Vision Zero San Francisco Truck Side Guard Initiative

Technical Assessment and Recommendations

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Volpe

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Executive Summary

Overview

This report summarizes Volpe's research and recommendations supporting San Francisco Municipal Transportation Agency (SFMTA) efforts to improve pedestrian and bicyclist safety through truck-based strategies. Specifically, this initial report focuses on side guards, which are vehicle-based safety devices designed to prevent pedestrians, bicyclists, and motorcyclists from being run over by a large truck's rear wheels in a side-impact collision.

Why Side Guards?

Truck-based strategies can go a long way toward ensuring pedestrian and bicyclist safety, as trucks are currently one of the most dangerous traffic elements for vulnerable road users (VRUs). According to the Vision Zero San Francisco Large Vehicle Working Group, large trucks or buses were involved in only 4% of all collisions with VRUs, yet were responsible for 17% of all VRU fatalities in the City from 2007-2011. Furthermore, collisions involving trucks were over 8 times more likely to result in death of the VRU than collisions involving automobiles.[1] Side-impact crashes comprise a large percentage of fatal truck collisions with pedestrians and bicyclists, highlighting the importance of side guards for crash mitigation.

Contents of This Report

Section 1 describes the nature and magnitude of truck safety challenges; identifies overarching and side guard-relevant factors and trends for fatal crashes; and describes the three pillars of urban truck safety, situating side guards within that context.

Section 2 provides background on side guards, including existing precedents, a review of data on their safety benefits, and a discussion of practical concerns and solutions, e.g., procurement, installation, maintenance, and operational needs.

Section 3 provides recommendations for San Francisco City Fleet vehicles.

Key Conclusions and Recommendations

Volpe identified between **231 (likely) and 541 (likely and possible) vehicles** from the City vehicle inventory that are **expected to benefit from side guards** and 2,449 that are not likely to benefit, as shown in the chart below. This assessment is based on the body styles, makes, and models 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. In screening vehicles, Volpe was able to rule vehicles out more easily than rule them in; some cases will require agency discretion about accommodating current vehicle design as well as agency- and vehicle-specific operational constraints, work rules, and practices. **Volpe generally recommends the use of side guards above the 10,000 lbs. gross vehicle weight rating (GVWR) threshold**.

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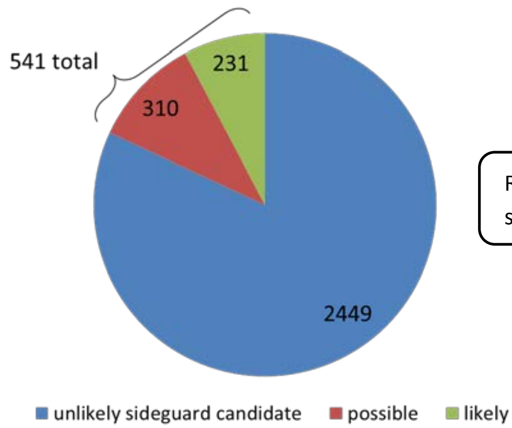
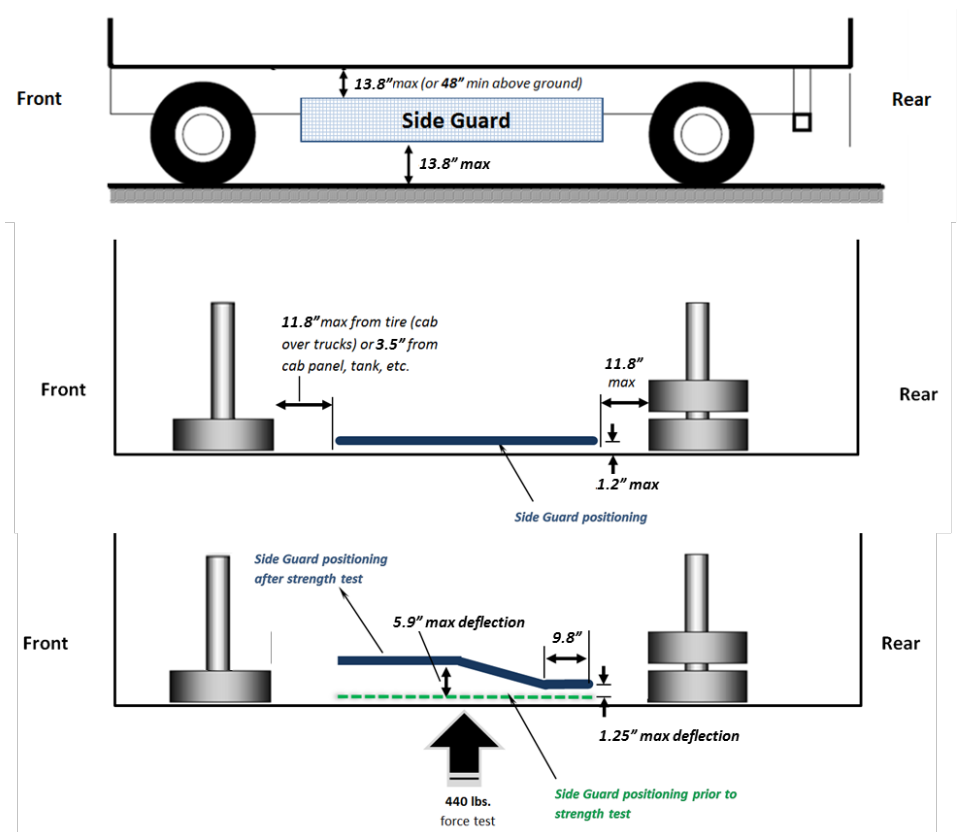
[1] Recommendations of the Large Vehicle and Safer Streets working group
https://www.sfmta.com/sites/default/files/projects/2015/Recommendation%20of%20the%20Large%20Vehicle%20and%20Safer%20Streets%20working%20group%20-%20Final.pdf



Results of City Fleet vehicle side guard suitability screening

For developing and implementing a City Fleet side guard specification, **Volpe recommends specifications as depicted in the schematic below and described in section 3.2, while allowing reasonable flexibility for special operational requirements, as discussed in sections 2.2, 3.3, and 3.5.** Based on Volpe's site surveys, fleet manager input, and the hill crest analysis in section 3.3, **the 13.8-inch recommended maximum ground clearance is expected to allow vehicles to continue normal operation citywide**. However, before finalizing specifications and installing more broadly, Volpe recommends **confirming operability in the field using a long-wheelbase truck pilot installation on the most severe hill crests.**



1 Introduction

Every year in San Francisco, about 30 people lose their lives and over 200 are seriously injured while traveling on city streets, as mapped in Figure 1. The City and County of San Francisco adopted Vision Zero as a policy in 2014, committing to adopt policy changes that save lives and to ultimately eliminate traffic fatalities by 2024.

