, twice as high as the EU's 1 kN (220 lbs.) requirement. **Volpe recommends adopting at least the 440 lbs. strength requirement.**[37]

Consistent with EU and UK requirements, **Volpe recommends a maximum allowed deflection of 1.0 inches for the rearmost 10 inches of the side guard and a maximum allowed deflection of 5.5 inches along its remaining length** when 440 lbs. of perpendicular force is applied on any part of the outside

[37] This recommendation is consistent with the requirements of New York City's recently enacted side guard law (Local Law 56 of 2015), and it reflects recent increases in the Assumed Average Weight Per Person adopted by the U.S. Coast Guard and by the Federal Transit Administration.

surface of the side guard.[38] The City of Cambridge can test for side guard strength compliance in at least three different ways:

(1) For installed side guards, apply the 440 lbs. perpendicular force at several locations on the side guard surface, including the rear bottom corner and any potential weak points between mounting brackets, using a screw, pneumatic piston, hydraulic piston, or other force applicator. A load cell should be installed in series with the piston or jack to measure the applied force, and the deflection of the side guard may be measured with a tape measure.
(2) For uninstalled side guards, assemble a testing rig to mount a side guard horizontally (parallel to the ground), and set a 440 pound object (e.g., cement cylinder, or a barrel containing 53 gallons of water) on several areas of the side guard surface, including the rear bottom corner and any potential weak points between mounting brackets. Deflection may be measured with a tape measure.
(3) Computer simulation or engineering calculations can be produced by the fabricator to show that the side guard does not deflect more than allowable when the test force is applied on several areas of the side guard surface, including the rear bottom corner and any potential weak points between mounting brackets.

Figure 21. A Boston-based example of a tag axle that reduces the required length of the side guard.

[38] Volpe recommends use of either of the specified EU R73 deflection testing methods for strength compliance: (1) an engineering calculation such as a computer finite element analysis model, or (2) apply the 440 pounds of perpendicular force to specified areas of the installed side guard using a mechanical ram and load cell, in which the force is applied over a circular area of 8.7 inches (220 mm) maximum diameter.

Figure 22. Local example of installed toolboxes that achieve a flush, continuous side guard surface. The example at left has an excessive gap and would need to be covered with a short side guard segment as shown at right.

To minimize salt corrosion and maximize lifespan, materials such as stainless steel and plastic composites are preferred over aluminum construction, unless the aluminum is properly surface treated (e.g., anodized or powder coated). For an installation that uses toolboxes to meet the Volpe-recommended specifications, the toolboxes would need to be mounted flush against the front wheel arch, avoiding a large gap as seen in Figure 22 at left. Alternatively, a short panel would need to be added to span the gap as shown at right (Figure 22 at right), or the leading edge of the toolbox could be rounded and turned inward (see Figure 15).

Wide rail style (with toolbox)	Panel and/or toolbox

Figure 23. Recommended future packer side guard design options

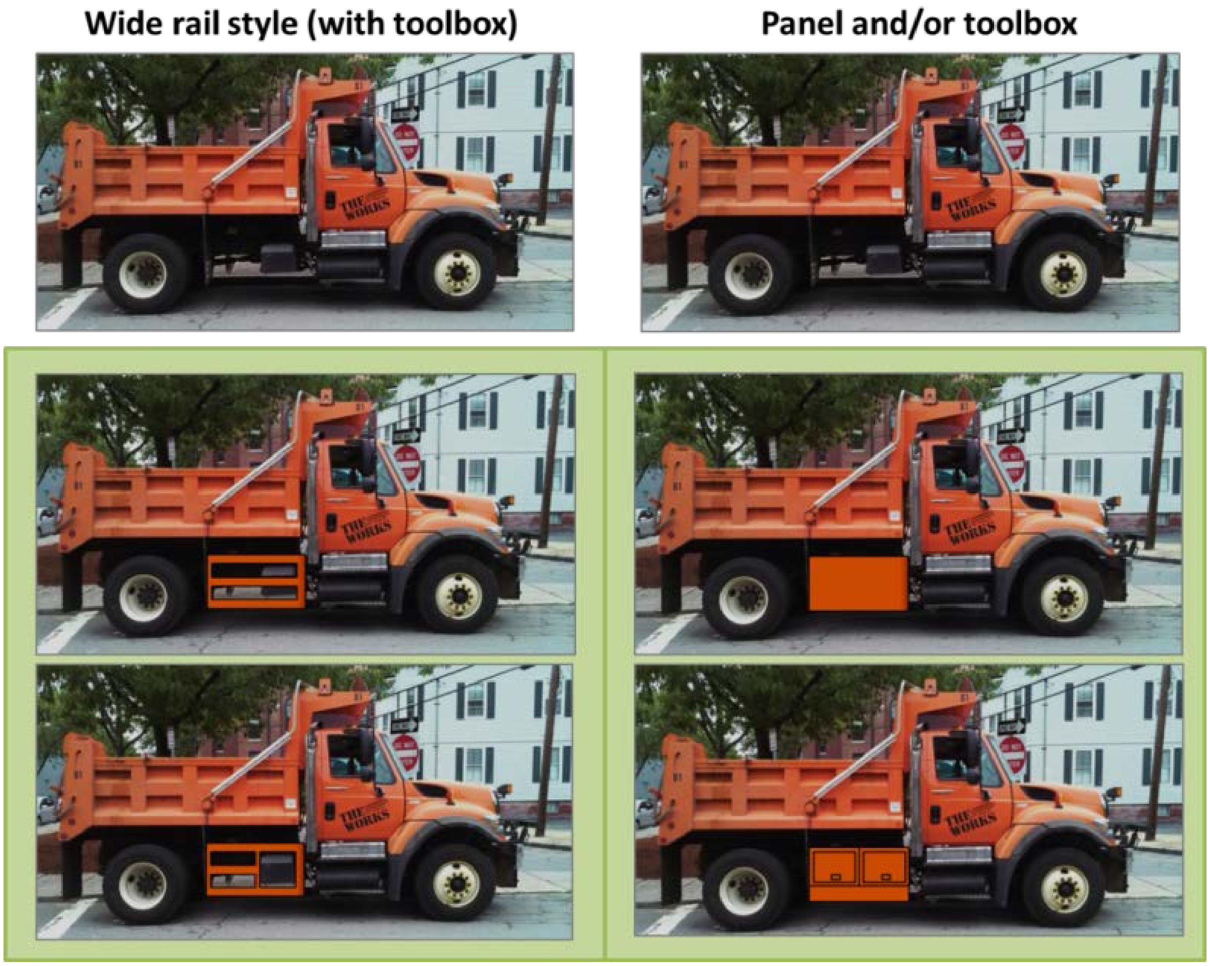

Figure 24. Recommended future dump truck side guard design options

2.2.2 Target vehicles for side guards

Volpe identified 52 vehicles from the medium- and heavy-duty vehicle inventory that are expected to benefit from side guards and two that are not likely to benefit, shown in Table 6. This assessment is based on the body styles and GWVR of these vehicles, which indicate that they may have large exposed spaces between the axles due to high ground clearance and in some cases extended wheelbases. Based on the 2013 and 2014 National Transportation Safety Board (NTSB) Safety Recommendations**, Volpe generally recommends the use of side guards above the 10,000 lbs. GVWR threshold**, a value comparable to the existing UK/EU threshold of 3.5 metric tons (7,716 lbs.).

Table 6. DPW vehicles that are expected to benefit from side guards.

ION	ID	TYPE	GVRW (lbs.)	WHEELBASE (in.)
Hot box	**86**	Heavy Duty Truck	35000	156
Boom	**142**	Heavy Duty Truck	35000	176
Flat bed	**70**	Heavy Duty Truck	35000	156
Utility	**95**	Heavy Duty Truck	26000	177
Clam Shell	**148**	Heavy Duty Truck	35000	192
Vactor	**141**	Heavy Duty Truck	41000	219
9yd Dump	**78**	Heavy Duty Truck	40000	156
9yd Dump	**80**	Heavy Duty Truck	40000	156
Boom	**143**	Heavy Duty Truck	35000	176
9yd Dump	**76**	Heavy Duty Truck	40000	156
Clam Shell	**145**	Heavy Duty Truck	35000	182
9yd Dump	**73**	Heavy Duty Truck	35000	156
Hot Box	**96**	Heavy Duty Truck	35000	156
Vactor	**140**	Heavy Duty Truck	46000	241
Crane	**144**	Heavy Duty Truck	38620	228
Packer	**34**	Heavy Duty Truck	41000	212
Packer	**35**	Heavy Duty Truck	41000	212
Packer	**27**	Heavy Duty Truck	41000	212
Packer	**23**	Heavy Duty Truck	41000	212
Packer	**24**	Heavy Duty Truck	41000	212
Packer	**26**	Heavy Duty Truck	41000	218
Packer	**36**	Heavy Duty Truck	41000	217
Packer	**29**	Heavy Duty Truck	41000	217
Packer	**25**	Heavy Duty Truck	33000	184
Packer	**20**	Heavy Duty Truck	33000	184
Packer	**28**	Heavy Duty Truck	41000	217
Packer	**21**	Heavy Duty Truck	42000	216
Packer	**22**	Heavy Duty Truck	45120	216
Salter	**84**	Heavy Duty Truck	35000	160
Salter	**83**	Heavy Duty Truck	35000	160
Salter	**75**	Heavy Duty Truck	35000	160
Salter	**72**	Heavy Duty Truck	35000	160
Salter	**74**	Heavy Duty Truck	35000	160
Salter	**85**	Heavy Duty Truck	35000	160
Salter	**82**	Heavy Duty Truck	35000	160
Salter	**79**	Heavy Duty Truck	35000	160
Salter	**87**	Heavy Duty Truck	35000	160
Salter	**81**	Heavy Duty Truck	35000	160

ION	ID	TYPE	GVRW (lbs.)	WHEELBASE (in.)
Salter	**71**	Heavy Duty Truck	37600	160
Utility/response	**60**	Mid Duty Truck	14000	132
2-3yd dump	**94**	Mid Duty Truck	25600	128
1 Ton Dump	**48**	Mid Duty Truck	12000	135
1 Ton Dump Salt	**56**	Mid Duty Truck	12000	135
1 Ton Dump	**89**	Mid Duty Truck	13000	141
1 Ton Dump Salt	**47**	Mid Duty Truck	13000	141
1 Ton Dump	**49**	Mid Duty Truck	10100	137
1 Ton Dump	**69**	Mid Duty Truck	13000	147
2-3yd dump	**92**	Mid Duty Truck	19500	165
1 Ton Dump Salt	**98**	Mid Duty Truck	13000	141
2-3yd dump	**91**	Mid Duty Truck	19500	165
1 Ton Dump Salt	**90**	Mid Duty Truck	14000	141
Rackbody/appliance	**259**	Mid Duty Truck	17995	152

Table 7. DPW vehicles that are not expected to benefit from side guards.

DESCRIPTION	ID	TYPE	GVRW (lbs.)	WHEELBASE (in.)
Utility/response	**60**	Mid Duty Truck	14000	132
1 Ton Dump	**49**	Mid Duty Truck	10100	137

Figure 25. Examples of high-clearance trucks that Volpe expects to benefit from side guard installation.

Figure 26. Example of a lower clearance truck that Volpe does not expect to benefit from side guard installation.

3 Truck blind spot countermeasures

3.1 Review of truck blind spot countermeasures

The previous section discussed side guards, which can mitigate a crash and improve crash outcomes for a vulnerable road user (pedestrian or bicyclist). This section of the report discusses blind spot countermeasures, which can prevent crashes from occurring in the first place. Blind spot countermeasures may include mirrors, lenses, or advanced driver assistance systems (ADAS) for pedestrian and bicycle detection and avoidance.

In a medium or heavy duty vehicle such as a truck or bus, the driver's view around the vehicle is significantly more limited than in smaller vehicles such as passenger cars. As seating height of a truck driver increases, so does the extent of blind spot areas and the need for larger mirrors.[39] A truck driver must depend on indirect vision through mirrors and other devices in order to see many of the areas abutting the vehicle. A 2006 analysis of national crash data found that 20% of truck crashes occur in configurations where truck driver vision (or lack thereof) may have been an important factor contributing to the crash.[40]

The U.S. Federal regulatory requirements for mirror systems on large trucks are minimal. Federal Motor Vehicle Safety Standard (FMVSS-111) requires that all vehicles with a GVWR greater than 10,000 lbs. have a rear view planar mirror on each side of the cab, but the standard does not require any other mirror type. FMVSS-111 does have more specific mirror requirements for school buses, but these do not apply to other large vehicles. Despite the lack of Federal requirements, there are a variety of other mirrors in common use in the U.S., demonstrating that many truck and fleet operators recognize and have attempted to address blind spots. For example, truck drivers often add door/hood/fender-mounted rear view convex mirrors, proximity mirrors on the passenger side door, and fender/hood-mounted cross over mirrors.

3.1.1 Overview of blind spots of a large, single-unit truck

Figure 27 depicts what a truck driver can and cannot see through direct vision. It also shows the indirect fields of view that are possible with the use of some sample mirror types. The image shows a combination vehicle with a conventional cab, but the result would be similar for a large single-unit truck. Dark blue lines show the boundaries of what the driver can see through direct vision (minus obstacles, such as the A-pillar). The area below the light blue lines shows what the driver would be able to see indirectly through door-mounted rear convex mirrors. The area below the orange lines shows what the driver would be able to see with fender-mounted rear convex mirrors. This rendering does not show the fields of view that other devices, such as front cross over mirrors, proximity mirrors, or Fresnel lenses would afford.

[39] Sivak, M., Schoettle, B., and Flannagan, M., Lighting, Signaling, and Rearview Mirrors for Large Trucks: A Review of Human Factors Considerations, 2002. http://deepblue.lib.umich.edu/bitstream/handle/2027.42/49462/UMTRI-2002-30?sequence=1

[40] Reed, M., Blower, D., and Flannagan, M., Prioritizing Improvements to Truck Driver Vision, 2006.

Figure 28 shows the indirect fields of vision made possible by a wider variety of mirror types (rear planar, door-mounted rear convex, close proximity (look down), and front cross over). The image depicts the minimum requirements that each mirror class must meet according to the United Nations Economic Commission for Europe (UN ECE) Regulation 46. Refer to Figure 29 below for an image of the corresponding mirror types. Class II mirrors refers to rear planar mirrors. Class IV refers to rear convex mirrors. Class V refers to close proximity, or "look-down" mirrors, which are for the passenger side. Class VI refers to front projection mirrors, which are the closest equivalent to cross over mirrors for cab-over trucks. Figure 35 shows the location of test cylinders for the school bus field of vision test as per FMVSS-111. It does not depict the field of view of any one particular mirror type, but it shows what the school bus driver must be able to see through the overall mirror system.