According to the Vision Zero San Francisco Large Vehicle and Safer Streets Working Group, 17% of all bicyclist and pedestrian traffic fatalities from 2007-2011 involved large trucks or buses, even though these large vehicles represented only 4% of all collisions with bicyclists and pedestrians. Furthermore, collisions involving trucks were over 8 times more likely to result in death of the person walking or bicycling than collisions involving automobiles.[2]

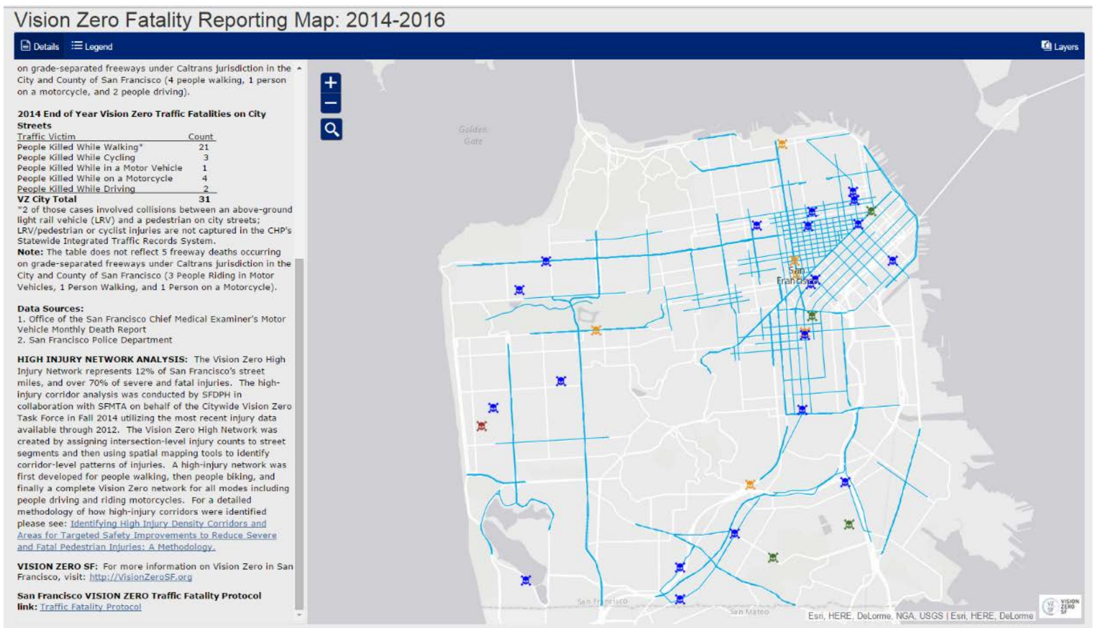


Figure 1. Vision Zero SF crash map showing traffic fatalities in 2014-2016. 17% were caused by large vehicle collisions.[3]

Building on its recent partnerships with Boston, Cambridge, and New York City, the Volpe National Transportation Systems Center (Volpe) partnered in 2015 with the San Francisco Municipal Transportation Agency (SFMTA) to establish recommendations and an implementation path forward for large truck safety technologies in San Francisco. Specifically, Volpe is working with SFMTA to: 1) establish recommendations for large truck side underride protection and other vehicle-based safety

[2] Recommendations of the Large Vehicle and Safer Streets working group https://www.sfmta.com/sites/default/files/projects/2015/Recommendation%20of%20the%20Large%20Vehicle%20and%20Safer%20Streets%20working%20group%20-%20Final.pdf

[3] http://sfgov.maps.arcgis.com/apps/MapTools/index.html?appid=38d13e08cd74492ea674cdf27343370a

countermeasures in San Francisco; 2) assess the market capacity and discover the available supplier networks necessary to meet a side guard mandate; and 3) examine the effectiveness of additional select vehicle safety technologies

At SFMTA's discretion, Volpe will also review and recommend safety countermeasures for municipal buses operating in San Francisco; assist in designing and evaluating the outcomes of side guard and other safety technology pilot implementations; assist in performing a truck traffic census and/or in analyzing existing truck census data to identify non-regulated trucks to be targeted and conflict points due to truck traffic; and support a strategic effort to align the state and private fleets with the above initiatives, ideally extending Vision Zero actions beyond City jurisdiction.

This report highlights regulatory and voluntary precedents for truck side guard deployment, available safety data, and recommended technical specifications and deployment considerations for City truck side guards.

1.1 Safety Challenges

Large trucks are disproportionately represented in bicycle and pedestrian fatalities. Nationally, large trucks comprise 4% of the United States vehicle fleet,[4] yet are associated with 7% of pedestrian fatalities (297 annually) and 11% of bicyclist fatalities (76 annually).[5,6] 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 2—and to the increased likelihood of people walking or biking to be fatally run over (or suffer underride) in a collision with a high ground clearance truck as opposed to collisions with a low ground clearance car. In nearly one out of three fatal crashes involving large trucks, bicyclists and pedestrians first come into contact with the side of the truck, based on five years of national crash data, as shown in Figure 3. Approximately half of all bicyclists killed in crashes involving large trucks first hit the side of the truck, and 37% specifically hit the right side of the truck before they were killed.

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[4] 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

[5] 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/safety/safety-studies/Documents/SS1301.pdf

[6] NTSB Safety Recommendations to NHTSA, April 3, 2014. http://www.ntsb.gov/safety/safety-recs/RecLetters/H-14-001-007.pdf

Figure 2. 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.[7]

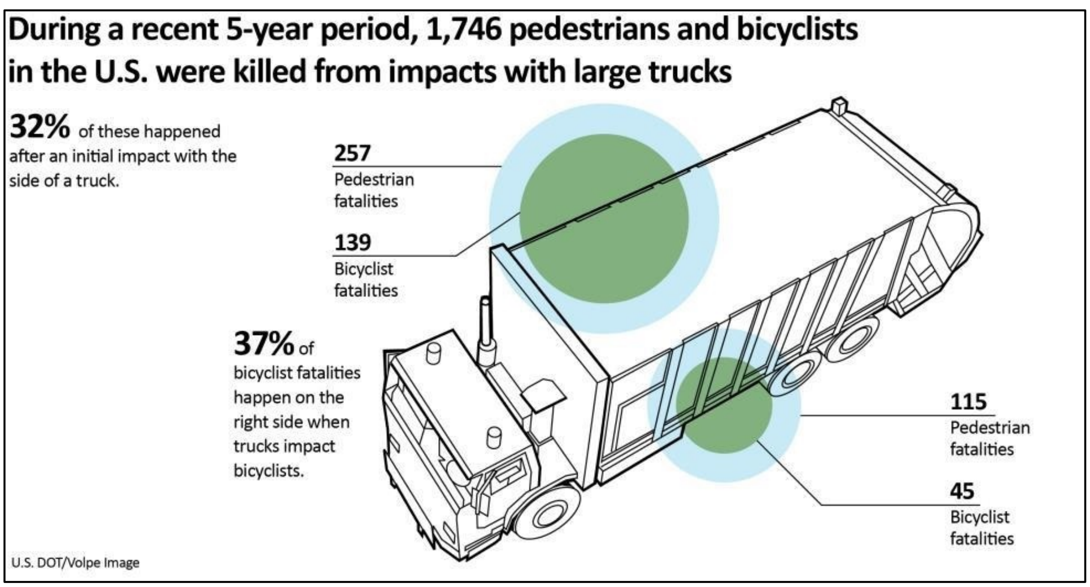

Figure 3. Relative prevalence of side impact collisions between large trucks and vulnerable road users, based on U.S. 2005-2009 TIFA data.

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

1.2 Urban Truck Safety Strategies

Three fundamental strategies for achieving a safer urban truck fleet are crash avoidance, crash mitigation, and evaluation, as depicted in Figure 4. The first strategy, crash avoidance, broadly includes complete streets infrastructure, such as separated bicycle facilities, raised crosswalks, and other traffic calming and visibility measures; separation of freight and VRUs in space (e.g., through judicious truck routing) or time (e.g., with off-hours delivery); road user education, e.g., through more rigorous operator training, exterior decals warning of blind spots, and enforcement; and improved situational awareness of the truck operator about vulnerable road users (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 windshields and lower side windows for greater visibility, as is being implemented by certain original equipment manufacturers (OEMs) in the European Union and potentially soon required by London,[8] as well as by the addition of blind spot mirrors, Fresnel lenses, ultrasonic/radar systems, and camera systems.

The second strategy, crash mitigation, represents the last line of defense in situations where a crash is not avoided through infrastructure, education, enforcement, or visibility measures such as blind spot mirrors. Side guards are the primary crash mitigation tool considered in this report. Other possible vehicle redesign strategies for protecting VRUs in collisions include energy-absorbing nose cone bumper designs for trucks and wheel guards on buses (as currently implemented on buses operated by the SFMTA).

The third strategy is evaluation, which is important for the long-term success of any safety initiative. Evaluation involves assessing whether safety interventions or enhancements are achieving the desired effects, adjusting these interventions as necessary, and reinforcing a process of continual, data-driven improvement. Evaluation may require detailed crash, operator, and vehicle configuration data to determine how well an intervention such as side guards is working. Cross-agency collaboration, particularly with police departments, is important in collecting this data and effectively evaluating success.

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[8] https://consultations.tfl.gov.uk/roads/safer-lorries

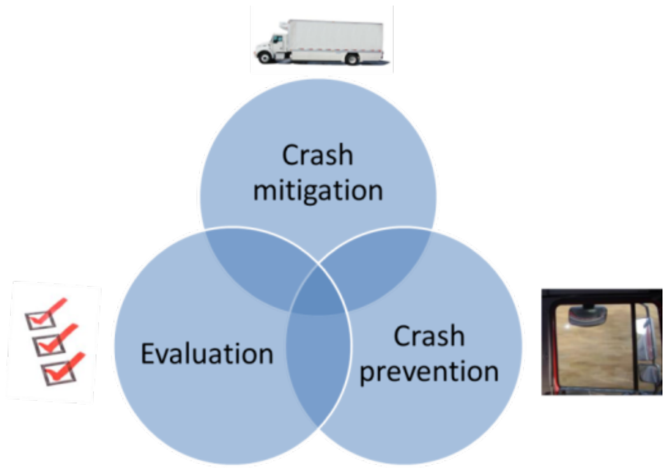

Figure 4. Three pillars of vehicle-based technology for VRU safety.

The Vision Zero SF program provides an ideal framework for the City of San Francisco to lead among U.S. municipalities on truck safety for bicyclists and pedestrians. Although safety technologies such as side guards have significant international precedence, their domestic deployment has been limited; as such, developing side guard supportive policies stands to place San Francisco at the leading edge of urban truck safety in the United States. Choosing to lead by example may accrue additional associated benefits; e.g., side guard adoption amongst private fleets. Volpe will help disseminate all findings made by the City nationally via the USDOT.

2 Truck Side Guards Background

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 by the rear wheels.

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 most large trucks, trailers, and semi-trailers in Japan; the European Union, including the United Kingdom; and Brazil. Side guards are also prevalent in China and other South American countries, and Australia provides advisory standards. Some side guard variants are designed to also provide environmental benefit in the form of improved fuel efficiency by reducing a truck's aerodynamic drag when it is driven at higher speeds. In the U.S., the cities of Portland, OR, Washington, DC, New York, Boston, Fort Lauderdale, Orlando, Cambridge, MA, Somerville, MA, and Newton MA have implemented side guards on various scales. Additionally, the University of Washington retrofitted its fleet of 31 trucks in 2015.[9] The most extensive implementation in the U.S. to date is New York City's retrofit of over 300 City trucks (and growing) as of December 31, 2015.[10]

2.1 Side Guard Deployment Safety Impacts

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 review drew 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, those that occur during turns. According to the National Transportation Safety Board, the prevalence of these types of crashes in the U.S. ranges as high as 25% for pedestrians with single-unit trucks and 55% for bicyclists with tractor-trailers.[11]

The safety effectiveness of side guards on large trucks was demonstrated by a UK study, which showed significant reductions in the rate of bicyclist fatalities for the relevant crash types prior to and after the

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[9] http://blogs.uw.edu/tsmedia/2015/05/13/uw-installs-life-saving-side-guards-on-trucks-to-protect-cyclists/
[10] http://www.nyc.gov/html/visionzero/assets/downloads/pdf/vision-zero-year-two-report.pdf
[11] NTSB, Crashes Involving Single-Unit Trucks that Resulted in Injuries and Deaths, 2013
http://www.ntsb.gov/doclib/safetystudies/SS1301.pdf

enactment of a national side guard requirement.[12] **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[13] and cited by the National Research Council Canada in a 2010 report.[14]

Figure 6. Diverse 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[15] compared the crash outcomes for British trucks exempt and non-exempt from the side guard regulation.[16] The fatality rates in bicycle left-hook collisions from 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 1. **Whereas only one in four bicyclists was killed or seriously injured in crashes 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 1. 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%**

[12] National Research Council Canada, Side Guards for Trucks and Trailers Phase 1: Background Investigation, 2010.
[13] 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
[14] National Research Council Canada, Side Guards for Trucks and Trailers Phase 1: Background Investigation, 2010.
[15] 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.
[16] 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.

2.2 Operability of Major Side Guard Types

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

- Removable or stowable designs
    - Facilitates occasional access to undercarriage components is facilitated by a removable panel design. Some models include a panel that can be removed from the vehicle without tools. Other designs employ a flip-up or hinged system that swings out.
- 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.
- Diesel particulate filters (DPFs)
    - No evidence has been identified of side guard-DPF incompatibility based on Boston's experience, as well as based on recent European emissions control standards, which have required DPFs since MY2011/2012.

2.3 Custom Fabricated Versus Commercial Off-the-Shelf (COTS)

Side guard retrofits for existing large trucks can be procured as custom fabrication at metal shops or other small-medium manufacturers, purchased as commercial off-the-shelf aftermarket products (e.g., from aerodynamic trailer skirt manufacturers or internationally), or purchased already integrated in the vehicle by the OEM (Daimler, Volvo, Ford, etc.). The City of Boston's side guard deployment has relied on a combination of COTS and custom fabricated models, as seen in Figure 7.

In European, Asian, and South American markets, truck original equipment manufacturers (OEMs) incorporate side guards during design and assembly; in the long term, such integration is the preferred solution to avoid the need for retrofitting, but the timeline for widespread availability of OEM side guards in North America is unclear. Both domestic and international retrofit side guard sources are available, and Volpe will further research supply sourcing strategies in the next task.

Figure 7. Boston's side guard installation have been a mix of off-the-shelf (left) as well as custom fabricated models (center and right).

2.4 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, but are 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 2. Example North American side guard retrofit reported costs.

U.S. city	Reported approximate cost per vehicle	Side guard type
Boston[17]	$1,800	Steel rail; fiberglass panel
New York City[18]	$3,000	Fiberglass panel
Portland[19]	~$1,000 small trucks - $4,000 trailers; $200-$250 per toolbox	Metal panel and toolbox

Based on a review of side guard costs from 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. Such variation in costs is attributable to costs of different designs, the quantity of product needed to fit different size vehicles, and the labor

[17] http://www.cityofboston.gov/news/default.aspx?id=20121
[18] http://www1.nyc.gov/office-of-the-mayor/news/101-15/city-begins-installing-truck-side guards-protect-pedestrians-cyclists
[19] Interview with Don DePiero and Donny Leader, City of Portland City Fleet, Bureau of Internal Business Services, November 30, 2012.

required for installation. 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.[20] On the low end, a pair of pre-certified, twin-rail 10-foot side guard kits from UK suppliers, including mounting hardware, can be purchased for about $300 plus shipping costs.[21] UK side guards are able to mount to the truck body[22] or bolt to the frame rail.[23]

In addition to the costs of purchase and installation, any additional costs of maintenance should be considered. Based on a Volpe interview with the City of Portland, OR, the municipal fleet in that city has not seen additional operations and maintenance costs since installing truck side underride protection in 2008. The Portland fleet used a combination of side guards and tool boxes.[24] According to New York City Director of Fleet Services, the 330 side guard installations to date in that city have not resulted in additional maintenance costs since the program's February 2015 inception; a small number of initial minor damage and installation issues were resolved by the side guard installers at no cost to the agency fleets. In the future, side guard inspection will likely be added to the City's annual vehicle inspection checklist, which the Director estimated will require 15 minutes of staff time.[25] According to the Boston Public Works Department, there have been no added maintenance costs since installing side guards on over 60 trucks starting in 2013.[26] The additional maintenance burden of side guards can be expected to be similar to that of tool boxes, since both are similarly mounted to the truck body and have few or no moving parts.