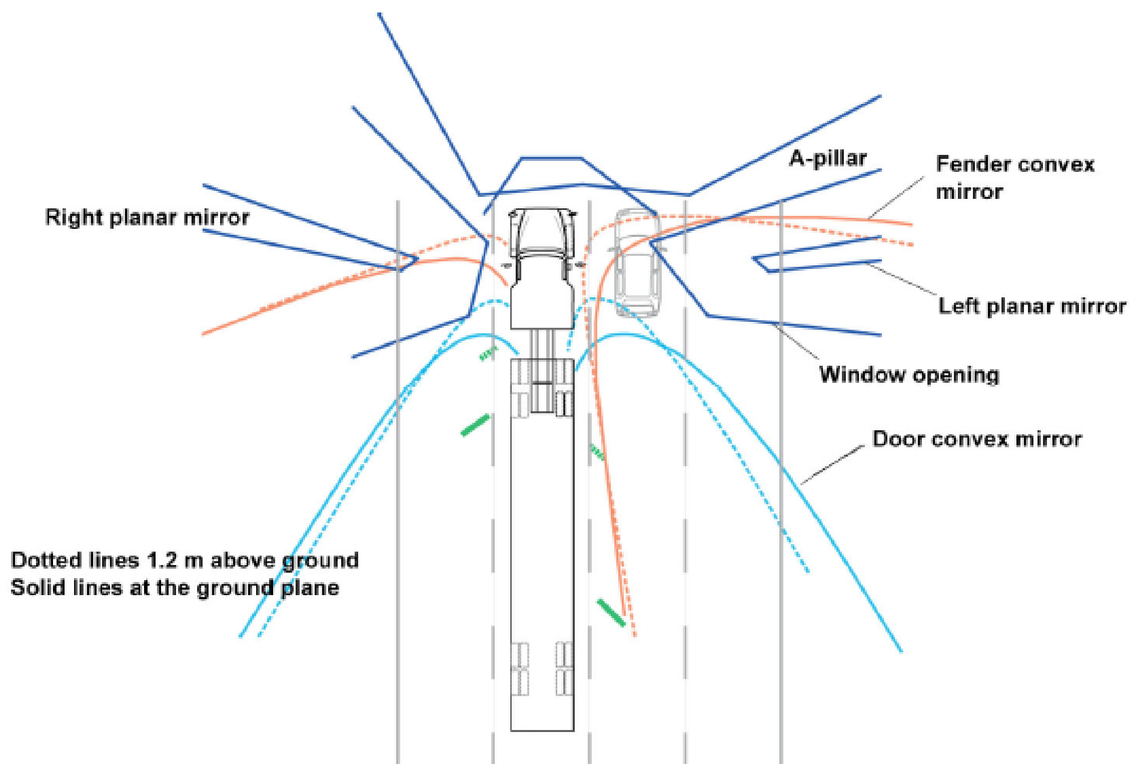

Figure 27. Driver's fields of view from the cab of a combination vehicle.[41]

Some blind spots may be more problematic than others. A 2006 multi-part study analyzed national data on truck crashes and documented vision-related collisions with motorists and vulnerable road users. The study also experimentally tested truck driver performance. Both analyses pointed to similar conclusions, and led the researchers to suggest a priority ranking for blind spot countermeasures. According to the study, the highest priority for improvements to driver vision is the area directly to the right of the truck cab, which could be addressed through the use of a front cross over mirror, potentially in combination

[41] Source: Blower, D., Truck Mirrors, Fields of View, and Serious Truck Crashes, 2007. http://deepblue.lib.umich.edu/bitstream/handle/2027.42/58728/99830.pdf?sequence=1.

with a look-down (close proximity) mirror and/or Fresnel lens. Right movements accounted for more than half of the documented crashes, and the area to the right of the cab is also the pre-crash position of many nonmotorists involved in right turn and start up crashes. The researchers noted another priority zone directly in front of the vehicle, in order to avoid start up crashes with pedestrians and bicyclists. Front cross over mirrors could also help the driver see this zone. The researchers also noted that the entire area on the right side to the rear of the truck also merits attention based on the relatively large percentage of crashes in which truck drivers fail to detect conflicts in these areas.[42] Rear convex mirrors could help the driver to see a larger area on the right side of the truck.

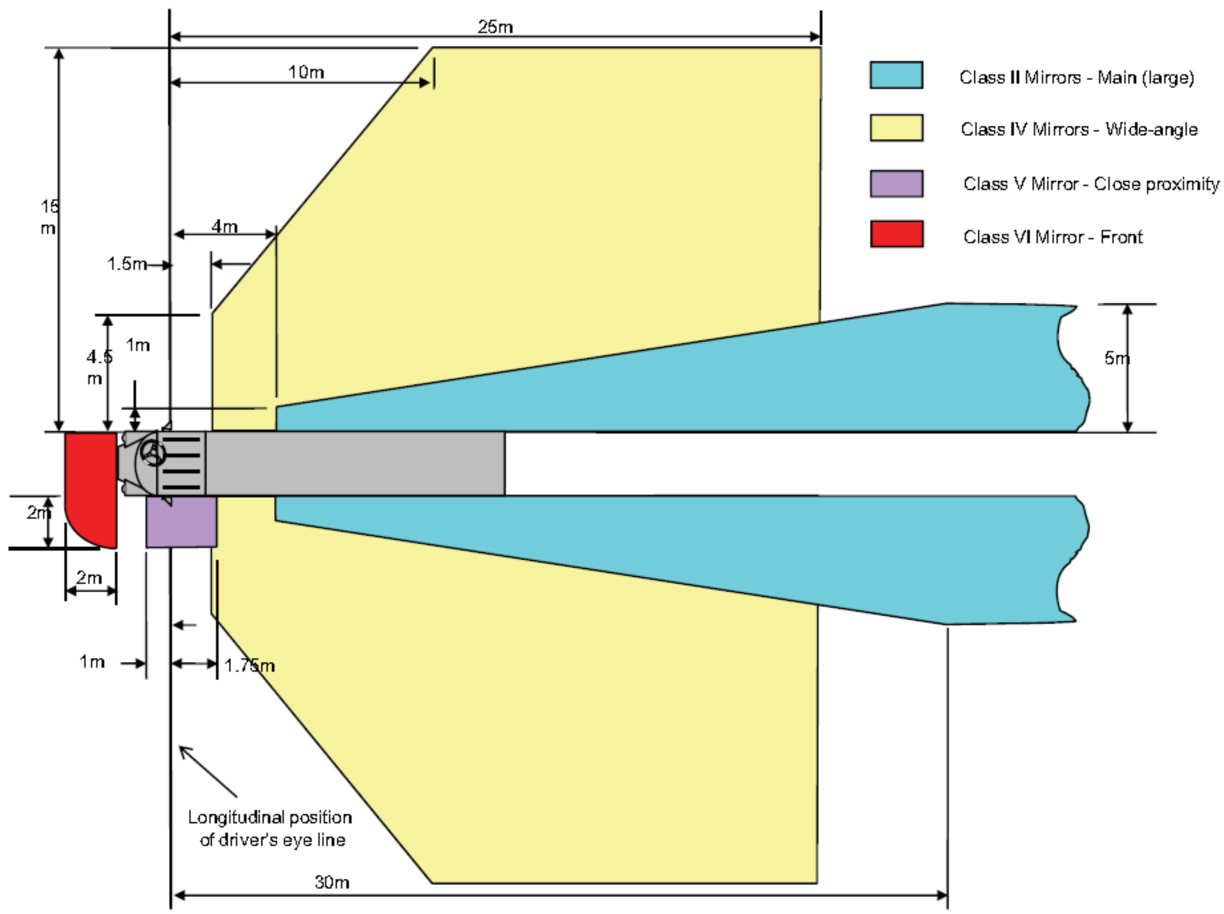

Figure 28. Schematic of field of vision requirements according to UN ECE Regulation 46 (diagram is for the United Kingdom, so the passenger side appears on the left).[43]

[42] Reed, M., Blower, D., and Flannagan, M., Prioritizing Improvements to Truck Driver Vision, 2006.
[43] Source: Dodd, M., Follow Up Study to the Heavy Goods Vehicle Blind Spot Modeling and Reconstruction Trial, 2009.

3.1.2 Mirrors and lenses for mitigating blind spots and increasing driver awareness of vulnerable road users

In addition to the standard planar rear view mirrors, truck operators may add a wide variety of other mirrors to improve the driver's view around the truck, including rear view convex mirrors (door-mounted and hood-mounted), front cross over mirrors, and door-mounted look-down (proximity) mirrors on the passenger side. Additional blind spot countermeasures include Fresnel lenses and ADAS.

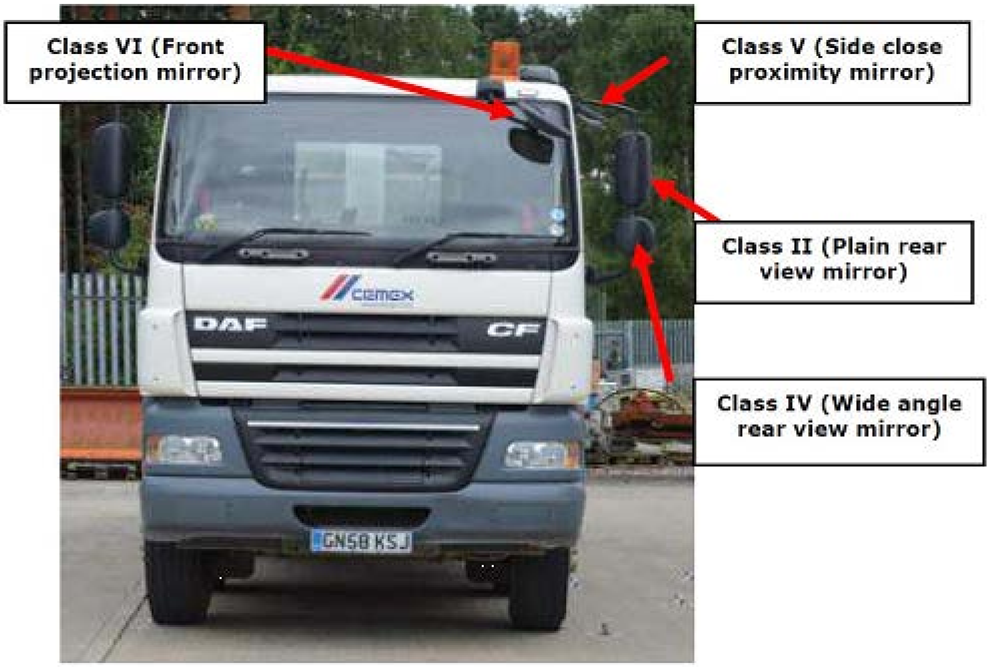

Figure 29. Photograph of mirror types (image is from the UK, which is why the Class V and Class VI mirrors appear on the left (passenger) side of the vehicle. In other European countries they would appear on the right (passenger) side.[44]

3.1.2.1 Cross over (cross view) mirrors

3.1.2.1.1 Field of vision

Also known as front or forward "cross view" mirrors, front cross over mirrors help the driver see objects in front of the vehicle that are too near to be directly visible. They may also help the driver to see objects along the side of the vehicle, which are too far forward for the driver to detect through the side rear view mirrors or direct vision. Figure 30 depicts the approximate field of vision that cross over mirrors provide when installed and adjusted properly on both sides of the hood. The actual field of vision likely extends beyond what is shown here, but this represents the minimum expectation based on vendor brochures on cross over mirrors. All cross over mirrors are convex, and they all introduce a certain amount of image distortion, reducing apparent sizes and distances.

[44] Source: Transport for London. https://consultations.tfl.gov.uk/buses/safer-lorries

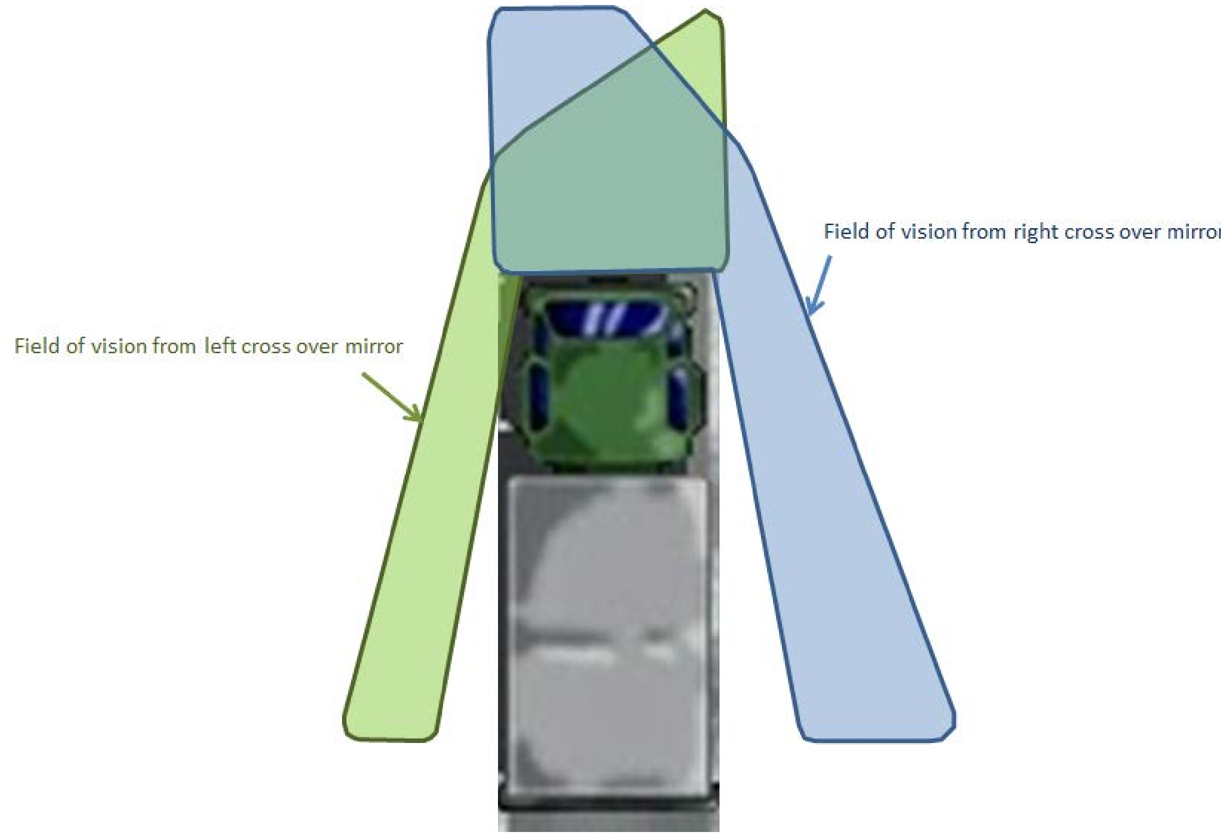

Figure 30: Depiction of the approximate field of vision provided by cross over mirrors.

3.1.2.1.2 Precedents and regulations

Table 8 summarizes examples of existing requirements for cross over mirrors on large vehicles. The first entry in the table is for a Class VI mirror, which is the closest European equivalent of the front cross over mirror. It is not exactly the same, however, since most European trucks have a cab-over design (flat front in which the cab is over the engine) and most U.S. trucks have a conventional cab configuration. Figure 32 shows the distinction.

The Boston ordinance and the Oregon code are the two existing U.S. precedents that have the most stringent weight threshold, requiring cross over mirrors on vehicles above 10,000 lbs. According to Oregon staff, they established the threshold at 10,000 lbs. in order to include small delivery vehicles that otherwise would have been excluded if they had chosen a higher threshold. A small delivery vehicle of about 10,000 lbs. killed a small child in Oregon; this was the incident that inspired the code. That said, Oregon staff acknowledge that the exact weight threshold is somewhat arbitrary, and clearly the size and shape of the vehicle are more definitive indicators. Small delivery vehicles under 10,000 lbs, such as U.S. Postal Service vans that weigh only 2,700 lbs.,[45] also often have cross over mirrors, but this may be partly to compensate for the fact that drivers sit on the right-hand side of these vehicles. On postal vans

[45] https://en.wikipedia.org/wiki/Grumman_LLV

the cross over mirror is typically mounted on the left-hand side, as shown in Figure 31. Installation of crossover mirrors on the delivery van fleet started with a U.S. Postal Service employee suggestion.[46]

Figure 31. U.S. Postal Service delivery van with cross over mirror

Aside from the examples listed in Table 8, the United Nations Economic Commission for Europe (UN ECE) Regulation 125 is also relevant. It addresses the driver's forward field of vision for passenger cars. The UN ECE updated Regulation 125 in 2013 to address a concern that the original downward vision requirements may not adequately address passenger vehicles with high driving positions (e.g. light duty trucks, people carriers, multipurpose vehicles, sport utility vehicles) leading to a situation where a driver may be unable to identify VRUs directly in front of the vehicle. The amendment applies to all vehicles where the driver's eyes are more than 165 cm above the ground. It specifies that a 120 cm tall cylindrical object with a diameter of 30 cm must be visible from the driver's eye points when it is placed 200 cm in front of the vehicle at any lateral location between 40 cm outboard of the driver's side of the vehicle to 60 cm outboard of the passenger side of the vehicle.

[46] https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=INTERPRETATIONS&p_id=22336

Figure 32. Front cross over mirror, depicted at left on a conventional cab configuration, performs a similar function as the European Class VI "front projection"mirror, depicted at right on a cab-over configuration.

Table 8. Summary of existing requirements for front cross over mirrors

Scale	Entity	Applicable vehicles	Exemptions	Requirement	Name of law/rule
International	European Union	*Vehicles over 7.5 metric tons (16,535 lbs.) *Vehicles between 3.5 to 7.5 metric tons (7,716 to 16,535 lbs.) where a Class V mirror can be fitted		Note that the specifications are most relevant for cab-over trucks, since that is the style most common in Europe. Requirement is for one front mirror with a minimum radius of curvature of 200 mm (must be fitted at least 2 m off the ground). See "Class VI" in Figure 28 (page 41) for required field of vision.	UN ECE regulation 46
Federal	NHTSA	School buses nationwide		A diagram specifies 9 locations in the front of the truck (from 0 to 12 feet away) and additional locations at left and right, from which cylinders of specific dimensions must be visible to the driver. The cylinders should be 1 foot high and 1 ft. in diameter, and the entire top surface of each cylinder must be visible.	FMVSS-111 (49 CFR 571.111)

Scale	Entity	Applicable vehicles	Exemptions	Requirement	Name of law/rule
State	New York	Trucks, tractors, and tractor-trailers or semi-trailer combinations with a maximum gross weight of 26,000 lbs. or more and a conventional cab configuration	*Cab-over designs *Vehicles not registered in the State of New York *Vehicles not operated in a city of one million or more *Vehicles on controlled access highways *Any vehicles the commissioner decides to exempt in the future, where mirrors would not increase the visibility of persons or objects located directly in front of the vehicle	Vehicle must be equipped with a convex mirror (or mirrors) on the front of the vehicle whenever operated within a city with a population of one million or more on highways other than controlled-access highways. The mirror(s) must permit the driver to see anything that is at least three feet tall, passing a foot in front of any portion of the truck.	Section 375 of the Vehicle and Traffic Law, subdivision 10-e
State	Oregon	Truck with a combined weight of more than 10,000 lbs. used in commercial delivery	*Commercial buses *Tow vehicles *Vehicles owned or operated by the United States or by any governmental jurisdiction within the United States except when owned or operated as a carrier of property for hire * Vehicles owned or operated by a mass transit district created under ORS chapter 267 *Vehicles used for solid waste or recycling collection.	Requires the driver to use a forward crossview mirror *OR* inspect the intended path of the vehicle to verify that the path is free of persons or objects before reentering.	Oregon Vehicle Code 815.237, "Forward crossview mirror; failure to inspect; exemptions; penalty"
State	Maryland	School vehicles		Every school vehicle shall be equipped with at least one convex mirror not less than 7-1/2 inches in diameter which shall be firmly mounted on the left front corner forward of the seated driver so that he may observe a reflection of the road from the front bumper to a point where direct observation is possible.	State Regulation 11.14.02.13
City	Boston	Vehicles over 10,000 lbs. and semi-trailers with a total weight over 26,000 lbs. with a conventional cab configuration, used by city of Boston vendors within the city of Boston	*Cab-over designs *Vehicles with a maximum speed less than 15 miles per hour *Agricultural trailers *Fire engines *Emergency medical vehicles *Vehicles used solely for snow removal *Street sweepers *City of Boston fleet vehicles purchased before July 1, 2014 *Vehicles that the city decides to exempt upon receipt of a request for exemption	Objects must be visible to the driver three feet above the ground, from the front bumper to where direct vision is possible.	Ordinance to Safeguard Unprotected Road Users

3.1.2.1.3 Types available and installation considerations

There a number of manufacturers of cross view mirrors and many models available. They are all convex and therefore reduce the apparent size of objects to varying degrees.

3.1.2.1.3.1 Influence of shape on glare

Figure 33 shows how oval elliptical (hemispheric) mirrors and elongated oval elliptical mirrors can cause glare, impeding the driver's view, whereas quadraspheric lenses can reduce or eliminate glare. All three photographs were taken under the same conditions. As depicted in Figure 34, some models also have a special coating or other features that help to reduce glare.

Figure 33: Three basic shapes for cross over mirrors. The quadraspheric ("cat-eye") shape, on the right, is ideal for reducing glare.[47]

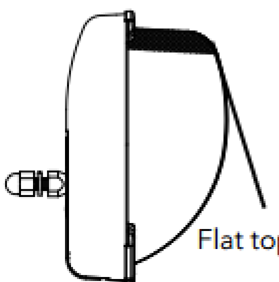

Figure 34. Some mirrors have a dark coating and/or flat shape on top to prevent glare.[48]

3.1.2.1.3.2 Uniform versus asymmetric curvature

Some mirrors have uniform (spheric) curvature throughout. However, an asymmetric (aspheric) curvature may be preferred because it can optimize visibility in the most important portions of the view and minimize size distortion (apparent reduction of image size). The only disadvantage to an asymmetric curvature is that the size distortion is not uniform, which may not be an issue as long as drivers understand through training and/or signage that the mirrors are not meant to be used to judge distances while driving.

3.1.2.1.3.3 Manufacturers

There are a variety of cross over mirror manufacturers. Rosco appears to have the most comprehensive information readily available on mirror performance and specifications. The company produces several

[47] Source: www.mirrorliteco.com/quad.html
[48] Source: www.roscomirrors.com/upload/brochure_pdf4546a3e982d1feCrossViewMirrorSystems_102214.pdf

models, but the Eye Max LP is the only one that it actively promotes as an aftermarket solution to meet the New York State requirements. Table 9 lists some potential vendors of front cross over mirrors.

Table 9. Potential vendors of front cross over mirrors.

Make/Model	Purpose/Relationship to Existing Requirements	Shape
Rosco (Eye Max LP)	Meets New York State requirements and FMVSS-111 (instructions for ensuring compliance are available from manufacturer)	Quadraspheric (cat-eye)
Velvac (product number 714621 or 714628(left)/ 714629(right))	Meets New York State requirements (instructions for ensuring compliance are available from manufacturer)	Spherical, 8.5 inch diameter
SurePlus Cross View (product number 875 or 1080)	Meets New York State requirements	Spherical or Quadraspheric (cat-eye)

3.1.2.1.3.4 Number of necessary mirrors

If Cambridge DPW elects to use the New York State specifications for cross over mirror systems, only one cross over mirror per vehicle would be necessary, ideally mounted on the right (passenger) side. However, in the event that Cambridge DPW elects to use the specifications in FMVSS-111 (System B covers the cross over mirror system), or the more stringent Volpe recommendation extending to 18 feet, two cross over mirrors per vehicle would be necessary, mounted on the left and right sides. Figure 35 illustrates the limitations of the right cross over mirror for a conventional school bus, which fall short of the FMVSS-111 requirement. The left cross over mirror has a similar limitation, but in reverse. Of course, this would vary on a vehicle-by-vehicle basis, such that certain vehicle types may be able to pass the more stringent field of vision test with only one cross over mirror. Field testing could confirm this for each vehicle type.

3.1.2.1.3.5 Conventional cab versus cab over design

Research has shown that even in trucks with cab-over designs the height of the cab in combination with the driver eye position obstructs the view immediately in front of the vehicle.[49] With this in mind, front cross over mirrors would enhance safety for both conventional as a well as cab over vehicles. In the European Union, where most trucks have a cab-over design, UN ECE regulation 46 requires applicable vehicles to have one front mirror. See “Class VI” mirror in Figure 28 (page 41) and Figure 29 (page 42). See Table 8 on page 45 for more information on the European requirement.

3.1.2.1.3.6 Installation options

Vendors provide a variety of means to install and mount cross over mirrors on trucks. In the case of school buses, the original equipment manufacturer (OEM) typically purchases and installs the mirrors before selling the vehicle to the consumer. For aftermarket installations on other types of vehicles, the mirror manufacturers typically do not install the mirrors. Instead, they sell mounting equipment in kits

[49] Blower, D., Truck Mirrors, Fields of View, and Serious Truck Crashes, 2007. http://deepblue.lib.umich.edu/bitstream/handle/2027.42/58728/99830.pdf?sequence=1

with manuals so that consumers can install the mirrors themselves. Most manufacturers have installation instructions and documentation that is specific to the New York State and FMVSS-111 requirements. Any vehicle can support front cross over mirrors, regardless of whether there is already hardware on the vehicle.

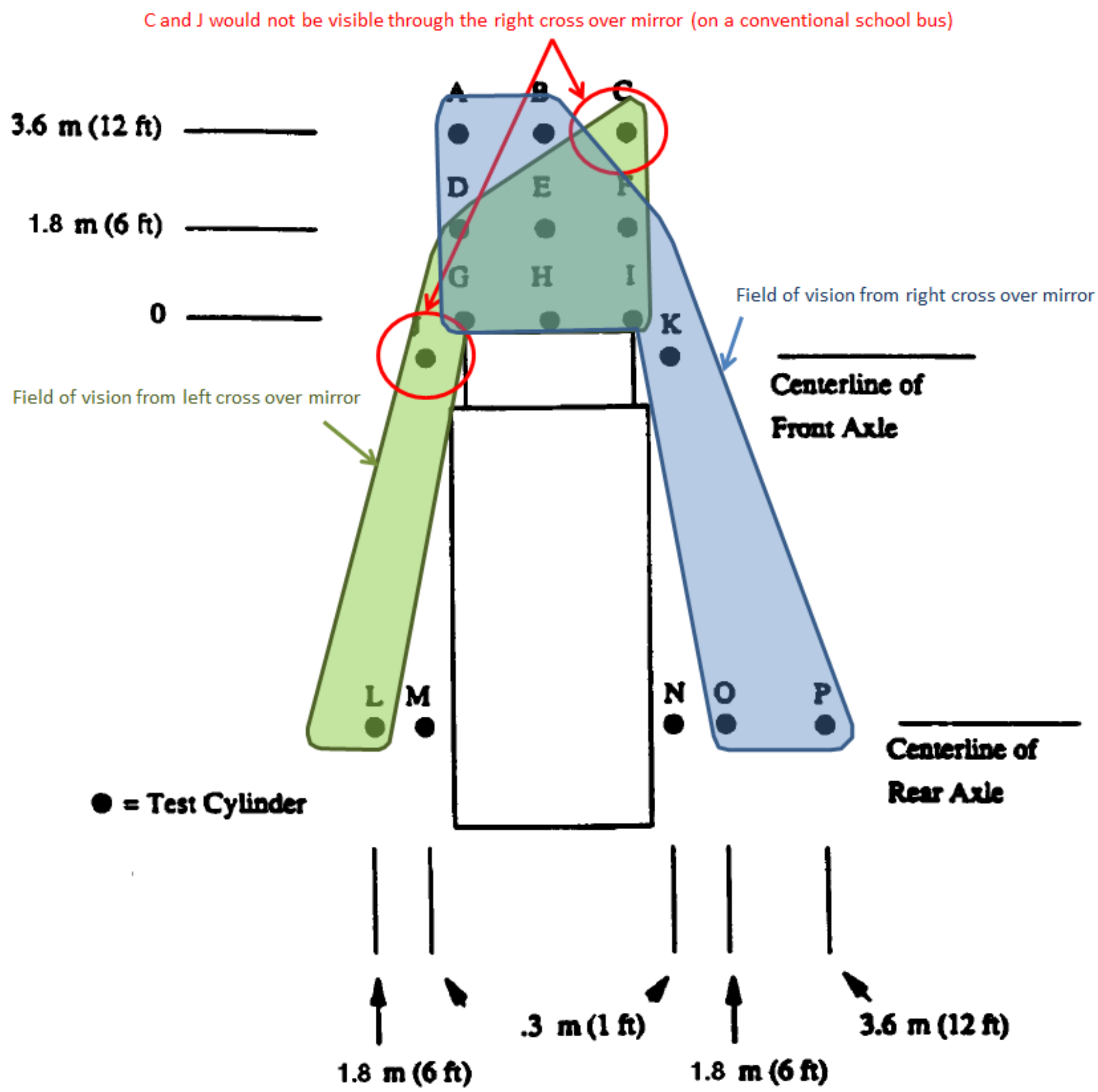

Figure 35. Location of test cylinders for school bus field of vision test, as per FMVSS-111. As shown, the right cross over mirror does not provide a view of cylinders C and J when mounted on a conventional school bus.

One mounting option is a “tunnel/tube” style, which allows the mirror to rotate in a horizontal plane for adjustment. The alternative, a “ball stud” style mount, allows adjustment in all directions. The disadvantage of the latter style is that it creates more opportunity for maladjustment. When tilted too far upward, a mirror can create glare for the driver and may not adequately reflect low height objects. Figure 36 shows each of these two mounting options.

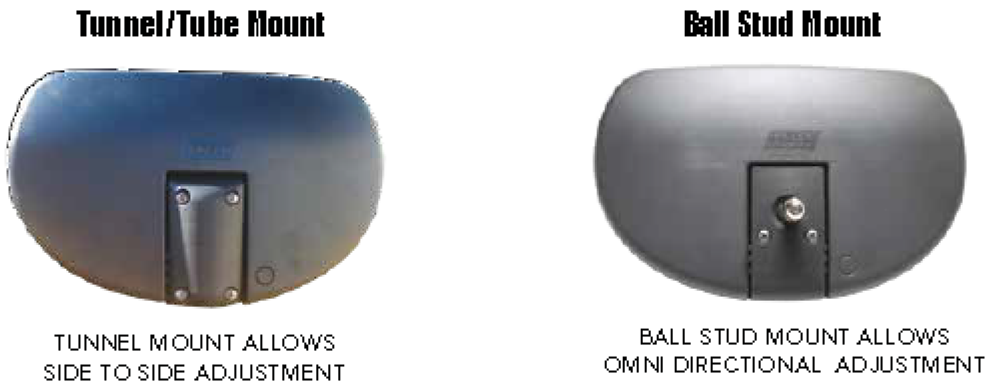

Figure 36. Two mounting styles for front cross over mirrors.[50]

For most vehicles, the optimal mounting position for a cross over mirror will be as far forward on the vehicle as possible, while still visible to the driver. For vehicles that already have a tripod assembly mounted far enough forward on the fender/hood (e.g. for a rear view convex mirror), it is possible to attach the front cross over mirror to that same structure with the use of a twisted mounting bracket. Figure 37 shows two examples from one manufacturer. For vehicles that have an existing tripod that is mounted too far back, it may still be possible to attach the front cross over mirror to that same tripod with the use of an extendable brace arm and wrap around clamps. However, both of these methods of attaching a cross over mirror to an existing tripod would require a ball stud mount, which may not be optimal for adjustment.. According to one manufacturer, most operators choose to install the cross over mirror on a separate mounting structure, as shown in Figure 38, rather than an existing tripod.

Figure 37. Left: A twisted mounting bracket can attach a front cross over mirror to an existing tripod assembly, provided it is mounted far enough forward on the vehicle. An extendable brace arm can attach a front cross over mirror to an existing tripod assembly, while positioning the cross over mirror in a more optimal position (further forward).[51]

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[50] Source: www.roscomirrors.com/upload/brochure_pdf4a8d6363511bbEyeMax%20LP%20Brochure.pdf
[51] Source: www.sureplus.com/crossview.htm

Figure 38. According to one manufacturer, most vehicle operators in New York choose to install a front cross over mirror on its own separate mounting structure rather than an existing tripod.[52]

3.1.2.2 Rear view, wide angle (convex) side mirrors

3.1.2.2.1 Field of vision

A rear view convex, or wide angle, mirror is designed with an outward curve that protrudes toward the user to create a wider field of view than is possible with a planar mirror. Generally, a convex rear view mirror is considered to be spherical in shape unless otherwise stated (i.e. it has a constant radius of curvature across the entire surface). As mentioned in the cross over mirror section above, a convex mirror reduces apparent sizes and distances.

Convex mirrors widen the rear field of vision beyond what a planar mirror would provide. Figure 39 shows two examples of the field of vision that such a mirror can afford the driver. The lower example may be preferred because it is mounted further forward on the vehicle such that the resulting field of vision includes more of the area immediately to the side of the cab. A conventional cab truck may be able to cover some of the same blind spot through the front cross over mirror or a hood-mounted rear view convex mirror. Figure 40 shows how the field of view for a convex mirror differs from that of a planar mirror.

[52] Photograph source: www.roscomirrors.com/upload/brochure_pdf24e847c1e751e8EyeMaxLP_NYSLaw.pdf

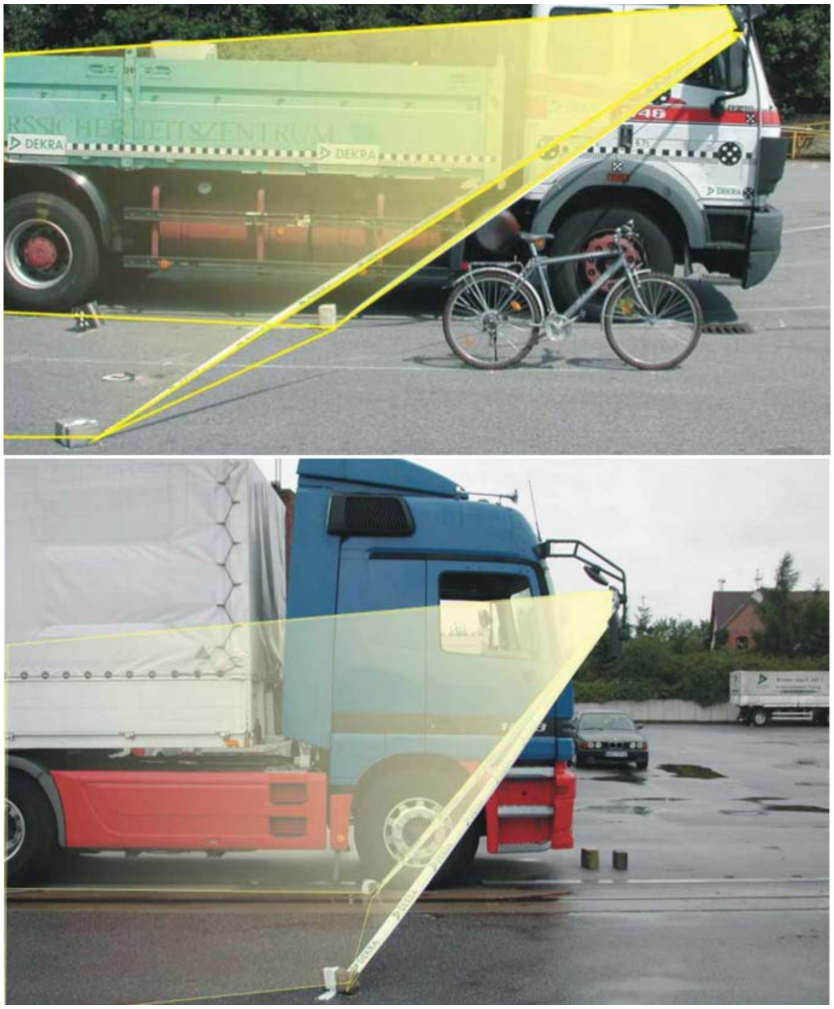

Figure 39. Images showing the indirect field of vision from the driver's perspective via two different styles of rear view convex (wide angle) mirrors.[53]

[53] Source: Niewoehner, W., Berg, F.A., Endangerment of Pedestrians and Bicyclists at Intersections by Right Turning Trucks.