2.5 Installation and Maintainability

Volpe considered potential installation and maintainability issues that could arise with the implementation of side guards on trucks in City agency fleets. Installation can either be frame-mounted, body-mounted, or both. Some frame rail installations 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 has required up to 8-16 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

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[20] National Research Council Canada, Side Guards for Trucks and Trailers Phase 1: Background Investigation, 2010.
[21] For example: http://www.nationwide-trailer-parts.co.uk/collections/side-guard-systems-hgv-trailer
[22] For example: http://www.nationwide-trailer-parts.co.uk/collections/side-guard-systems-hgv-trailer/products/sideguard-legs
[23] For example: http://www.nationwide-trailer-parts.co.uk/collections/side-guard-systems-hgv-trailer/products/chassis-mounted-sideguard-support-beam
[24] Volpe interview with Don DePiero and Donny Leader, City of Portland City Fleet, Bureau of Internal Business Services, November 30, 2012.
[25] Volpe interview with Jack Graczyk, City of New York Director of Fleet Services, April 8, 2016.
[26] Volpe communication with Kris Carter, City of Boston Mayor's Office of New Urban Mechanics, April 8, 2016.

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 also aluminum or are isolated by rubber bushings, washers, etc. to prevent galvanic corrosion between 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 periodically for proper torque to detect possible loosening. If loosening occurs, consider eliminating washers and instead adding rubber bushings to help isolate road vibration and to slow or stop bolt loosening.

Figure 8. Left: Frame-mounted installation of a side guard. Right: Body-mounted side guard.

3 Recommendations for San Francisco City Fleet Vehicles

3.1 City Fleet Overview

Based on a unified City Fleet inventory provided to Volpe by SFMTA, the San Francisco City Fleet currently consists of 2,990 vehicles operated by multiple agencies, ranging from small sedans to heavy-duty, Class 8 trucks. Volpe performed an initial screening of vehicle suitability for sideguards and other safety measures, considering vehicle types, vehicle counts, possible operational requirements, and highlighted truck types and agencies that were priorities for site visits and follow-ups. **Per Volpe's initial screening, 231 to 541 vehicles City vehicles have been deemed suitable candidates for side guard implementation.**

3.2 Recommended Specifications

In this section, Volpe provides a set of side guard implementation recommendations for the City of San Francisco's City Fleet. Side guards should be designed with the aim of safety, and considering strength, weight, and ease of operations and maintenance. The recommended side guard specifications for City-owned and contracted large trucks are depicted in Figure 9. Note that the specifications shown are more stringent than required by the City of Boston's 2014 ordinance[27] and consistent with the 2015 City of New York Local Law 56 requirements.[28]

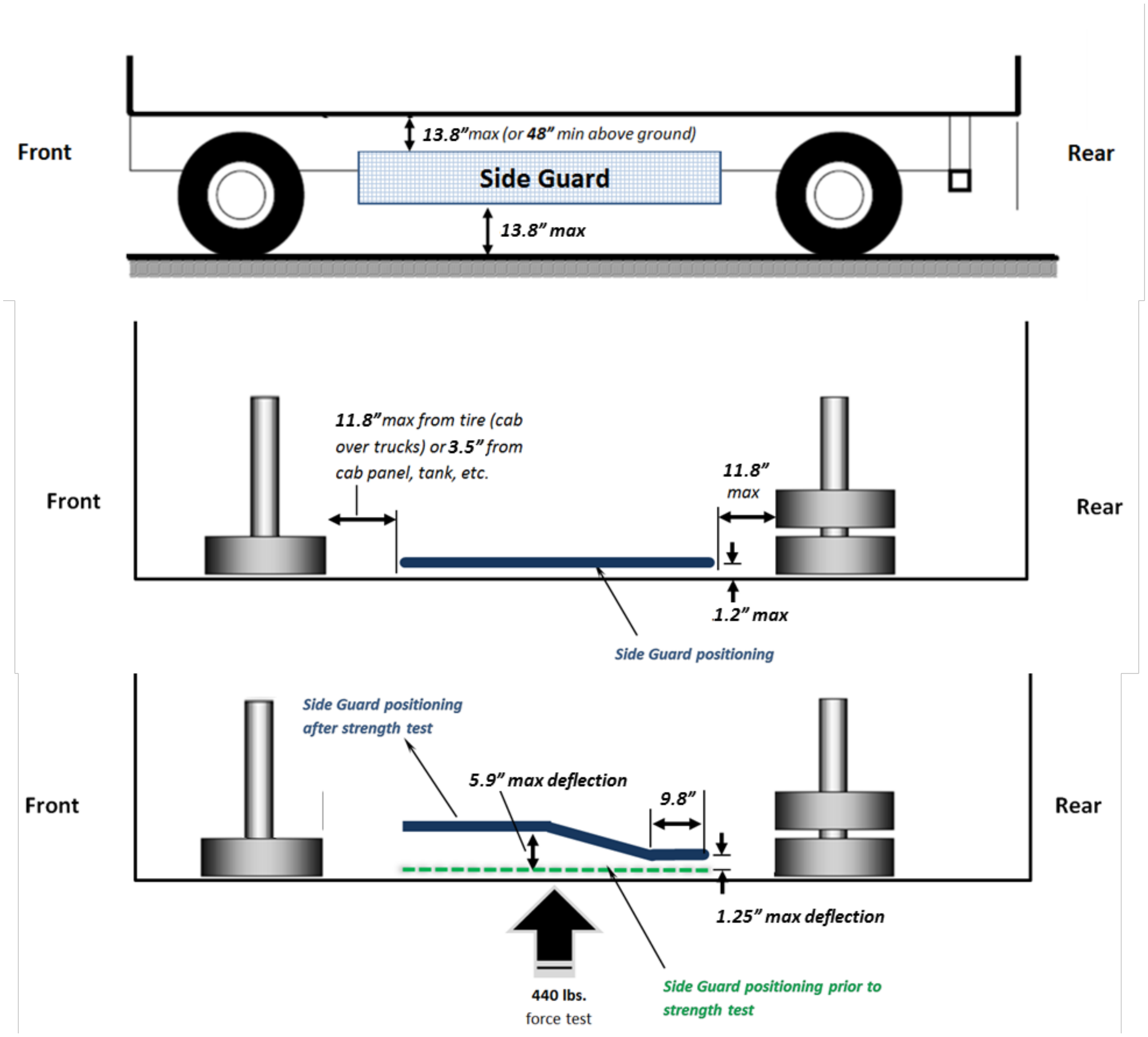

Figure 9. Recommended side guard specifications for Vision Zero SF.

If a side guard standard or regulation were adopted in San Francisco, it should stipulate maximum ground clearance, minimum strength requirement, and define the areas of installation as shown in Figure 9 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.

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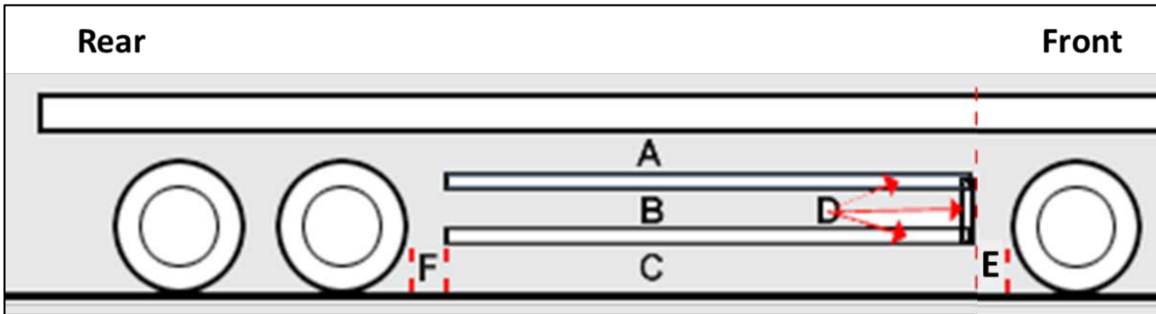
27 http://www.cityofboston.gov/isd/pdfs/FinalTruckSideGuardhandoutvF1.pdf
28 http://legistar.council.nyc.gov/LegislationDetail.aspx?ID=1687945&GUID=9621FABE-B038-4D87-BD30-54547AD24E3F

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

Based on both published recommendations by Monash University and UK guidance on the effectiveness of improved side guards, [29] as well as based on analysis of ground clearance compatibility, **Volpe recommends implementing a maximum 13.8 inch (350 mm) ground clearance requirement.** This maximum clearance is preferred because it provides greater protection for vulnerable road users while generally not impeding on-road operations.



Specifications

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

*The gap between the side guard's leading edge and the wheel, wheel arch, or other permanent vehicle structure should not exceed 11.8 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 10. Recommended dimensional requirements for rail-style side guards, based on European standards with the exception of the ground clearance Dimension C, which is more stringent for improved safety.

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 11); 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 12. The forward gap should not exceed 11.5 inches.

Additionally, any gap between the cab and the top of the side guard exceeding 13.8 inches, as seen in Figure 11, should be filled with an additional rail or panel of equal strength to the side guard.

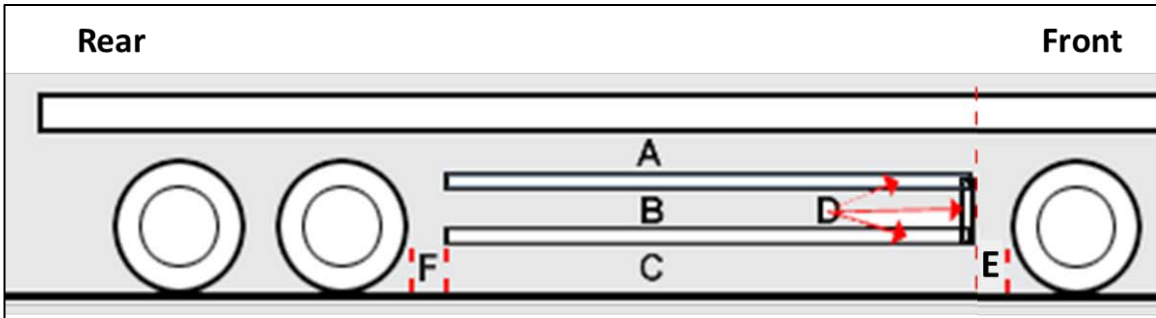
[29] R Cookson and I Knight, Side guards on heavy goods vehicles: assessing the effects on pedal cyclists injured by trucks overtaking or turning left. 2010.

Figure 11. 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 (13.5 in.) should be filled with an additional rail or panel of equal strength.[30]

Figure 12. 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.[31]

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 offer new "real estate" for safety-related on-vehicle messaging. For any rail-style guards, the dimensional minimum and maximum figures shown in

[30] Images from Freight Transport Association (UK) Sideguards Compliance Guide, 2010.
[31] Image from Freight Transport Association (UK) Sideguards Compliance Guide, 2010.



Specifications

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

*The gap between the side guard's leading edge and the wheel, wheel arch, or other permanent vehicle structure should not exceed 11.8 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 10 should be observed to ensure sufficiently close spacing of the rails.

Figure 13. 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 14. Wide, closely spaced rails on rail-style side guards (Left: UK example; right: Cambridge, MA example) are preferred over narrow rails.

For some vehicles facing retrofits, moving certain factory installed tanks or other large pieces of equipment to align flush with sections of a side guard may not be practical, and covering the equipment with a panel-style guard may not be an option due to required frequent access (assuming an access hole cannot be made that would avoid compromising the panel). In these cases, the following 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 15) for maintenance access.

Figure 15. Innovative designs for easier undercarriage access. Top Left: United Kingdom cement truck with flip-up lower truck side guard. Top right: NYC Sanitation removable section on pins; Bottom: Cambridge, MA flip-up, wide rail-style side guards.

3.2.1.2 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 a strength requirement of at least 440 lbs.**[32]

As consistent with EU and UK requirements, **Volpe recommends a maximum allowed deflection of 1.2 inches for the rearmost 9.8 inches of the side guard and a maximum allowed deflection of 5.9 inches along its remaining length** when 440 lbs. of perpendicular force is applied on any part of the outside surface of the side guard.[33] The City of San Francisco 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 or a third party (e.g., Volpe) 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.

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 17 at left. Alternatively, a short panel would need to be added to span the gap as shown at right (Figure 17 at right), or the leading edge of the toolbox could be rounded and turned inward (see Figure 12).

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[32] 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.

[33] 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 16. A Boston-based example of a tag axle that reduces the required length of the side guard.

Figure 17. Example of installed underbody equipment on a DPW vacuum truck that achieves a flush, continuous surface and therefore the function of a side guard. No additional side guard is needed on this vehicle.

3.3 Ground Clearance Compatibility with City Streets

A common question about side guards when first implemented on truck fleets is whether they allow sufficient ground clearance for operations that involve driving over a curb. As most curbs have a vertical reveal of 6 inches, the 13.8” maximum recommended side guard ground clearance does allow curb mounting. For certain specialized vehicles such as SFMTA’s track maintenance trucks, another operational concern may be driving over and straddling railroad tracks. Most surface Muni tracks are flush with the surrounding pavement; however, exposed ties and rails are taller. The typical height of 100-pound rail is 6 inches, so assuming the ballast is level with the tops of the track ties, 13.8” side guard clearance should still be adequate. However, this point should be verified in the field.

A special operability challenge for truck side guards in San Francisco is clearing the crests where steep streets level out midblock or transition to level intersections. Trucks that operate on all streets in the City must be able to clear the breakover angles of these crests without “high-siding” the side guards. Decreasing the side guard ground clearance too far on a given truck could result in frequent repairs and vehicle downtime.

In this section, Volpe uses three approaches to investigate required minimum ground clearance for the City fleet—mathematical calculation, vehicle measurements from a site survey, and fleet manager interviews—and proposes a path forward with respect to the breakover angle issue.

3.3.1 Calculation

As shown in Figure 19 and expressed mathematically in Figure 18, the *breakover angle* is the maximum possible supplementary angle that a vehicle with a given wheelbase and a given ground clearance can drive over without the crest hitting the underbody of the vehicle. Using this formula, it is also possible to calculate what the longest allowable truck wheelbase is for a given truck ground clearance and breakover angle. It is important to note, however, that this formula is conservative because it assumes the crest has no transition zone between the two street grades. While this may be realistic for certain loading docks or parking garages, roadway crests normally have a considerable transition zone where one grade smoothly curves into the other grade, which allows a lower ground clearance vehicle to clear the crest. Volpe used both the standard, conservative formula and a more realistic set of assumptions in the analysis that follows. Volpe also collected actual City vehicle ground clearance, wheelbase, and street grade information to determine whether the safety-driven, recommended side guard ground clearance is achievable on San Francisco's street network.

$$\text{breakover angle}_{approximate} = 2 \cdot \arctan\left(\frac{2 \cdot \text{ground clearance}}{\text{wheelbase}}\right)$$

Figure 18. Formula for maximum breakover angle as a function of ground clearance and wheelbase[34]