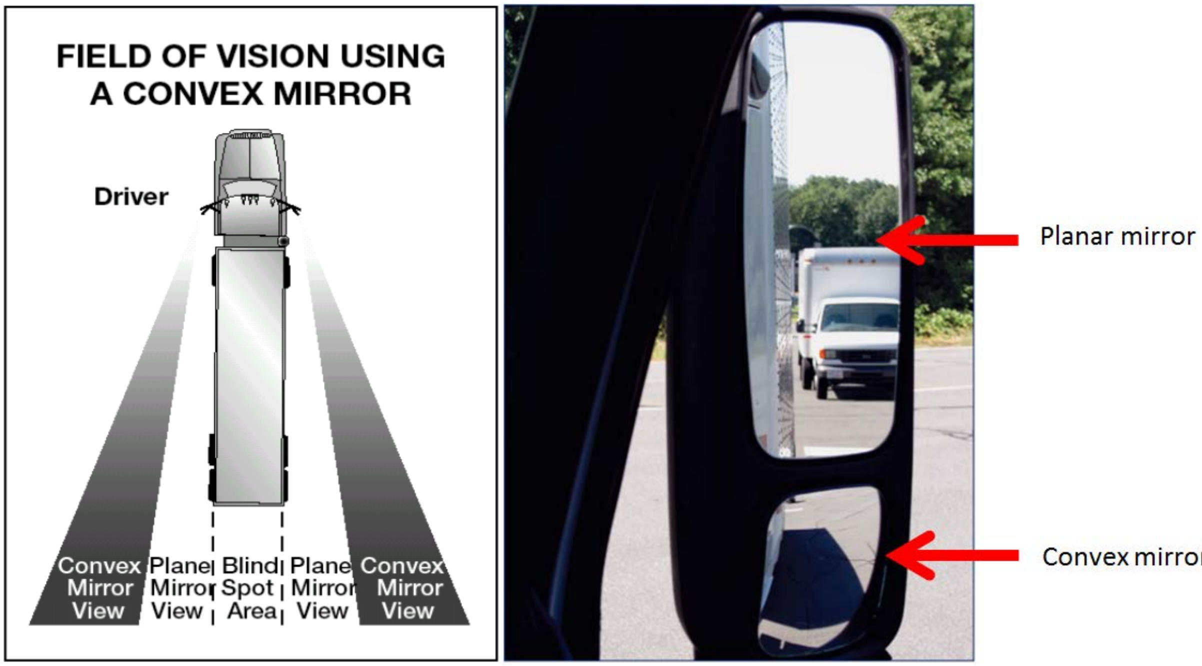

Figure 40. Left: Birds eye view of the field of vision that a convex mirror provides in relation to that of a planar mirror.[54] Right: A single mounting structure can house both a planar and a convex rear view mirror.

3.1.2.2.2 Precedents and regulations

There are no federal requirements for rear view convex mirrors for medium or heavy duty vehicles. However, state school bus manuals all appear to include a discussion of rear view convex mirrors, implying that the use of such mirrors is at least standard practice, if not an official requirement. At least one state (Maryland) has a regulation requiring rear view convex mirrors for school buses, but there do not appear to be any state requirements that apply to all trucks and buses. At the local level, the City of Boston requires convex mirrors and specifies that the rear view mirror system must allow the driver to see objects three feet above the ground down the full length of the vehicle. Table 10 summarizes examples of existing requirements for rear view convex mirrors that Volpe identified.

[54] Source: www.state.nj.us/mvc/pdf/Commercial/CDL_Manual_english.pdf

Table 10. Summary of existing requirements for rear view convex mirrors

Scale	Entity	Applicable vehicles	Exemptions	Requirement	Name of law/rule
International	European Union	Commercial vehicles over 3.5 metric tons (7,716 lbs.)		One mirror on each side of the vehicle, with a minimum radius of curvature of 300 mm. See "Class IV" in Figure 28 (page 41) for required field of vision.	UN ECE regulation 46
State	Maryland	School vehicles		There shall be on each side of vehicle a convex mirror of not less than 20 square inches of reflective surface. The convex mirrors may be incorporated in the plain view rearview mirror provided the plain view reflective area is not reduced, or they may be mounted independently. Either type shall be independently adjustable.	State Regulation 11.14.02.13
City	Boston	Vehicles over 10,000 lbs. and semi-trailers with a total weight over 26,000 lbs. with a conventional cab configuration, used by city of Boston vendors within the city of Boston	*Cab-over designs *Vehicles with a maximum speed less than 15 miles per hour *Agricultural trailers *Fire engines *Emergency medical vehicles *Vehicles used solely for snow removal *Street sweepers *City of Boston fleet vehicles purchased before July 1, 2014 *Vehicles that the city decides to exempt upon receipt of a request for exemption	Vehicles must have rear view convex mirrors installed. Objects must be visible to the driver three feet above the ground down the full length of the vehicle.	Ordinance to Safeguard Unprotected Road Users

3.1.2.2.3 Types available and installation considerations

Rear view convex mirrors are available from a variety of manufacturers, both as OEM installations as well as aftermarket retrofit options. Some manufacturers provide a single housing and mounting structure that contains both the planar as well as the convex rear view mirrors. Figure 40 shows an example. This arrangement can work well as long as each mirror can be independently adjusted.

Some operators of U.S. vehicles with a conventional cab configuration opt to supplement a door-mounted rear convex mirror with a fender or hood-mounted one. Figure 41 shows how this can afford a larger field of view because of its position at thefront of the vehicle, similar to the enhanced field of view depicted in Figure 39.

A quadraspheric, asymmetric, cross over mirror, when properly adjusted, shows an optimized view along the side of the vehicle in addition to the front. For a conventional truck that has quadraspheric, asymmetric, front cross over mirrors on each side (rather than the classic, spherical, "bubble" variety), it is unclear how much additional utility a hood-mounted rear view convex mirror would provide. In fact, contemporary school buses do not have hood-mounted rear view convex mirrors; instead they have only front cross over mirrors. In addition, it is unclear to what extent the view from a hood-mounted rear view convex mirror may overlap with the field of vision of a look down mirror (discussed in section 3.1.2.3 on page 55). There does not appear to be sufficient information in the existing research literature to address these questions. While European studies have extensively investigated other mirrors, they have not investigated fender- or hood-mounted rear view convex mirrors because most European trucks have a cab-over design, where such mirrors are not relevant. This would be a fruitful topic for additional research.

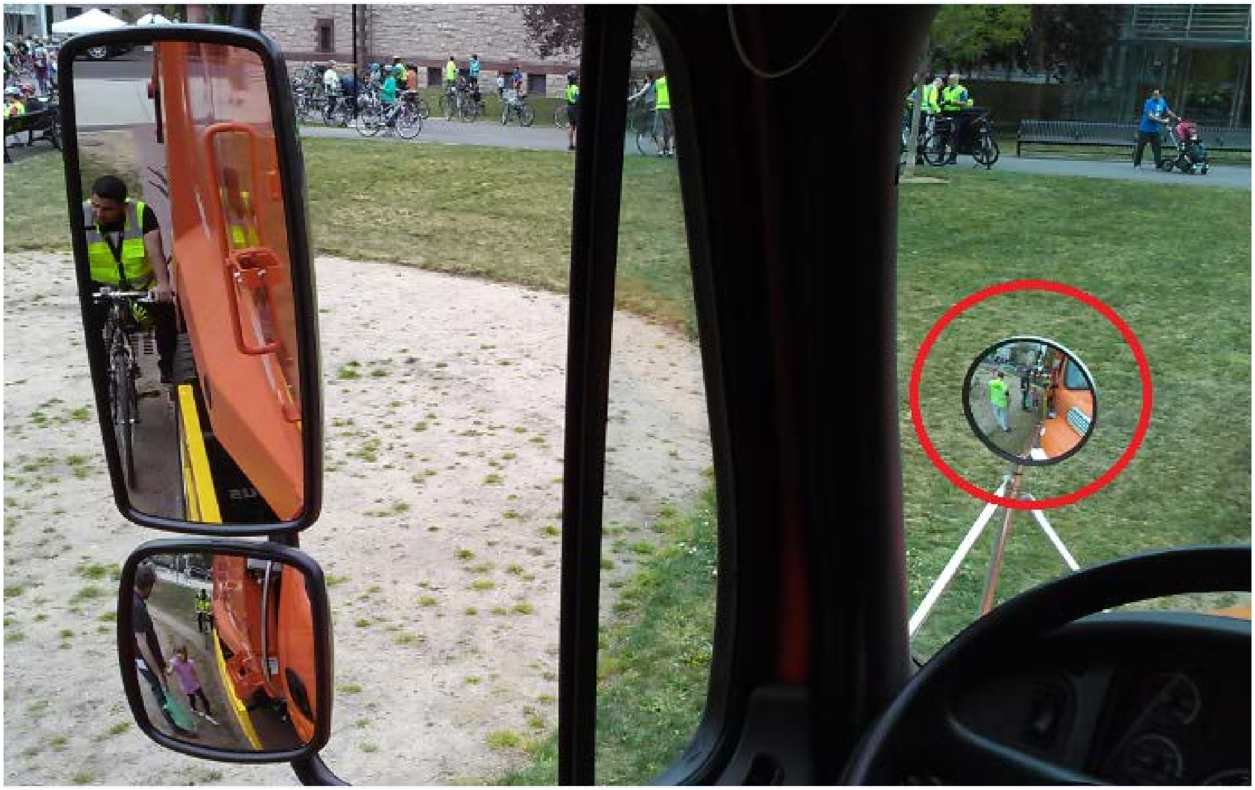

Figure 41. Operator view of the fields of vision provided by fender-mounted and door-mounted rear view convex mirrors.

3.1.2.3 Proximity (look down) mirrors

3.1.2.3.1 Field of vision

A proximity (look down) mirror is a convex mirror that helps the driver to view the area immediately to the side of the vehicle cab. Typically truck operators use these mirrors on the passenger side of the vehicle. Figure 42 shows the field of vision that a proximity (look down) mirror provides a truck driver.

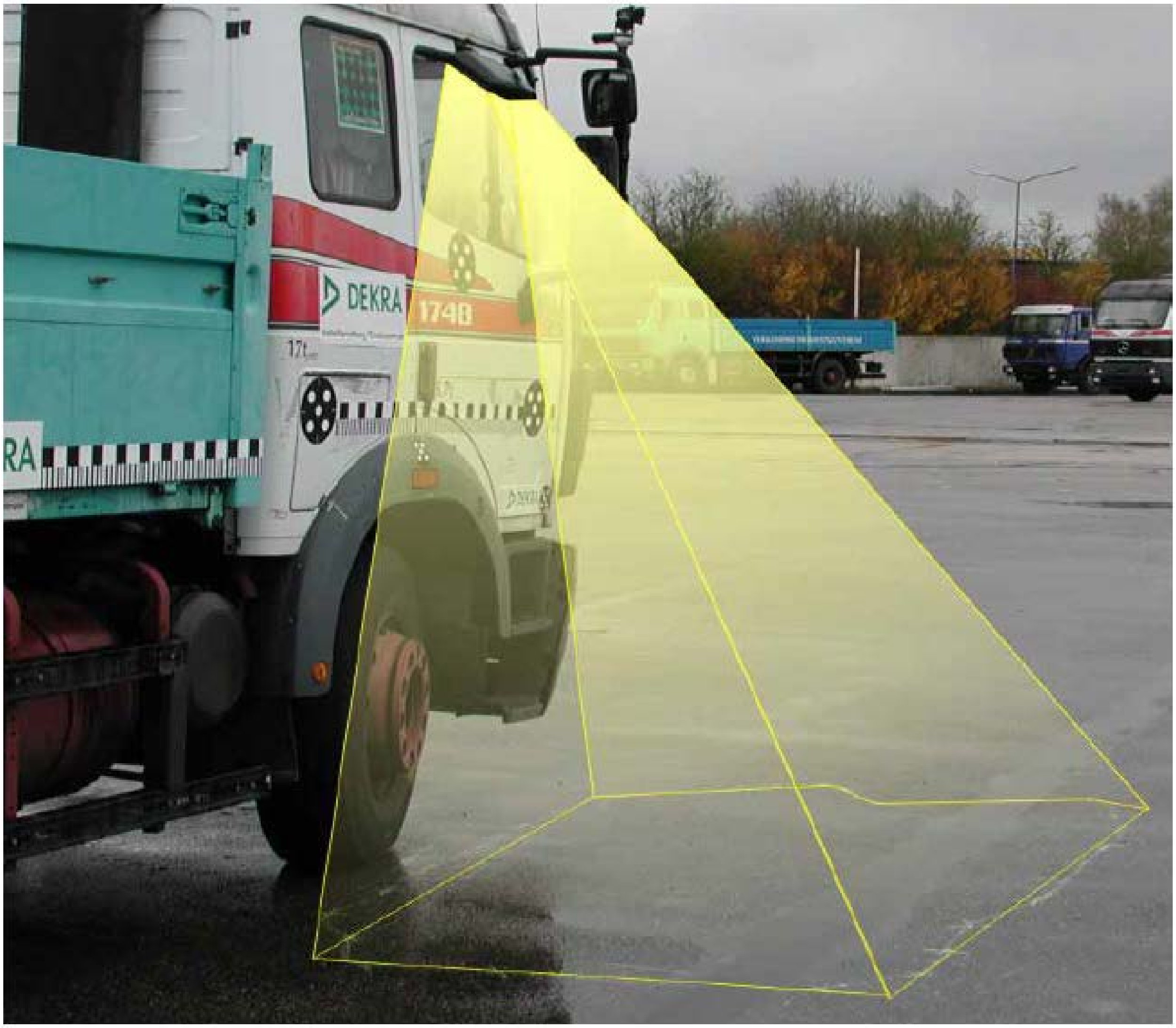

Figure 42. Field of vision that a proximity (look down) mirror provides a truck driver.[55]

3.1.2.3.2 Precedents and regulations

As of summer 2015, there were no regulations requiring look down mirrors anywhere in the U.S. The European Union does have a requirement, as detailed in Table 11. A look down (close proximity) mirror may be especially important for a cab-over vehicle, because there is a limit to how far forward a front projection mirror or a rear view convex mirror can be located, based on the geometry of the cab-over vehicle (see Figure 39 on page 52). In contrast, a truck with a conventional cab design can support a front cross over mirror and/or hood-mounted rear view convex mirror much further in front of the driver and the resulting field of vision would overlap more with the field of vision of a look down (close proximity) mirror. In some cases it is even possible that the field of vision from a front cross over mirror or hood-mounted rear view convex mirror may completely overlap with that of a look down mirror,

[55] Source: Niewoehner, W., Berg, F.A., Endangerment of Pedestrians and Bicyclists at Intersections by Right Turning Trucks.

rendering the latter redundant. In fact, the UN ECE regulation 46 notes that if the required field of vision for a Class V (close proximity/look down) mirror can be perceived through a combination of a Class IV rear view convex mirror and a Class VI front projection mirror, the installation of a Class V mirror is not compulsory. If this redundancy is possible on a cab-over vehicle, it is possible (and even more likely) on a conventional cab vehicle. There does not appear to be any information in the existing research literature to address the interaction (and the extent of potential redundancy) between the front cross over mirror, hood-mounted rear view convex mirror, and look down mirror fields of vision on a conventional cab truck. This would be another fruitful topic for additional research.