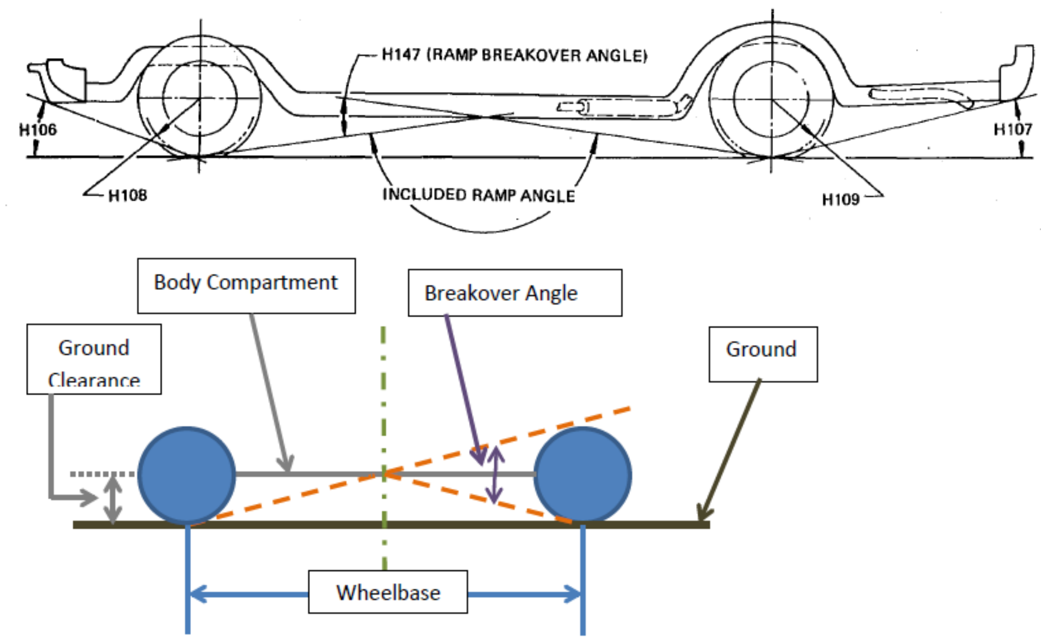

Figure 19. Top: Diagram of ramp breakover angle from SAE J1100 Motor Vehicle Dimension Standards.[35] **Bottom: Simplified breakover angle diagram.**

[34] By Rlboyce - I made this diagram using Inkscape, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=31627794

[35] https://law.resource.org/pub/us/cfr/ibr/005/sae.j1100.1984.pdf

The five steepest street segments in the City according to the San Francisco DPW are shown in Table 3. Volpe used the maximum 31.5% grade of Filbert Street between Leavenworth and Hyde to calculate the worst-case scenario. The conversion from engineering grade to degree angle is qualitatively shown in Figure 20; thus the top five steep streets range approximately 14 degrees to 17 degrees from horizontal.

Table 3. The Five Steepest Streets in the City[36]

Filbert between Leavenworth and Hyde (**31.5%** grade)
22nd between Church and Vicksburg (**31.5%** grade)
Jones between Union and Filbert (**29%** grade)
Duboce between Buena Vista and Alpine (**27.9%** grade)
Jones between Green and Union (**26%** grade)

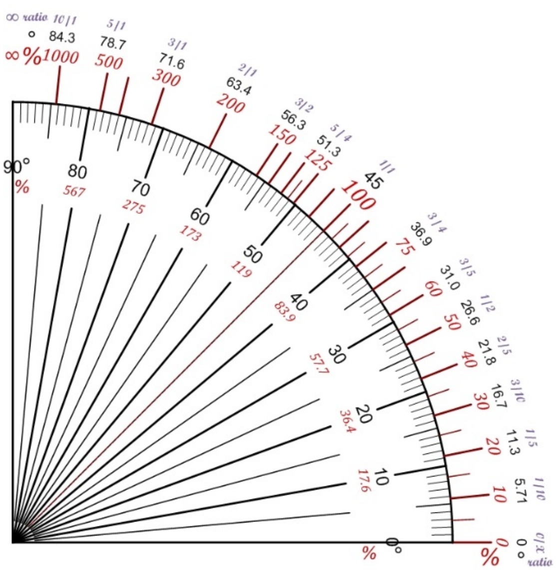

Figure 20. Grade, slope, and angle conversion[37]

In the hypothetical, worst case scenario of Filbert Street's 31.5% grade changing to 0% grade at a perfect apex, the breakover angle would be 17.2 degrees. For the 13.8 inch recommended maximum side guard ground clearance, the maximum vehicle wheelbase that will allow the truck to clear is 182.6 inches, or 15.2 feet. However, some City truck wheelbases that Volpe observed during the field survey were longer, for example 20 feet. These trucks would theoretically require a ground clearance of 18.1 inches to clear the crest, higher than the 13.8" recommended side guard ground clearance.

As noted previously, the breakover angle formula assumes that the street grade instantaneously changes at the crest, with no vertical curve or transition zone around the apex. During the site visit,

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[36] http://www.datapointed.net/2009/11/the-steeps-of-san-francisco/ and http://bsm.sfdpw.org/subdivision/keymap/

[37] By Scientif38 - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=41143362

Volpe documented a number of crests to estimate the length of a typical transition zone between different street grades. At level intersections where steep streets start their descent, these transitions appeared to be 10-15 feet long, as shown in Figure 21. The longer the transition zone, the more it will reduce the minimum vehicle ground clearance required to clear the crest. **For a grade transition zone of only ten feet across, using the same worst-case scenario as above, the minimum vehicle ground clearance for a 20-foot wheelbase truck becomes 13.6 inches instead of 18.1 inches.**[38] This minimum ground clearance then falls below the 13.8” recommended maximum side guard clearance, indicating that **a 20-foot wheelbase truck should still be able to operate throughout the City with these side guards installed.**

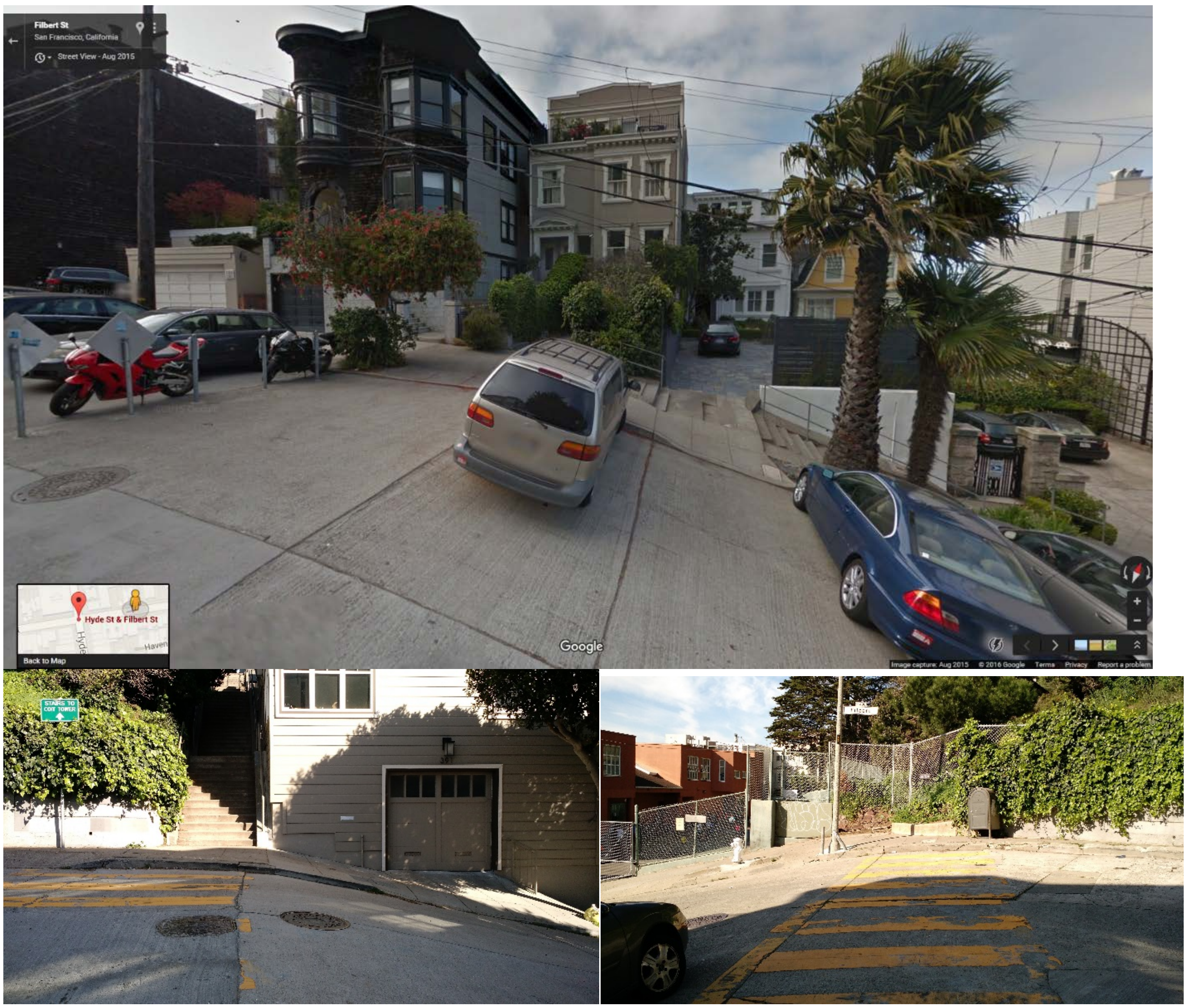

Figure 21. Google Street View (above) and Volpe images (below) of ramp breakover angles on Filbert Street showing the nonzero vertical curvature of grade transitions that occur over 10-15 horizontal feet.