Table 11. Summary of existing requirements for close proximity (look down) mirrors

Scale	Entity	Applicable vehicles	Exemptions	Requirement	Name of law/rule
International	European Union	Vehicles over 3.5 metric tons (7,716 lbs.)	If the required field of vision can be perceived through the combination of the field of vision from a Class IV rear view convex mirror and that of a Class VI front projection mirror, the installation of a Class V close proximity mirror is not compulsory.	One Class V mirror on the passenger side, with a minimum radius of curvature of 300 mm. See “Class V” in Figure 28 on page 14 for required field of vision. An additional Class V mirror on the driver’s side is optional.	UN ECE regulation 46

3.1.2.3.3 Types available and installation considerations

Despite the lack of U.S. requirements, some truck OEMs, such as Volvo, do install look down mirrors on their vehicles (see Figure 43). Operators also install them as aftermarket retrofits and they are commercially available in the U.S. from a variety of manufacturers, such as Truck-Lite, Prutsman, Grote, Retrac, Rosco, and others. Figure 44 shows a few examples. There are minor differences between the models, but the essential designs are largely the same. Typically operators install look down mirrors on the passenger side of a vehicle.

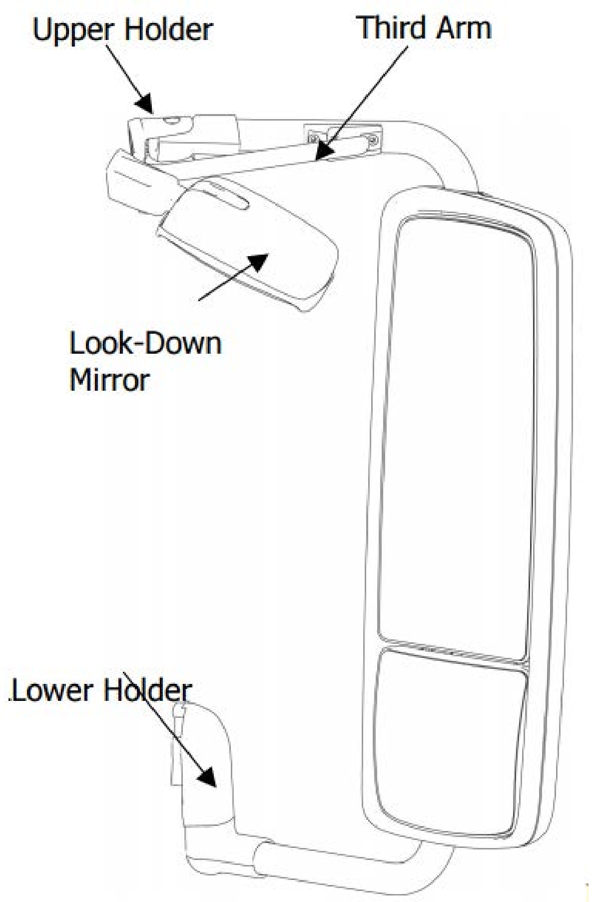

Figure 43. Image of a look down mirror included as part of a Volvo truck OEM component.[56]

Figure 44. Images of look down (close proximity) mirrors.

[56] . Source: www.lang-mekra.com/pdf/service/service-manual-472.pdf.

3.1.3 Fresnel lenses

3.1.3.1.1 Field of vision

A Fresnel lens is a low-cost (typically under $20) measure to improve visibility. It is a clear, flat, plastic lens (typically polyvinyl chloride (PVC) or acrylic) with concentric ridges. It takes advantage of the Fresnel principle to widen the cone of view, allowing the user to see around a visual obstruction. For large trucks, it is often placed on the passenger door window glass to afford the driver a downward view of objects or persons close to the cab, including vulnerable road users. Many U.S. trucks also have a small 'peeper' window in the lower section of the passenger side door. This window is an ideal location to install a wide angle Fresnel lens to further increase the field of view around the blind spot. Some drivers also install Fresnel lenses at the rear of vehicles, for example on passenger vans, to afford a better view while reversing. Figure 47 shows a situation in which a Fresnel lens would be essential for viewing a vulnerable road user. The lower photograph shows the pedestrian's location in relation to the truck. The upper photograph shows that the pedestrian is not visible to the truck driver in the rear view planar mirror (lower left), rear view convex mirror (upper left), or proximity (look down) mirror (top). The Fresnel lens, on the other hand, does reveal the pedestrian to the driver, as shown in the yellow circle.

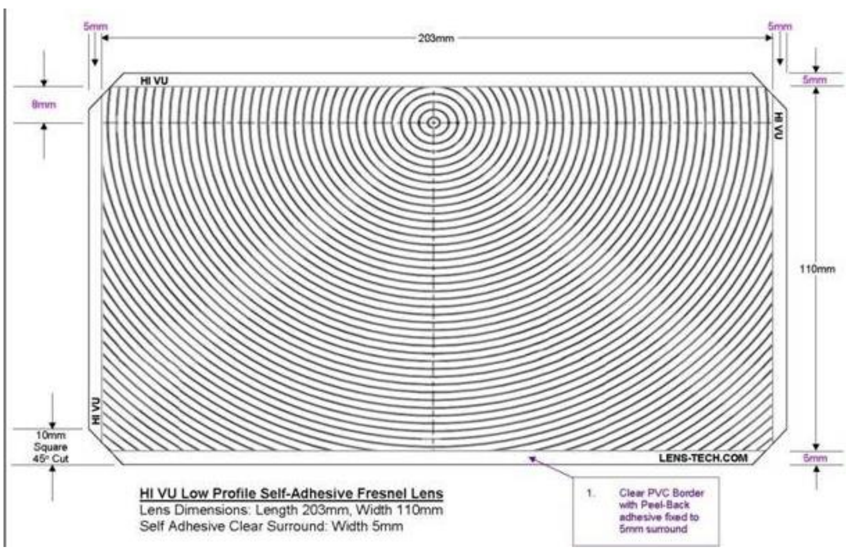

Figure 45. Image of a Fresnel lens

Figure 46 shows the additional visibility that a Fresnel lens provides. The Transport Research Laboratory in the UK conducted a heavy-duty vehicle blind spot modeling and reconstruction trial in order to determine what additional benefit, if any, a Fresnel lens could provide in addition to the mirrors mandated by UN ECE regulation 46. All three of the vehicles in the study had a cab-over design, so the results of the study are not directly applicable to the Cambridge DPW fleet where most vehicles have a conventional cab configuration. With that caveat in mind, it is nevertheless notable that the study found that Fresnel lenses did offer additional benefit to the mandatory mirrors and eliminated some of the remaining blind spots. For the three test vehicles and three ocular points (i.e. driver heights) used in the study, the Fresnel lens eliminated 78% to 90% of the remaining blind spots on the passenger side of the cab.[57]

The study also found that:

- The lens provided the best visibility at the lower edge of the window.
- When placed at the front of the window, the external rear view mirror partially obstructed the view, suggesting that it may be preferable to place the lens toward the lower rear of the window.
- Glare from the sun had the potential to obstruct the view through the lens.
- Even with the Fresnel lens and other supplementary devices in place, some potential blind spots still existed alongside the test vehicles which were large enough to hide a passenger car or VRU. A class VI (front mirror) would likely have eliminated the remaining blind spots.[58]

A United Kingdom safety initiative reduced lane changing crashes between trucks and cars by 59% after issuing Fresnel lenses to left-hand drive trucks entering through UK ports.[59] A similar initiative is underway to address cyclist fatalities in London, the majority of which are caused by large trucks.

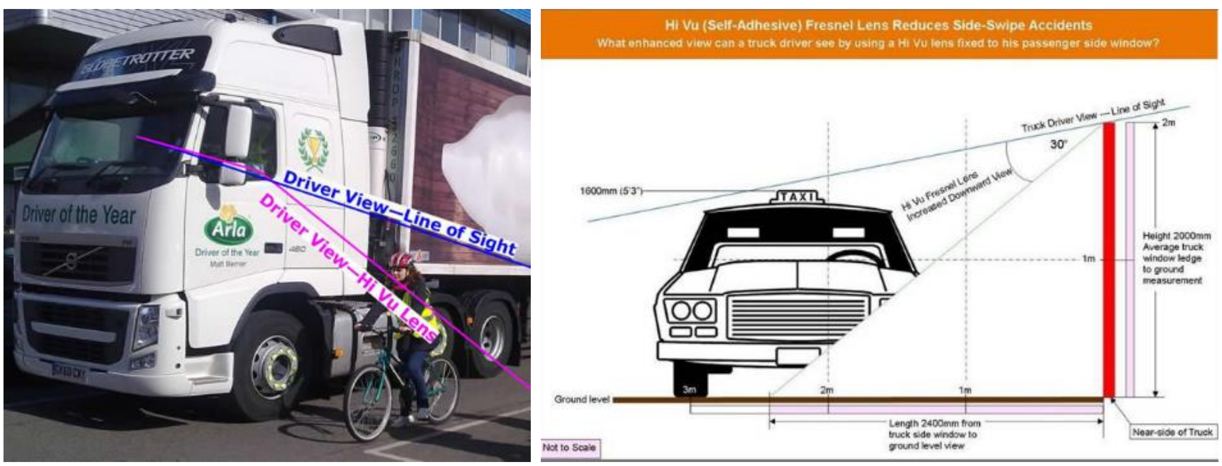

Figure 46. A Fresnel lens provides a wide angle downwards view close to and around the truck's passenger door, helping to reduce side swipe crashes.[60]

[57] Dodd, M., Follow Up Study to the Heavy Goods Vehicle Blind Spot Modeling and Reconstruction Trial, 2009. www.connekt.nl/uploads/2012/09/trl-blind-spot.pdf
[58] Ibid
[59] Truckview information sheet, 2008. http://truckview.net/BiggerPicture.pdf
[60] Source: www.lens-tech.com/fresnel-vision-aids/truck-lens/truck-lens/

Figure 47. Situation in which a Fresnel lens would be essential for viewing a vulnerable road user.[61]

3.1.3.1.2 Precedents and regulations

As of summer 2015, there were no regulations requiring Fresnel lenses anywhere in the U.S. The technology is most common in the UK, and it is not yet common in the U.S. After a 1987 collision between an 1987 Amtrak train and a semitractor in Illinois, NTSB recommended the evaluation of wide-

[61] Source: Niewoehner, W., Berg, F.A., Endangerment of Pedestrians and Bicyclists at Intersections by Right Turning Trucks

angle window lens to improve driver visibility for vehicles weighing more than 10,000 lbs. NHTSA evaluated the safety benefits associated with using a Fresnel lens, but concluded that the large lens size blocked normal vision in the truck window and created glare related problems.[62] However, contemporary Fresnel lenses are smaller, mitigating the issues that NHTSA identified in 1987. They warrant reconsideration in the urban context given their early signs of success in reducing collisions with pedestrians and cyclists in the UK.

In Virginia, regulations regarding windshield glass specifically allow (but do not require) a tractor truck with a gross vehicle weight rating over 26,000 lbs. to have "one optically grooved clear plastic wide angle plastic lens affixed to the right front side window, providing the lens does not extend upward from the bottom of the window opening more than six inches or backward from the front of the window opening more than eight inches."[63] Similarly, California law allows for (but does not require) a "clear, transparent lens affixed to the side window opposite the driver on a vehicle greater than 80 inches in width and that occupies an area not exceeding 50 square inches of the lowest corner toward the rear of that window and that provides the driver with a wide-angle view through the lens."[64]

In contrast, Fresnel lenses are commonly recommended and utilized in the UK and other parts of Europe. The UN ECE Regulation 46 has required trucks with a GVWR exceeding 7.5 metric tons (16,535 lbs.) to be fitted with a close proximity mirror since 1987. The new 04 series of amendments to ECE 46 further improves the effectiveness of the close proximity mirror by extending the required field of vision forward by 2 m and outwards from the vehicle by 2.5 m.[65] As shown in Figure 48, some versions of close proximity (look down) mirrors may not provide the full extended field of vision in the new requirement. For trucks that are unable to fit mirrors that can provide the required field of vision, Fresnel lenses are one alternative technology that can help meet the field of vision requirements. The requirements of ECE 46.04 became effective for new types of heavy trucks as of June 2014 and for all trucks as of June 2015.

[62] NHTSA safety recommendation. www.ntsb.gov/about/employment/_layouts/ntsb.recsearch/Recommendation.aspx?Rec=H-89-025

[63] Code of Virginia § 46.2-1165 199019VAC30-70-580, derived from VR545-01-07 § 58

[64] California vehicle code section 26708.(a)(9)

[65] Bower, N., ECE Requirements on Driver's Vision Updated, 2013. www.interregs.com/articles/spotlight/ece-requirements-on-driver39s-vision-updated-000138

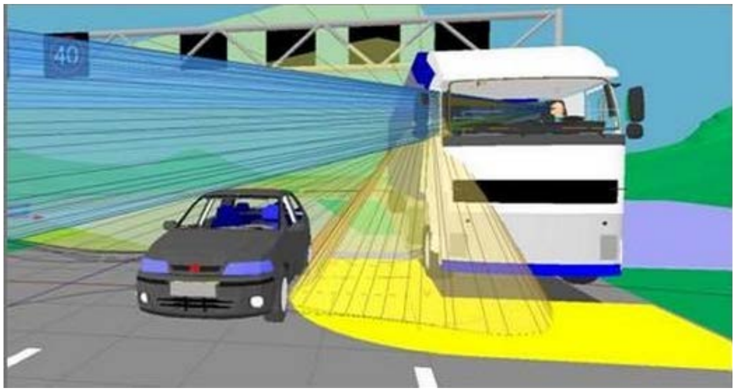

Figure 48. Situation in which the look down mirror may not capture a passenger car.[66]

3.1.3.1.3 Types available and installation considerations

Fresnel lenses are designed with different focal points for specific applications, thus the lenses specifically intended for passenger vehicles should not be installed on heavy duty vehicles. In some cases manufacturers provide lenses that are generally appropriate for a wide range of vehicles. Although not yet common in the U.S., several UK companies sell Fresnel lenses designed for heavy duty vehicles. Truckview and Hi Vu are two commonly available brands. The TruckView Fresnel lens is specifically designed to the specifications of the Vehicle and Operator Services Agency in the UK (www.truckview.net). Hi Vu is a newer, low-profile, self-adhesive Fresnel lens that can be utilized in many types of vehicles. Previous lenses were thought to take up too much of the passenger window space, obscuring the driver's view of oncoming traffic at intersections. The Hi Vu lens occupies less space within the window area (21 cm x 12 cm), allowing the driver to more easily see past the lens to oncoming traffic. Hi Vu lenses are available as a less expensive PVC material model, or as a premium acrylic material. According to the manufacturer the acrylic version is superior to the PVC in that it provides the driver a clearer, brighter view through the lens; prevents air bubbles; and lasts longer.[67] Based on inspection at Volpe, the difference in view between the PVC and the acrylic versions was difficult to discern, but when coupled with the other benefits the improved visibility may be worth the additional cost, considering that the acrylic version is only slightly more expensive ($13 as compared to $11). Both lenses are installed by peeling back the self-adhesive cover surrounding the clear border of the lens and pressing it to the clean window glass.

[66] Source: www.lens-tech.com/fresnel-lens-truck-mirror-blind-spot-lenses-hgv/
[67] www.lens-tech.com/fresnel-vision-aids/truck-lens/truck-lens/

Figure 49. A view of a Fresnel lens installed in a 'peeper' window within a truck door.[68]

Press-fit Fresnel lenses can be positioned at different locations on the passenger side windows. A TRL study in the UK found that it was most advantageous to place the lens at the bottom rear of the window. Positioning the lens at the bottom of the window offers a field of vision closer to the side of the vehicle, and positioning the lens further to the back of the window results in less interference with the external rear-view mirror.[69]

Regardless of its position on the window, a Fresnel lens is only useful if the window is closed. This may eliminate the benefit for Cambridge DPW drivers if they typically drive with the passenger side window open. Some operators in the UK have complained that Fresnel lenses often peel off when passing through the rubber seal as the driver opens and closes the window, sometimes getting caught inside the window mechanism. However, Hi Vu claims that its "Next Generation" low profile Fresnel lenses stick fast, eliminating prior conflicts that earlier models caused with window-opening.[70] Better yet, Fresnel lenses that fit in the "peeper window" of large trucks (Figure 49) avoid conflicts with window opening and could provide the intended function regardless of whether the main windows are open. Hi Vu peeper window Fresnel lenses are accredited for use at select major US trucking manufacturers, and are available in a range of focal lengths.[71]

3.1.4 Educational on-vehicle messaging

Educational on-vehicle messaging can improve VRU awareness of driver blind spots, inspiring them to be more cautious around large vehicles. There are a variety of companies that can produce premade or custom decals.