[38] Trigonometric calculations assume constant curvature profile (circular with radius of 33 feet) along the transition zone from 0 degrees to 17.22 degrees

3.3.2 Vehicle Measurement and Fleet Interviews

In addition to the above mathematical estimates, Volpe measured dozens of truck types in the Department of Public Works (DPW), Public Utilities Commission (PUC), and Recology fleets and spoke with a number of fleet managers. Based on Volpe's measurements and fleet manager feedback, breakover angles have been determined to generally not be an issue for current City vehicles throughout the City street network. Specifically, Volpe identified existing trucks that have been reported to clear the City's crests with dimensions up to a 21-foot wheelbase with 13-inch ground clearance and up to a 13-foot wheelbase with 7-inch ground clearance. PUC Water staff reported that none of their vehicles have high-sided in the course of operating on streets when responding to water main breaks; Recology similarly reported that their trucks service all streets but have not experienced high-siding issues. These empirical data points, together with the above calculations, indicate that the Volpe-recommended side guard clearance should be operable even on longer wheelbase trucks operating in San Francisco. Table 4 shows select vehicles that have reportedly been successful in clearing city street crests.

Table 4. Select City vehicles that have reportedly been successful in clearing city street crests

Agency	Truck	Wheelbase	Ground clearance	Reportedly clears city street crests	Notes
PUC Water	7455063	**21'**	**13"**	**Yes**	Ground clearance measured 9' rear of the front axle; see Figure 23
PUC Water	47583	**21.5'**	**N/A**	**Yes**	Longest wheel base of all observed trucks
PUC Water	N/A (Crane)	**18'**	**15"**	**Yes**	
Recology	Collection	**15'**	**12"**	**Yes**	See Figure 22
Recology	Collection	**13'**	**7"**	**Yes**	See Figure 22
Recology	Collection	**17'**	**14"**	**Yes**	
Recology	Collection	**21'**	**N/A**	**Yes**	

Although Volpe's calculations, spot measurements of vehicles, and anecdotal fleet interviews indicate that the 13.8-inch recommended maximum side guard ground clearance will be operable, Volpe still recommends confirming this point in the field. The City should consider installing a test side guard, tool box, or other apparatus 13.8" from the ground midway between the axles under a long wheelbase (20'-21') City truck; operate it on the steepest grade locations, such as those identified in Table 3; and observe whether the test device high-sides or successfully clears the crests at these locations before finalizing side guard specifications for the City fleets.

Figure 22. Wheelbase and ground clearance measurements on two Recology trucks. Top: 15 feet and 12 inches; Bottom: 13 feet and 7 inches.

Alternatively, **City fleets may choose minimum breakover angles based on their specific operating requirements**, e.g., a fleet must be able to drive on all streets, or conversely a fleet can avoid certain locations by parking nearby, etc. These fleets can use their minimum breakover angle and the 13.8" ground clearance to solve for the maximum wheelbase vehicle on which they can install side guards that meet the Volpe recommended specification. Assuming that some vehicles will exceed the maximum wheelbase, the fleet managers would need to carefully consider each of those vehicles on a case-by-case basis and decide whether to increase the maximum allowable ground clearance to reach the minimum breakover angle. Incorporating any side guard protection is still preferable to no side guard, and while a medium height gap between a truck's wheels is less than ideal for safety, it is still preferable to a tall gap. It is recommended that side guards generally be considered in all cases unless otherwise deemed infeasible.

Figure 23. PUC Water wheelbase and ground clearance measurement: 21 feet and 13 inches.

3.4 Site Visit Observations of Pilot Side Guards

During a site visit in February 2016, Volpe staff documented trucks in San Francisco's Department of Public Works Street Repair unit, Central Shops, Public Utilities Commission, and the City's waste management contractor Recology. The City's initial pilot side guard installations on two DPW and one PUC vehicles—all unaffiliated with, and retrofitted prior to, this study—were observed. These installations included both an expanded metal mesh design and the Airflow fiberglass panel system. Volpe visually inspected the installations from a safety and operability perspective, but Volpe's review did not include mechanical testing or inspection of the mounting hardware.

DPW truck 432738 had Airflow panel style side guards installed. As shown in Figure 24 and Figure 25, Volpe observed a number of issues that could reduce both their safety benefit and the operability of the vehicle. In contrast, the installation on 43100050 (Figure 26) appeared well executed, with 11.5” ground clearance and a small access hole that did not substantially change the smoothness of the impact surface. The small, expanded metal mesh side guard on PUC crane truck 7455063 effectively covered the longitudinal gap between a ladder and a toolbox, but along with the ladder and toolbox, left an excessively tall ground clearance of over 22 inches, as seen in Figure 27. Additionally, while not part of the City’s pilot program, Volpe noted vacuum trucks 42500007 and 42500017 as examples with existing underbody equipment that already provides the recommended side underride protection, with no additional need for a separate side guard—see Figure 28

Figure 24 One of the first side guard installations by DPW on a packer truck. Observed tight rear tire clearance is a potential concern for operability.

Figure 25. The recessed and protruding boxes do not provide a longitudinally smooth side guard surface. If possible, these should be realigned to be flush with the side guard. Additionally, the vertical gap over the forward box is excessive and should be covered (compare to example in Figure 11).

Figure 26. Access hole on this DPW side guard installation is well executed: small, smooth-edged, and away from the structural ribs of the fiberglass panel.

Figure 27. Expanded mesh panel side guard is well incorporated among other components but exceeds the recommended ground clearance.

Figure 28. Examples of underbody equipment that already meets the recommended side guard dimensions.

3.5 Possible and Likely Target Vehicles for Side Guards

Volpe analyzed fleet-wide vehicle suitability for side guards to determine the likely number of City vehicles that would benefit from installation, and therefore the amount of potential investment that would be needed to implement side guards fleet-wide. Based on the unified roster provided by SFMTA, Volpe categorized suitability as follows:

- **Unlikely**: SUV, light-duty pickup, van
- **Possible**: flatbed, dump, utility, crane
- **Likely**: packer, tractor-trailer, many Class 7/8 trucks depending on configuration

Volpe identified between 231 and 541 vehicles from the City vehicle inventory that are expected to benefit from side guards and 2,449 that are not likely to benefit, as shown in Figure 29. This assessment is based on the body styles, makes and models 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.[39] Based on the 2013 and 2014 National Transportation Safety Board (NTSB)

[39] As caveats to this screening analysis, it was easier for Volpe to rule vehicles out than to rule in; some cases will require further research to assess vehicle design: underbody gaps, placement of toolboxes, fuel tanks, etc., and to reflect agency- and vehicle-specific operational constraints, work rules and practices. The SFMTA database did not include vehicles photos, and text descriptions were in some cases limited, e.g., "STRT TRK GEN PURP-3." Even when such generic information was clarified through discussion with the respective agencies or through the February 2016 on-site survey, vehicle descriptions for remaining vehicles that were not observed may not be consistent and actual designs may vary.

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 pounds).

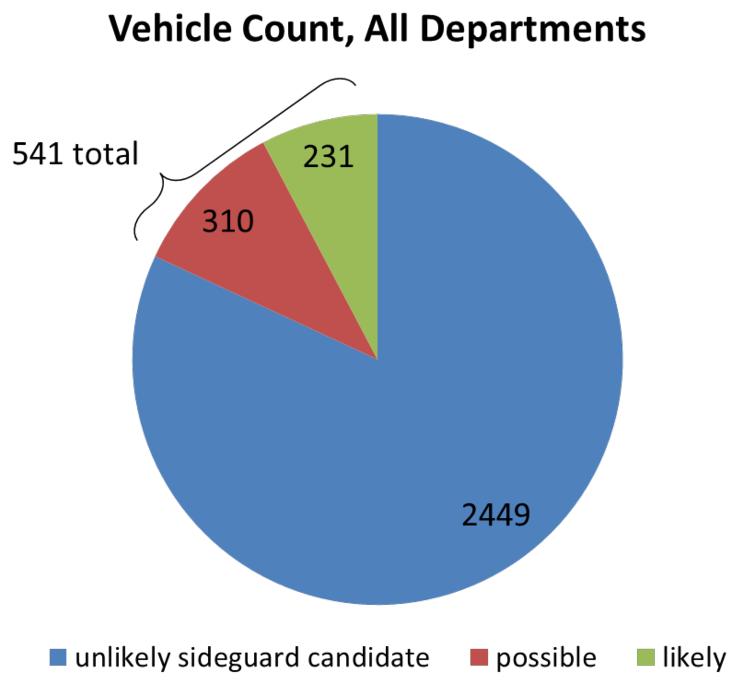

Figure 29. Vehicle side guard suitability fleet-wide

Potential priority vehicles to evaluate for retrofit are shown in Table 5, and it can be seen from Figure 30 that five agencies account for just over 50% of the target vehicles. Consistent with the recommendations that Volpe recommended for the City of New York, the City of San Francisco may adopt a number of vehicle type exemptions that would not be required to comply with side guards. The "impractical" exemption would give the City latitude to consider exempting potentially special, exotic vehicle cases. However, to minimize the reduction in safety to other road users, such exemptions should be granted only when an applicant can compellingly show the impracticality of installing side guards on a vehicle, including innovative designs that flip up or out, such as those shown in Figure 15. Based on an average likely cost range of $1,500-$2,500 to retrofit each truck, the investment needed to install side guards on all suitable vehicles may therefore range from $346,500 (low end vehicle count and low end cost estimate) to $1,352,500 (high end vehicle count and high end cost estimate). Larger volume purchasing and the identification of competing suppliers are both factors that will help to reduce per-unit cost.

Table 5. Potential priority vehicles to evaluate for retrofit

Vehicle description	Quantity	Main Agencies	Notes
TRUCK	216	MTA Municipal Railway; PUC Water Enterprise; PUC Water Supply; DPW Street Repair	Includes wide variety of sub-types & requires further examination (see next slide)
TRUCK-UTILITY	72	PUC Water Enterprise; MTA-DPT Sign Shop; Port Commission	
TRUCK-DUMP	66	DPW Urban Forestry; DPW Street Repair	
SWEEPER	63	DPW Street Env. Services	Often exempt from sideguard regulations but may warrant review for other safety features
TRUCK-CRANE	37	DPW Sewer Repair; PUC Water Enterprise	
TRUCK-AERIAL	26	Rec & Parks; DPW Urban Forestry	
TRUCK-FLATBED	29	MTA Municipal Railway	
PICKUP-FLATBED	11	SFO Airport Commission	
PACKER	5	DPW Street Env. Services	
TRACTOR	6	SFO Airport Commission	Sideguard would be fitted to trailer, if any
DIGGER-DERRICK	4	PUC Hetchy Power; MTA Municipal Railway	
FLUSHER	2	DPW Street Env. Services	

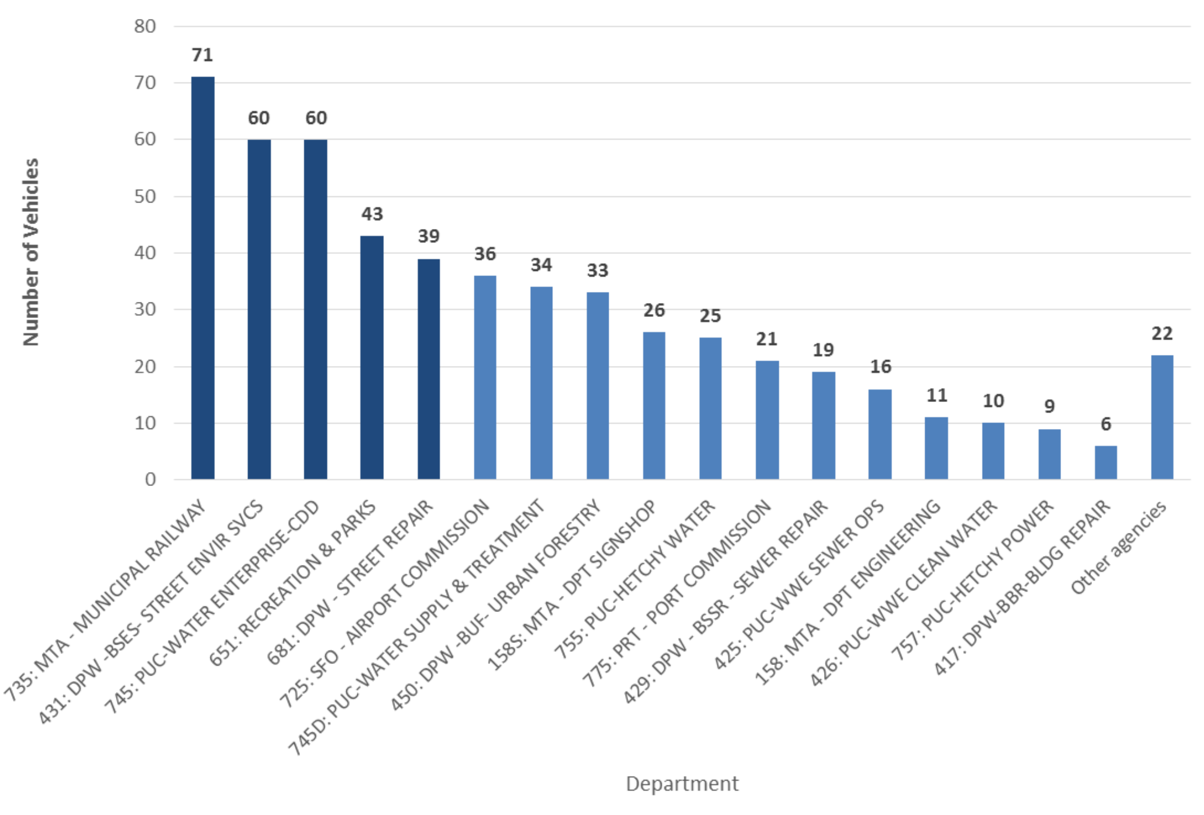

Figure 30. Distribution of likely or possible side guard candidate vehicles among the City agencies.

As a general point, the design of side guards and other devices used to provide side underride protection on the City's trucks should balance consistent specifications as recommended in this report with the uniqueness of each fleet's vehicles and operating needs. It may be necessary to account for special operational requirements such as extreme breakover angle for periodic off-road use or the need to access hydraulics or other equipment that is challenging to relocate on an existing vehicle that is being retrofitted. As part of developing and implementation a City fleet specification, SFMTA should consider serviceability and operability requirements, some of which have already been discussed in the breakover angle analysis. Additionally, considerations will include:

- Access needs for O&M
- Corrosion and detachment prevention
- Inspection and validation

Piloting new designs and evaluating them before installing broadly will help optimize performance, cost, and O&M compatibility for the final specs and standards

At a programmatic level, different measures including voluntary, procurement, and regulatory requirements can be used by the City to promote adoption and greater choice of available side guard designs. Additionally, strategies for near-term safety benefits would involve retrofitting existing fleet, while longer-term, it will be strategic to negotiate with OEMs as new vehicles are procured.

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