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[68] Source: www.lens-tech.com/fresnel-vision-aids/truck-lens/truck-peeper/

[69] Dodd, M., Follow Up Study to the Heavy Goods Vehicle Blind Spot Modeling and Reconstruction Trial, 2009

[70] www.lens-tech.com/fresnel-lens-truck-mirror-blind-spot-lenses-hgv/

[71] www.lens-tech.com/fresnel-vision-aids/truck-lens/truck-peeper/

The city of Boston requires city-contracted vehicles to have a minimum of three safety decals, located in blind spots on the side and rear of each vehicle. Each decal must be “safety yellow” or a similarly bright color to attract attention. Figure 50 shows an example from the City of Boston website.

Transport for London places safety decals at the rear of each fleet vehicle over 3.5 metric tons (7,716 lbs.). Figure 51 shows an example of the current decal. The new decals, which state “Blind Spot, Take Care” have replaced the original safety decals, which stated “Cyclists Stay Back.” Transport for London decided to change the original decals after cycling advocacy groups voiced concerns that their use on buses led some drivers to believe they had legal priority over cyclists.

In Portland, Oregon, a variety of public agencies and utilities have also opted to outfit their fleet vehicles with safety decals, including Portland General Electric, Portland Department of Transportation, Portland Bureau of Maintenance, and Portland Water Bureau. Figure 52 shows some examples.

Figure 53 shows another example of a safety decal, which the New York City bicycle share system has begun adding to the handlebars of its bicycles.

Figure 50. Example safety decal to improve VRU awareness.[72]

[72] Source: www.cityofboston.gov/isd/pdfs/FinalTruckSideGuardhandoutvF1.pdf.

Figure 51. Transport for London places safety decals at the rear of each fleet vehicle over 3.5 metric tons (7,716 lbs.).

Figure 52. Many agencies and utilities in Portland, Oregon use safety decals on their vehicles.

Figure 53. The New York City bicycle share system, Citi Bike, has begun adding safety decals to the handlebars of bicycles.

Educational on-vehicle messages can also remind the vehicle operator to adhere to safety protocols and use mirrors appropriately. For example, FMVSS-111 states that each school bus with a convex mirror that has an average radius of curvature of less than 889 mm shall have a label visible to the seated driver, which states: “USE CROSS VIEW MIRRORS TO VIEW PEDESTRIANS WHILE BUS IS STOPPED. DO NOT USE THESE MIRRORS TO VIEW TRAFFIC WHILE BUS IS MOVING. IMAGES IN SUCH MIRRORS DO NOT ACCURATELY SHOW ANOTHER VEHICLE'S LOCATION.” A more general version of this message could take the following form: “Use convex mirrors to check for the presence of objects while vehicle is stopped. Do not use these mirrors to judge distances. Mirrors reduce apparent sizes and distances.”

3.1.5 Training on mirror use

Mirrors are only effective if drivers know how to use them. Training and/or testing drivers in the use of mirrors can help to ensure that drivers understand how to use them safely and effectively. The school bus industry is one of the most robust sources of training examples and materials because school buses have the most stringent mirror requirements and school bus drivers have the most stringent certification requirements. Many insurance companies also provide information on setting up mirror check stations for trucks, and this could be a source of additional reference and/or training materials.

School bus drivers are required to demonstrate their competency with mirrors through a written exam and/or driving test that they must complete in order to obtain the school bus (S) endorsement on their commercial driver’s license (CDL). The Massachusetts CDL manual is intended as a study guide; section 10 on school buses includes instructions on how to properly adjust mirrors. The manuals for most (if not all) other States have exactly the same content. School bus fleets often use a mirror grid system to teach drivers how to adjust the mirrors for the required visibility. School bus mirror grids incorporate the safety protocol mandated in FMVSS 111 (see Figure 35 on page 49) and specified in the National Highway Traffic Safety Administration’s (NHTSA) school bus field-of-view test. Some choose to paint a grid on a section of parking lot to facilitate initial and refresher trainings for drivers and many districts repeat the training for all drivers at the beginning of every school year.

3.1.5.1 NHTSA Training Materials

NHTSA has produced a training program entitled *School Bus Driver In-Service Safety Series*. It is available for use on a voluntary basis, and school districts decide how and when to use it. It is intended to provide an in-service refresher training rather than training for new school bus drivers. It covers nine topics frequently requested by school bus drivers and supervisors, including materials on mirror adjustment and use. The materials include an instructor guide, PowerPoint slides, handouts, and suggestions for practice activities (including information on resources needed for the practice sessions). The section on mirror adjustment includes detailed suggestions for training drivers using the mirror grid specified in FMVSS-111.

3.1.5.2 State and Local Training Materials

There are a variety of State and local training materials for school bus driver training, many of which have relevant content for drivers of Cambridge DPW fleet vehicles. This section describes a few examples.

3.1.5.2.1 Michigan

The Michigan Pupil Transportation Act of 1990 requires that a driver of a school bus transporting pupils to or from school or school-related events complete an entry level school bus safety education course and a six-hour continuing education course within two years after the entry level certification, as well as each succeeding two years thereafter. Each course must be completed at an educational agency approved by the Michigan Department of Education.

The State has developed a *School Bus Driver Continuing Education Curriculum Manual*, which details the curriculum for the six-hour continuing education course. Page 10 of the document discusses proper mirror adjustment and use, including for cross over mirrors. It includes a “fill in the blank” exercise designed to test knowledge on mirrors, and suggests that school districts paint mirror adjustment grids on a parking lot areas so that drivers can use them to ensure that bus mirrors are adjusted to meet the safety standards.

3.1.5.2.2 Washington State

Washington State provides a *Guide for School Bus Driver Training*. There are no minimum or maximum hours required in teaching the comprehensive program. The trainer decides on an individual basis how much time needs to be spent with each candidate. On page 934 the training program describes how to create a mirror adjustment station for hands-on practice. It includes a lesson plan, evaluation, checklist for the trainer, handouts and transparencies, a list of required equipment, and reference material.

Relevant to cross over mirrors, drivers are expected to be able to do the following after completing the training:

- List three important mirror rules when approaching or leaving a stop.
- Explain what the driver should be able to see in the mirrors.
- List three reference points that can be used to adjust mirrors.
- Identify the correct distance around the bus that the mirror performance standards require.

The Washington State training reminds drivers that although the mirrors can help improve the field of vision, they themselves can also serve as obstacles, obstructing the driver's view, as depicted in Figure 54.

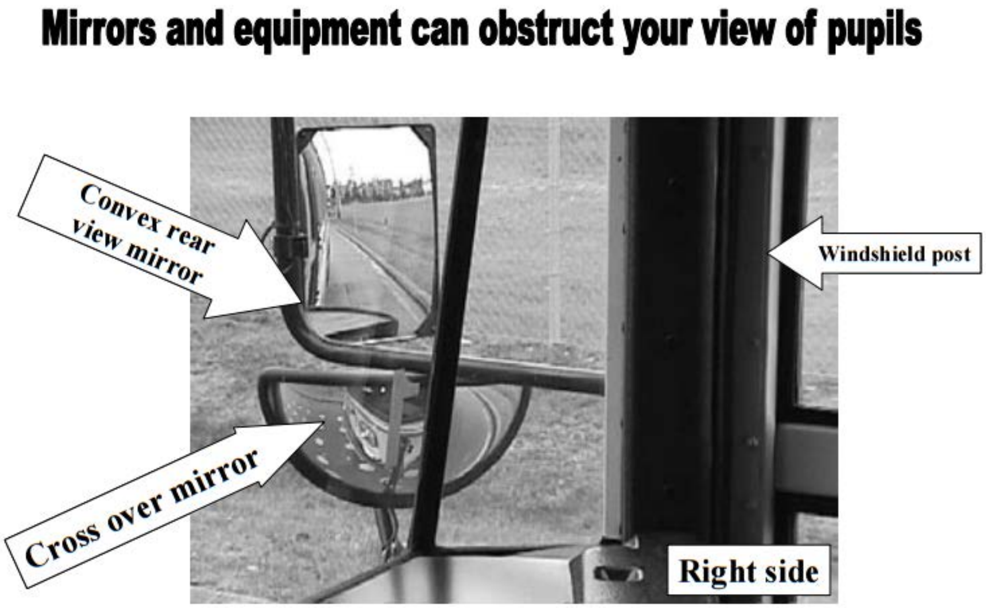

Figure 54: Washington State school bus driver training reminds drivers that the mirrors themselves and other objects can also obstruct the view.

3.1.6 Private sector training materials

Manufacturers of cross view mirrors also commonly provide free training materials so that consumers will understand how to properly adjust the mirrors. For example, Rosco provides an educational DVD, "Field of Vision," free of charge, which is intended to be used as part of a driver training program. It not only shows how to keep the mirrors adjusted in compliance with FMVSS-111, but also how to see blind spots not covered in FMVSS-111 regulations.

3.1.7 Field of vision tests

Field of vision tests can help to ensure that mirrors are properly adjusted so that they perform their intended function. Selection of appropriate field of vision standards and a corresponding test grid (or grids) depends on a variety of considerations. Factors to consider include:

- **Relevance:** Does the field of vision standard address the most problematic areas where collisions with VRUs (and others) are most likely to occur?
- **Simplicity:** Is the standard easy to understand and communicate?
- **Ease of testing:** Is the standard easy to test with a grid, vehicle reference points, or other means? If the testing process is lengthy or impractical, operators may not regularly check the mirror system.

Although the FMVSS-111, New York, and Boston specifications all require visibility of objects at specific heights off the ground, this does not necessarily mean that a fleet operator would need to set up cones or cylinders to test each vehicle before it leaves the yard. To test compliance with FMVSS-111, most school bus fleets simply paint two-dimensional circles instead of placing cylinders. Since it's more difficult to see an object at ground level, this two-dimensional grid is more stringent than the three-dimensional version; if drivers can view all of the circles it implies that the adjustment of the mirrors would also allow them to see the one foot cylinders (or in the case of New York State or Boston, the three foot objects).

3.2 Driver interaction with mirrors

"Human factors" is a field of study that focused on designing equipment that fits the human body and its cognitive abilities. Research from this field illuminates important considerations, which, if addressed, may help to ensure appropriate and safe mirror use. Ironically, most of the available research on driver interaction with mirrors focuses on drivers of passenger vehicles, and there is comparatively little research on drivers of medium or heavy-duty vehicles, for whom mirrors are even more essential. Nevertheless, it is likely that the research findings would also be applicable to drivers of large vehicles.

3.2.1 Distance estimation

As discussed, an image produced by a convex mirror is smaller than one produced by a planar mirror. Also, in comparison to a planar mirror, the image from a convex mirror appears to increase in size more quickly when the object moves toward the reflection surface. There have been numerous studies examining distance perception using convex rearview mirrors versus planar mirrors. On average, drivers will underestimate distance when using flat mirrors, which encourages conservative, safe behavior. When drivers estimate distance using convex mirrors, however, that underestimation is reduced or eliminated. Some drivers even overestimate distances, which could be dangerous. However, some research suggests that drivers may adapt to convex mirrors with repeated use, reducing but not eliminating the potential for distance overestimation.[73]

3.2.2 Visual search patterns

A variety of research has shown that mirror usage varies widely among individuals and is related to the habits of individuals rather than being determined solely by traffic patterns or the complexity of the driving task at hand. For example, in comparison to experienced drivers, novice drivers tend to concentrate their visual scanning to smaller, more restricted areas, and are less likely to engage in frequent scanning to check mirrors and blind spots.[74] Fatigued drivers are also less likely to engage in frequent visual scanning and tend to restrict their scanning more narrowly in the horizontal dimension.[75] The findings of one study suggest that all drivers, regardless of experience level, may change their visual

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[73] Rau, P.S., Wierwille, W.W., Schaudt, W.A., Spaulding, J., Hanowski, R.J., Study of Driver Performance/Acceptance Using Aspheric Mirrors in Light Vehicle Applications, 2008
Applications, 2007. www-nrd.nhtsa.dot.gov/pdf/esv/esv20/07-0237-w.pdf

[74] Underwood, G., Chapman, P., Bowden K., Crundall, D., Visual search while driving: skill and awareness during inspection of the scene, 2002

[75] Kaluger, N.A., Smith, G.L., Jr. Driver eye movement patterns under conditions of prolonged driving and sleep deprivation. 1970

search patterns in response to stressful stimuli. When presented with dangerous situations the study subjects narrowed their visual search patterns, increased their fixation durations, and reduced the variation in their fixation locations. [76] Ironically, precisely at the time when a driver senses danger or stress, he or she may be least likely to comprehensively scan the visual environment in order to respond safely.

These types of human factors limitations may be difficult to avoid, but well-informed drivers may be more self aware about their own limitations, and may therefore be able to compensate through conscious effort. Notably, the findings from one study support the hypothesis that the visual search patterns of novice drivers may be limited not because they have limited mental resources remaining from the basic task of driving the vehicle, but because they have an "impoverished mental model" of what is likely to happen on the road.[77] This would suggest that driver education that focuses on common occurrences (such as a collision with a VRU on the right side of a truck), may help to enrich a driver's mental model, and perhaps subsequently influence their conscious and unconscious visual search patterns while driving.

3.3 Additional blind spot countermeasures

3.3.1 Advanced Driver Assistance Systems (ADAS) for pedestrian and bicycle detection and avoidance

Advanced Driver Assistance Systems (ADAS) are technologies to help operators drive more safely and effectively. Typically they involve one or more sensor types and a system for processing the information in order to transmit alerts to the driver and/or automatically intervene through automated braking or other means. The goal is to avoid collisions or other problems that may result from human limitations or errors. The BikeWalkNC website[78] provides a broad overview of various ADAS technologies and their potential applicability to pedestrian and bicycle safety.

3.3.1.1 Vision-based sensors

Vision-based systems rely on a camera to record visual information. Mono cameras use one aperture, whereas stereo cameras use multiple apertures to assist the camera system with depth perception. Although stereo cameras are still available, the current trend is toward mono cameras because engineers have designed cameras that no longer need stereo vision to create a three-dimensional image of the environment. Instead, the processing system behind the camera uses a "structure from motion" technique: by analyzing two successive images, taking into account the time difference and vehicle movement, it is now possible to create a depth map that compares favorably with the image from a stereo camera.

Vision-based systems can provide information to drivers in several ways. A traditional "back-up camera" typically shows an image directly to the driver on a screen by the dashboard. In other types of vision-

[76] Chapman, P., Underwood, G., Visual search of driving situations: Danger and experience, 1998

[77] Underwood, G., Chapman, P., Bowden K., Crundall, D., Visual search while driving: skill and awareness during inspection of the scene, 2002

[78] www.bikewalknc.org/2015/05/defanging-the-automobile/

based systems, the driver may not actually see the raw input from the camera at all. Instead, the system would alert the driver to pay attention when a potential concern arises.

Mobileye produces the only aftermarket camera system currently on the market (as of 2015) that is specifically intended for large vehicles and can distinguish pedestrians and bicyclists from other objects. The Shield+, the newest version of their system, alerts the driver when a collision with a VRU may be imminent.

3.3.1.2 Other sensor types

Aside from vision-based systems, there are a variety of other sensor types on the market. However, in comparison to vision-based systems, most of the other commercially available sensors (with the exception of infrared sensors) cannot reliably distinguish a VRU from other objects. Some non-vision-based sensors also tend to have more false positives than vision-based systems, which may desensitize the driver to alerts. Certain sensor types do have other benefits in comparison to vision-based systems. For example, many will continue to perform under conditions in which a vision-based system would no longer be effective (e.g. in total darkness, with glare from the sun, or in rain, snow, or fog).

3.3.1.2.1 Radar

Drivers of large trucks have used radar-based collision warning systems for decades. Perhaps the best known example is the Eaton VORAD Collision Warning System, created in 1994 and purchased by Bendix in 2009. Radar has several advantages and disadvantages in comparison to vision-based systems, as detailed below. Note that Mobileye, a company that produces vision-based technology, is a major source of information comparing radar to vision-based systems. The company is not impartial, so some of the information referenced below may be biased, and may need further examination or corroboration.

Advantages:

- Long detection range for vehicles, up to 200 yards.[79] However, the detection range for pedestrians, bicyclists, and motorcyclists is only about 44-109 yards, depending on their size.[80]
- Ability to operate in almost all weather except dense fog.

Disadvantages:

- Narrow field of view for long-range sensing (15-20 degrees). However, the field of view for short-range radar sensing at a lower frequency can be up to 120 degrees. The restrictions on radar's field of view are based on the limited bandwidth that the Federal Communications Commission allows for specific frequencies.[81]

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[79] Schneider, M., Automotive Radar – Status and Trends. http://duepublico.uni-duisburg-essen.de/servlets/DerivateServlet/Derivate-14581/Paper/5_3.pdf
[80] www.bikewalknc.org/2015/05/defanging-the-automobile/
[81] www.bikewalknc.org/2015/05/defanging-the-automobile/

- Limited ability for pedestrian detection due to insufficient Doppler frequency and spatial resolution, and antenna side lobe effects.[82] As a result, more false positives, possibly desensitizing the driver to alerts.

Most U.S. car manufacturers today complement radar with camera-based and/or LIDAR sensing.[83]

3.3.1.2.2 LIDAR

Developers of fully autonomous cars favor laser radar (LIDAR) for its superior performance in self-localization and object tracking.

- Advantage: It provides a very high resolution image and serves as its own light source, operating under all types of ambient outdoor illumination.
- Disadvantages: It has a shorter range than radar, and is potentially much more expensive.[84]

Several car companies (including Volvo in their City Safety product) use short-range LIDAR as a supplement to radar and camera sensing for improved resolution of short range data. Increasing the power and range of LIDAR so that it could perform on its own would require additional measures, such as the large canisters seen above many prototype autonomous cars.[85]

3.3.1.2.3 Infrared

Infrared cameras can address some of the limitations of vision-based systems, because they are not restricted by the visible light spectrum.

Advantages:

- Can perceive objects even in low-light conditions.
- Reliably detects people because they emit heat.

Disadvantages:

- Expensive in comparison to vision-based systems.
- Does not differentiate VRUs from other objects that may emit heat.

3.3.1.2.4 Sonar

At very short ranges, ultrasonic sensors outperform other sensor technologies. Back-up safety systems on trucks have used sonar sensors for decades. These sensors could prevent backover collisions involving VRUs.

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[82] Bartsch, A., Fitzek, F., Rasshofer, R.H., Pedestrian recognition using automotive radar sensors, 2012. www.adv-radio-sci.net/10/45/2012/ars-10-45-2012.pdf

[83] www.bikewalknc.org/2015/05/defanging-the-automobile/

[84] www.wired.com/2015/04/cost-of-sensors-autonomous-cars/

[85] www.bikewalknc.org/2015/05/defanging-the-automobile/

3.3.1.2.5 GPS or Bluetooth smart phone detector
The BikeShieldApp is an example of an emerging technology that uses smart phones to alert drivers of the presence of VRUs. It uses the built-in global positioning system (GPS) function of the smart phone to monitor the positions of cyclists and drivers and sounds an alarm for the driver when a cyclist is near. For the technology to be effective, however, a critical mass of drivers and cyclists in an area would need to download and use the app on their respective phones.

3.3.1.2.6 Hybrid systems
Many ADAS systems combine multiple sensor types in a “fusion” system. The most common example of a fusion system combines information from radar and vision-based sensors.

3.3.1.3 Alerts and automated interventions
ADAS can provide alerts and automated interventions in a variety of different ways and to the driver as well as to VRUs.

3.3.1.3.1 Driver alerts
Driver alerts can be visual (e.g. flashing light), auditory (e.g. a beeping sound), and/or haptic (e.g. vibration in the driver’s seat). At this point there is little research on the relative effectiveness of each type of alert (or combination of alerts) for this specific application. However, there are examples of more general human factors research on these types of alerts in other applications. The more general research could be used to shed light on this particular research area, and the Volpe Center will be investigating this question as part of work for the New York City Department of Citywide Administrative Services. In the meantime, there is anecdotal information from manufacturers. Mobileye and its North American partner, Rosco, note that most customers (at this point mainly transit agencies) have elected to use a combination of visual and auditory alerts. Those that have chosen a haptic system have found that drivers sometimes do not notice a haptic alert due to the variety of other ambient vibrations and sensations that occur in the normal course of driving.

3.3.1.3.2 Vulnerable road user alerts
An ADAS can also provide alerts to those external to the vehicle, and these can take the form of either visual (e.g. flashing lights) or auditory (e.g. recorded voice) cues. At this point such systems are still new, so there is little research on the effectiveness of various types of VRU alerts. However, this is a promising area for future consideration and pilot testing.

3.3.1.3.3 Automated interventions
Currently, all ADAS sensor types have some kind of limitation (none yet provide 360° coverage in all conditions). However, reliable 360° coverage will likely be available in the near future. As ADAS technology improves, systems will move toward more system control versus human control. In other words, in addition to alerting the driver of an impending accident, the system may also automatically intervene (depending on the severity of the situation). Interventions may take the form of automated braking, steering assist, or other measures. Whereas other components of an ADAS could potentially be installed as part of an aftermarket retrofit, automated interventions would only be possible as part of an OEM installation, due to legal restrictions on aftermarket vehicle modifications. The technology for

automated interventions already exists, and as ADAS systems improve (along with our acceptance of them), this type of technology may become more and more common.

3.3.1.4 Limitations of ADAS

Advanced Driver Assistance Systems have great potential to improve safety outcomes for VRUs, but there are still limitations associated with the technologies currently on the market. They cannot prevent all crashes. No sensor system yet provides 360 degree coverage. Further, many collisions with bicyclists and pedestrians involve blocked sight lines until just before collision, as depicted in Figure 55. In this example, most of the various sensor types described in the preceding text would not be able to register the VRU blocked by another vehicle. Exceptions may include the BikeShieldApp, described in section 3.3.1.2.5 on page 74, or the Mobileye Shield+ vision-based system, which would not register the VRU at the moment depicted, but may have registered the person previously, noting the direction of motion, and through predictive algorithms may have alerted the driver of the potential crossing.

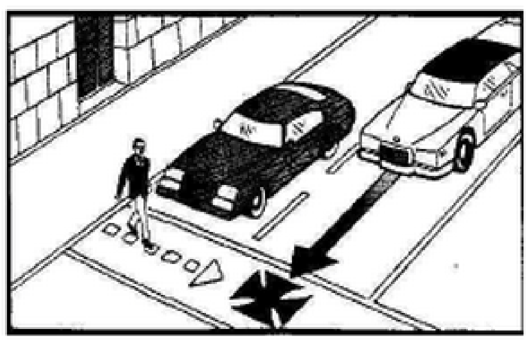

Figure 55. Many collisions with bicyclists and pedestrians involve blocked sight lines until just before collision, as depicted in this "multiple-threat" pedestrian crash.[86]

A similar situation exists when traffic screens the view between a left turning driver and a through bicyclist traveling in the opposite direction. Research into occluded view collision prevention systems has focused on using vehicle-to-vehicle (V2V) and infrastructure-to-vehicle communication to supplement the sensors on a single vehicle. This strategy would use sensors at one or more locations and transmit it to multiple vehicles that may encounter conflicts. Initial deployment of V2V or infrastructure-to-vehicle communication is still pending the resolution of various liability, privacy, security and safety challenges.[87]

An additional concern about ADAS is the possibility that drivers will become over reliant on the technology, and may become less vigilant. More research is needed on this question of "risk compensation."[88]

[86] Source: Federal Highway Administration via BikeWalkNC (http://www.bikewalknc.org/2015/05/defanging-the-automobile/).
[87] www.bikewalknc.org/2015/05/defanging-the-automobile/
[88] www.bikewalknc.org/2015/05/defanging-the-automobile/

3.4 Recommendations for City of Cambridge vehicles

3.4.1 Target vehicles for blind spot countermeasures

Volpe recommends prioritizing all vehicles over 10,000 lbs. for the initial installation of mirrors and other blind spot countermeasures. The 10,000 lbs. threshold is a general rule of thumb based on U.S. and European precedents, but it is a proxy, and ultimately the size and shape of the vehicle are more definitive indicators of need. For that reason, some vehicles at or slightly above the threshold may not need all recommended mirrors. Similarly, some vehicles slightly below the threshold may benefit from mirrors. Cambridge DPW could assess the need for borderline vehicles on a case-by-case basis by using field of vision tests, as described in section 3.4.3 beginning on page 80.

Table 12 shows 54 vehicles from the medium- and heavy-duty vehicle inventory that Volpe identified as immediate candidates for blind spot countermeasures, based on a GVWR over 10,000 lbs., a general indicator of size. One of the applicable vehicles (identification number 259) has a cab-over design, so it may need a European style class VI “front projection” mirror rather than a front cross over mirror. Many of the example mirror requirements described in Table 8, Table 10, and Table 11 use GVWR as a primary criterion in determining applicability. In the U.S. examples, a typical GVWR threshold is 10,000 lbs. In the European examples, a typical GVWR threshold is 7,716 lbs. (3.5 metric tons).

Generally, as vehicle height and overall size increase, driver visibility decreases. Blind spots are the largest and most problematic for the largest vehicles. However, blind spots exist even for large passenger vehicles. As described in the cross over mirror section, the UN ECE updated its Regulation 125 in 2013 to address a concern that its original downward vision requirements may not have adequately addressed passenger vehicles with high driving positions (e.g. light duty trucks, people carriers, multipurpose vehicles, and sport utility vehicles) leading to a situation where a driver may be unable to identify shorter VRUs directly in front of the vehicle. In light of this consideration, Volpe recommends assessing the field of vision of all vehicles in the DPW fleet, including those below 10,000 lbs. Even if Cambridge DPW elects not to install additional blind spot countermeasures on a particular vehicle, the field of vision tests will still serve an important purpose, increasing staff awareness of vehicle blind spots.

Table 12. DPW vehicles that are expected to benefit from additional blind spot countermeasures.

DESCRIPTION	ID	TYPE	GVRW (lbs.)	WHEELBASE (in.)
Hot box	**86**	Heavy Duty Truck	35000	156
Boom	**142**	Heavy Duty Truck	35000	176
Flat bed	**70**	Heavy Duty Truck	35000	156
Utility	**95**	Heavy Duty Truck	26000	177
Clam Shell	**148**	Heavy Duty Truck	35000	192
Vactor	**141**	Heavy Duty Truck	41000	219
9yd Dump	**78**	Heavy Duty Truck	40000	156
9yd Dump	**80**	Heavy Duty Truck	40000	156
Boom	**143**	Heavy Duty Truck	35000	176
9yd Dump	**76**	Heavy Duty Truck	40000	156
Clam Shell	**145**	Heavy Duty Truck	35000	182
9yd Dump	**73**	Heavy Duty Truck	35000	156
Hot Box	**96**	Heavy Duty Truck	35000	156
Vactor	**140**	Heavy Duty Truck	46000	241
Crane	**144**	Heavy Duty Truck	38620	228
Packer	**34**	Heavy Duty Truck	41000	212
Packer	**35**	Heavy Duty Truck	41000	212
Packer	**27**	Heavy Duty Truck	41000	212
Packer	**23**	Heavy Duty Truck	41000	212
Packer	**24**	Heavy Duty Truck	41000	212
Packer	**26**	Heavy Duty Truck	41000	218
Packer	**36**	Heavy Duty Truck	41000	217
Packer	**29**	Heavy Duty Truck	41000	217
Packer	**25**	Heavy Duty Truck	33000	184
Packer	**20**	Heavy Duty Truck	33000	184
Packer	**28**	Heavy Duty Truck	41000	217
Packer	**21**	Heavy Duty Truck	42000	216
Packer	**22**	Heavy Duty Truck	45120	216
Salter	**84**	Heavy Duty Truck	35000	160
Salter	**83**	Heavy Duty Truck	35000	160
Salter	**75**	Heavy Duty Truck	35000	160
Salter	**72**	Heavy Duty Truck	35000	160
Salter	**74**	Heavy Duty Truck	35000	160
Salter	**85**	Heavy Duty Truck	35000	160
Salter	**82**	Heavy Duty Truck	35000	160
Salter	**79**	Heavy Duty Truck	35000	160
Salter	**87**	Heavy Duty Truck	35000	160
Salter	**81**	Heavy Duty Truck	35000	160

Salter	**71**	Heavy Duty Truck	37600	160
Utility/response	**60**	Mid Duty Truck	14000	132
2-3yd dump	**94**	Mid Duty Truck	25600	128
1 Ton Dump	**48**	Mid Duty Truck	12000	135
1 Ton Dump Salt	**56**	Mid Duty Truck	12000	135
1 Ton Dump	**89**	Mid Duty Truck	13000	141
1 Ton Dump Salt	**47**	Mid Duty Truck	13000	141
1 Ton Dump	**49**	Mid Duty Truck	10100	137
1 Ton Dump	**69**	Mid Duty Truck	13000	147
2-3yd dump	**92**	Mid Duty Truck	19500	165
1 Ton Dump Salt	**98**	Mid Duty Truck	13000	141
2-3yd dump	**91**	Mid Duty Truck	19500	165
1 Ton Dump Salt	**90**	Mid Duty Truck	14000	141
Rackbody/appliance	**259**	Mid Duty Truck	17995	152
Utility/response	**60**	Mid Duty Truck	14000	132
1 Ton Dump	**49**	Mid Duty Truck	10100	137

3.4.2 Recommended mirrors

Identifying an arrangement of vehicle mirrors of various types is a starting point rather than an ending point for ensuring safety. A more robust standard for any mirror system will be performance-based, using a grid or other means to test a driver's actual field of vision when using the mirrors. There could be more than one mirror arrangement that achieves the desired total field of vision for the driver. As a case in point, the UN ECE regulation 46 states that if the required field of vision for a Class V (close proximity/look down) mirror can be seen through a combination of a Class IV rear view convex mirror and a Class VI front projection mirror, the installation of a Class V mirror is not required. Such caveats notwithstanding, **Volpe offers the following proposed mirror specifications for each vehicle over 10,000 lbs.**, followed by cost estimates in Table 13 and a discussion of field of vision requirements in section 3.4.3.

3.4.2.1 Highest priority

Front cross over mirrors: At a minimum, install one cross over mirror mounted as far forward on the passenger side of the vehicle as possible (while still visible to the driver). Consider installing an additional cross over mirror at a similar location on the driver's side. **Use a quadraspheric, asymmetric lens** for best visibility, and **use a tunnel/tube mount** to reduce the potential for maladjustment. For some smaller vehicles, a small bubble convex mirror may suffice rather than a quadraspheric, asymmetric lens. DPW can assess this on a case by case basis using the field of vision tests described in section 3.4.3 on page 80.

Door-mounted rear view convex mirrors: At a minimum, install two door-mounted rear view convex mirrors (one on each side). If a rear view convex mirror is within a structure that also houses a planar mirror, **ensure that each mirror is independently adjustable**.

3.4.2.2 Lower priority

Hood-mounted rear view convex mirrors: For vehicles that already have hood-mounted rear view convex mirrors in place, conduct field of vision tests to determine how much (if any) additional visibility these mirrors provide aside from what the driver can see in cross over mirrors and the rest of the mirror system. Based on those results, consider whether to install hood-mounted rear view convex mirrors on other vehicles of each type. See related discussion in section 3.1.2.2.3 on page 54. See also related item in "Future Work," section 4.3 on page 85.

Look down mirror: Install one look down mirror on the passenger side of one representative example of each applicable vehicle type (i.e., one packer, one salter, etc.). Conduct field of vision tests to determine how much (if any) additional visibility these mirrors provide aside from what the driver would already be able to see in the front cross over mirrors and/or hood-mounted rear view convex mirrors. Based on these results, consider whether to install look down mirrors on additional vehicles of each type. See related discussion in section 3.1.2.3.3 on page 57). See also related item in "Future Work," section 4.3 on page 85.

Fresnel lens: Conduct a pilot test to examine the potential utility of Fresnel lenses. As part of the pilot, install each type of Fresnel lens (acrylic and PVC) on a few different vehicle types. Use the field of vision grid to measure how the lenses affect driver visibility and collect feedback from the drivers to understand their perspectives on the utility of the lenses. Research has shown that the most effective location for a Fresnel lens is typically on the lower rear corner of the passenger side window. However, DPW drivers often drive with the window down. To address that, either 1) install the lenses on vehicles with non-movable peeper windows, 2) attach one lens to the top and one to the bottom of movable windows, or 3) pilot the lens only in the winter months when the windows will not be rolled down.

Finally, wherever feasible, consider installing heated mirrors to prevent loss of visibility due to weather conditions.

Table 13. Estimated costs for various mirror and lens types, not including installation costs.

Type of Mirror/Lens	Estimated Cost per Unit (U.S. Dollars)
Front cross over mirror	$80-$120
Door-mounted rear view convex mirror	$40
Hood-mounted rear view convex mirror	$100
Look down mirror	$40
Fresnel lens	<$20

3.4.3 Recommended performance requirements and field of vision tests

Volpe recommends establishing a regular protocol for adjusting and testing mirrors to ensure that they provide the desired field of vision. The mirrors should work together as a system, and when adjusted properly, the field of vision from various mirrors (and direct vision) should partially overlap with one another. Table 14 shows proposed performance requirements. Figure 56 shows a proposed grid to help drivers check their mirrors in accordance with Table 14 specifications.

Table 14. Proposed performance requirements for mirror systems.

Mirror Components	Proposed Performance Requirements
Front cross over	Provides the following: • Indirect vision to all portions of the designated area in Figure 56 (unless observable by direct vision).[89] • Rearward view that overlaps with the view from the rear mirror system. The look down mirror field of vision (purple box in Figure 56) and other designated areas can help the driver to judge this.[90] • View of front tires at ground level.[91]
Rear view planar	Provides the following: • View of the designated area in Figure 56.[92] • View of rear tires at ground level.[93]
Rear view convex	Provides a view of the designated area in Figure 56.[94]
Look down (close proximity)	Provides indirect vision (if not observable by direct vision or the cross over mirrors) to the designated area in Figure 56.[95]

The proposed grid is largely based on the UN ECE Regulation 46, but Volpe suggests a number of modifications. The front cross over portion represents an extended area in front of the vehicle, based on the observation that the blind spot on a conventional school bus typically extends to 18 feet. The thick black, green, and blue lines that appear in Figure 56 are an important part of the grid, and should also be painted on the pavement, as they help the driver to position the vehicle for testing. It is necessary only to paint the outline of each shape indicated in Figure 56, not the interior of each shape. The green circles at the corners may either be painted or marked by cones. If it is not possible to paint a permanent grid on the pavement, another option is to measure out the distances each time on an as-needed basis, and to use cones or other objects to mark the corners. In that case, it is best to use objects that are easy to differentiate from one another, e.g., different colors, to help the driver confirm that he or she can in fact see all of the required corners.

[89] Based on UN ECE regulation 46, with a modification to reflect Rosco information on the typical blind spots of a conventional school bus.
[90] Based on Washington State *Guide for School Bus Driver Training* (http://web3.esd112.org/docs/default-source/school-bus-driver-training/instructor%27s-guide-for-school-bus-driver-training.pdf?sfvrsn=2)
[91] Ibid
[92] Based on UN ECE regulation 46
[93] Based on Washington State *Guide for School Bus Driver Training* (http://web3.esd112.org/docs/default-source/school-bus-driver-training/instructor%27s-guide-for-school-bus-driver-training.pdf?sfvrsn=2)
[94] Based on UN ECE regulation 46
[95] Based on UN ECE regulation 46

A proposed procedure for testing field of vision with the grid is as follows:

1) Position the vehicle so that the front bumper aligns with the thick black line and such that the red area in front of that line is squarely in front of the vehicle.
2) With assistance from another person on the ground, adjust the front cross over mirrors so that the driver can see the ground enclosed by all of the green markers around the red area.
3) Check to make sure that the rearward view from the cross over mirrors overlaps with the view from the rear mirror system. The look down mirror field of vision (purple box in Figure 56) and other designated areas can help the driver to judge this.
4) Check to make sure that the cross over mirrors show a view of the front tires at ground level.
5) Reposition the vehicle so that the driver's eye position aligns with the thick green line and the right side of the vehicle abuts the thick blue line.
6) Adjust the right door-mounted rear planar mirror, door-mounted rear convex mirror, and look down mirror (if applicable) so that they each allow the driver to see the ground enclosed by all of the green markers surrounding each respective area.
7) Repeat steps 3 and 4 for the left side of the vehicle. Depending on the width of the vehicle, it may not be necessary to repeat step 3.

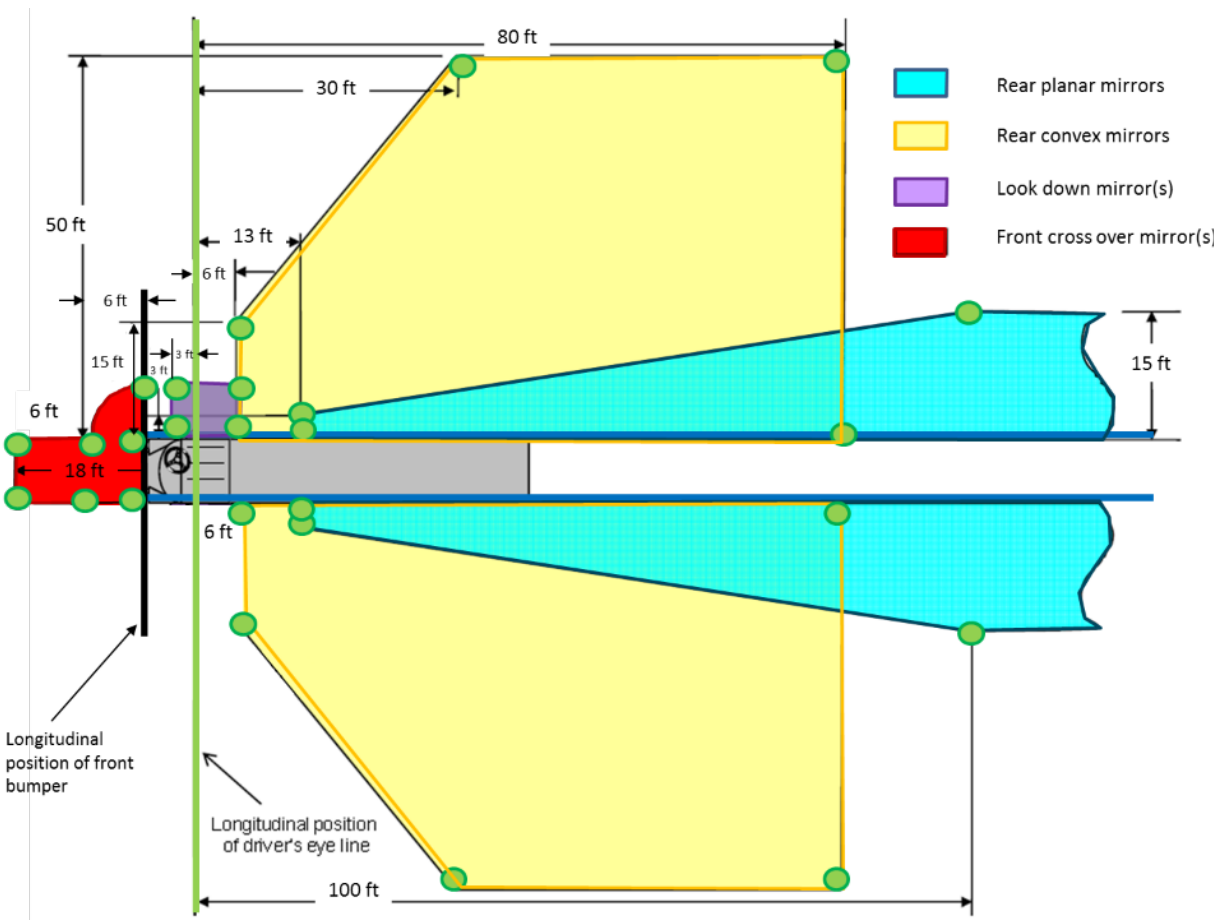

Figure 56. Proposed grid system to test the fields of vision of the mirror system.

Recognizing that it may not be practical for drivers to perform this test frequently, Volpe recommends considering other supplemental ways to help drivers check their mirrors for the required field of vision on an ongoing basis. For example, once the mirrors on a vehicle are in proper adjustment in accordance with the field of vision grid, Cambridge DPW could take photographs of each mirror from the driver's viewpoint and then clip the photographs to the sun visor. The driver can then refer back to those pictures and look at the locations of key reference points (e.g. location of tire or bumper in the mirror image) to get a general sense of whether each mirror is properly adjusted.

3.4.3.1 Recommended installation and maintenance considerations

Mounting options can reduce the chance of damage due to vibration or collision. For example, Rosco provides a mounting base with a spring for its Eye Max LP cross over mirror; other manufacturers may also provide similar technologies. In addition to avoiding damage, such a mount can avoid the need to readjust the mirror after a minor impact. Figure 57 shows what the base looks like without the cover. Other mounting options may also help to avoid damage from vibration. Figure 58 shows the damage that can occur over time from vibration, and how a rubber washer can avoid that damage. Regardless of the mounting mechanism, it is a good idea to establish a regular routine in which drivers or mechanics ensure that all fasteners are tight. Otherwise the bolted joints will loosen over time, augmenting vibration, making the mirrors harder to use, and potentially causing damage.

Figure 57. Spring loaded mounting base (shown without the cover). Source: www.roscomirrors.com/upload/brochure_pdf24e847c1e751e8EyeMaxLP_NYSLaw.pdf.

Figure 58. Damage that can occur from vibration in the absence of a rubber washer.

3.4.3.2 Recommended operator mirror training

Training is important to ensure that operators understand how to adjust and use mirrors safely and effectively. Training should:

- **Provide opportunities for hands-on practice** adjusting mirrors using a mirror grid or some other similar means. Classroom instruction or a written exam cannot substitute for field practice. School districts and/or bus fleets typically conduct such trainings, so it may be possible to hire a local school bus instructor to lead an initial training for Cambridge DPW drivers.
- **Remind drivers not to use convex mirrors (e.g. cross over or rear view convex mirrors) to judge distances while the truck is in motion** because the mirrors reduce apparent distances.
- **Remind drivers to check the mirror adjustments each time before operating a vehicle.**
- **Present information on the most common crashes between trucks and VRUs.** As discussed in "3.2.2 Visual search patterns" on page 70, a driver's visual search patterns may be influenced by his or her "mental model" of what is likely to occur out on the road. For example, if a driver knows that right-hand collisions with VRUs are common, he or she may be more likely to scan the relevant mirrors and blind spots regularly in the course of driving.
- **Retrain regularly.** Often school districts hold a training session for all drivers once per year.

There are a variety of existing training materials publicly available for reference. Section 3.1.5, beginning on page 67, provides some examples.

3.4.4 Recommended on-vehicle messaging

Volpe recommends two types of on-vehicle messaging: exterior safety decals for VRUs, and interior messages for the driver on mirror usage.

Regarding the exterior safety decals, there are a variety of examples presented in "3.1.4 Educational on-vehicle messaging" on page 64. Regardless of the style chosen, the exterior safety decals for VRUs will ideally be:

- Located at the rear as well as the right side of the vehicle.
- Understandable (at least in a general sense) for those who are not fluent in written English.
- Brightly colored with a bold, clear font.

Regarding the interior decals for the driver on mirror usage, the key messages are that the driver should:

- Use the mirror system frequently to check for the presence of VRUs.
- Not use the convex mirrors to judge distances.
- Check the mirror adjustments frequently, and every time after switching drivers.

4 Future work

There are a number of possible future tasks that would build on the initial research and recommendations in this Phase 1 report. Tasks in the unfunded Phase 2 portion of the original statement of work include:

- Review and recommendation of bus wheel guards
- Review and recommendation of bus crash prevention countermeasures
- Technology pilot design and evaluation
- Truck traffic census
- Strategy recommendations memo

A potential complementary task is to investigate the potential overlap and level of redundancy between front cross over mirrors, hood-mounted rear view convex mirrors, and look down mirrors for various vehicle types in order to determine whether it would be advisable to install all three on Cambridge DPW vehicles. This could be added as a sub task within "technology pilot design and evaluation."

A brief description of each task follows.

4.1 Review and recommendation of bus wheel guards

Volpe would review evidence of effectiveness, cost-effectiveness, and operability of wheel guards (S-1 Gard) for school buses, Harvard, MIT, MASCO, EZ-Ride, and/or other bus fleets. Volpe would recommend one or more optimal designs and specifications for pilot evaluation on selected bus fleets.

4.2 Review and recommendation of bus crash prevention countermeasures

Volpe would review evidence of effectiveness, cost-effectiveness, and operability of educational on-vehicle messaging, sensors and alarms, including emerging low-cost products, such as Bike Shield and Bike Beacon wheel guards (S-1 Gard) for school buses, Harvard, MIT, MASCO, EZ-Ride, and/or other bus fleets. Volpe would recommend one or more optimal designs and specifications for pilot evaluation on selected bus fleets.

4.3 Technology pilot design and evaluation

Volpe would assist with experimental design, pilot oversight, and safety performance evaluation of selected technologies reviewed in initial research to inform future vehicle specifications. Examples may include:

- Evaluate bus wheel guard for bus crash mitigation and Fresnel lens for crash prevention.
- Assess the potential overlap/redundancy between front cross over mirrors, look down mirrors, and hood-mounted rear view convex mirrors on specific vehicle types (see related discussion in section 3.1.2.2.3 on page 54 and section 3.1.2.3.3 on page 57).
- Characterize effects on blind spots of a specific DPW truck and/or test bus.
- Assess operator acceptance and maintenance issues.
- Use results to create and/or refine recommended specifications for city-owned and contracted vehicles.

4.4 Truck traffic census

Volpe would design and organize a data collection effort and analyze the data to understand truck activity along select Cambridge truck routes. The objectives of this analysis would include identifying conflict points between truck activity and bicyclist/pedestrian activity; identifying the domicile states and/or company ownership distribution of trucks; and informing strategy options to be investigated in the “strategy recommendations memo” described below.

- Data collection may include characterizing the number and distribution of truck types, times of day, their jurisdictions (in or out of State) and affiliations (company). Volpe envisions that volunteers or interns will be trained for this purpose.
- Volpe may produce GIS mapping visualizations of truck types along with existing bike-pedestrian data.

4.5 Strategy recommendations memo

Volpe would develop a guidance document for Cambridge to promote safety technology adoption via State action and private fleet adoption.

- Using the truck traffic census findings (described above) and jurisdictional research, Volpe would propose measures available to Cambridge to expand the adoption of technologies recommended in the pilot.
- Recommended measures may be voluntary, procurement, or regulatory-based, and may be implementable solely by the City of Cambridge or in coordination with Boston and/or MassDOT.

Appendix A: City of Boston side guard dimensions

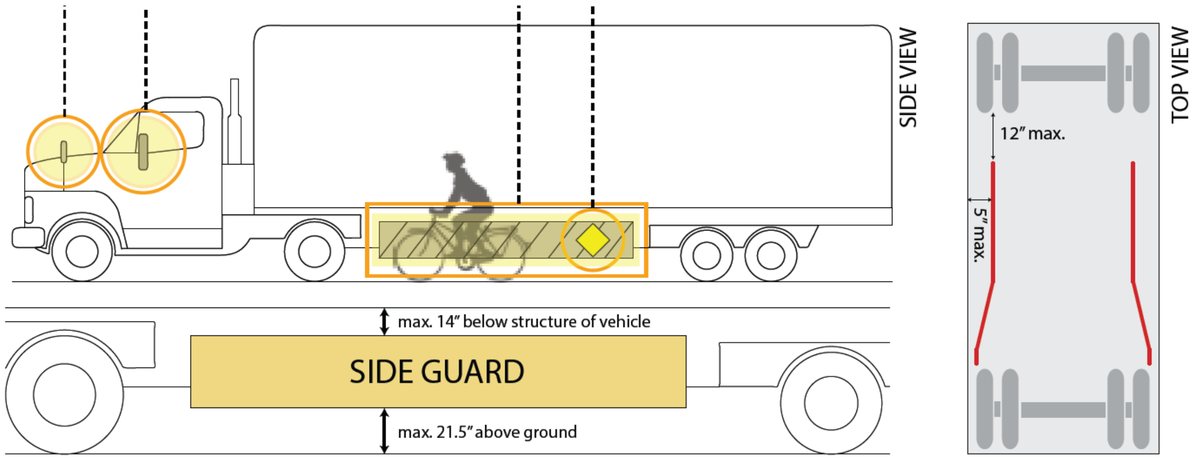

Figure 59. Dimensional requirements under the City of Boston's contracted fleet requirements. Note that these requirements are less stringent than the Volpe-recommended requirements in this report.[96]

Appendix B: Side guard relevant Cambridge crashes

Date	Pedestrian/Bicycle	Maneuver	Initial Impact Point	Truck (type)	Location
02/08/10	Pedestrian	Left turn	1, 12		Mt Auburn St
03/25/10	Bicycle	Right turn	2-3		JFK St / Elliot St
05/22/10	Bicycle	Straight	12		Rindge Ave / Clifton St
01/18/11	Bicycle	Move around cut off	6	Trailer	JFK St
05/06/11	Pedestrian	Left turn	11		Broadway / Windsor St
06/07/11	Bicycle	Right turn	3-5		Prospect St / Gardner Rd
06/27/11	Bicycle	Right turn	1-3		Mass Ave / Essex St
06/27/11	Bicycle	Straight	3-5		Garden St / Mason St
08/09/11	Pedestrian	Straight	1		Mass Ave
08/12/11	Bicycle	Right turn	1-3		Franklin St / Western Ave
11/15/11	Bicycle	Straight	1-2		Gore St / Lambert St
10/21/11	Bicycle	Right turn	3-4	Tractor trailer	Main St / Windsor St
08/28/12	Bicycle	Left turn	3-5	Trailer	Mass Ave / Albany St
04/11/13	Pedestrian	Straight	12		Mass Ave
09/05/13	Bicycle	NA	11		Mass Ave
12/06/13	Bicycle	Right turn	1-3	Box 18-wheeler truck	Mass Ave / Vassar St

[96] http://www.cityofboston.gov/isd/weightsandmeasures/side guards/