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# Side Impact Guards for Combination Truck-Trailers: Cost-Benefit Analysis

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**16. Abstract**


This analysis presents the benefits and costs of requiring trailers of combination trucks (CTs) or articulated trucks consisting of a tractor unit and one or more attached trailers to be equipped with side impact guards to mitigate injuries and fatalities resulting from side-underride crashes involving CTs and light passenger vehicles (LPVs). LPVs include passenger cars, light trucks, and vans with gross vehicle weight ratings of 10,000 pounds or less. Estimated safety impacts were converted into monetary equivalents using estimated comprehensive economic costs of crashes, and compared with estimated hardware, installation, and incremental fuel costs to identify estimates of net benefits, benefit-cost ratios, and cost-effectiveness. A sensitivity analysis considered a range of input assumptions to account for uncertainty in the target population of side underride fatalities, side guard effectiveness, hardware costs, and fuel consumption impacts.

The cost-benefit analysis presented here indicates that equipping CT trailers with side underride guards would mitigate fatalities and would likely also mitigate serious injuries for LPV occupants associated with side underrides, but that the costs of doing so exceed the benefits across the range of assumptions considered in the analysis. The predominant driver of high-cost impacts relative to safety benefits is hardware costs across the scenarios evaluated, but the effect of side guard weight on CT fuel costs is also a critical factor. Based on this finding, we conclude that alternative approaches to mitigating LPV-CT trailer crashes warrant further attention. As a focal example, ADAS represents a countermeasure that could reduce the frequency of LPV-CT trailer crashes.


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# Executive Summary

This analysis presents the estimated benefits and costs of requiring trailers of combination trucks (CTs, or articulated trucks consisting of a tractor unit and one or more attached trailers) to be equipped with side impact guards to mitigate injuries and fatalities resulting from side-underride crashes involving CTs and light passenger vehicles (LPVs). LPVs include passenger cars, light trucks, and vans with gross vehicle weight ratings (GVWRs) of 10,000 pounds or less. For this analysis, Fatality Analysis Reporting System (FARS) 2008-2017, National Automotive Sampling System General Estimates System (NASS-GES) 2008-2015, and National Automotive Sampling System Crashworthiness Data System (NASS-CDS) 2008-2017, Crash Report Sampling System (CRSS) 2016-2017, and police crash reports (PCRs) were used to estimate fatalities and injuries in side-underride crashes. Safety impacts were converted into monetary equivalents using estimated comprehensive economic costs of crashes, and compared with estimated hardware, installation, and incremental fuel costs to identify estimates of net benefits, benefit-cost ratios (BCRs), and cost-effectiveness measures.

**NHTSA Side-Underride Crash Research**

In 2019 the National Highway Traffic Safety Administration studied side-underride crashes involving CTs and LPVs; key findings from the study are presented in this analysis as a basis for estimating fatalities and serious injuries in side underrides that could be mitigated with trailer side guards (guards placed along the lower left and right of CTs to mitigate the risk of side underride). The study focused on the side-underride crashes between CTs and LPVs where the CTs received damage to the side or undercarriage, and the LPVs received damage to the front or top of the vehicle; only side-impact, sideswipe, and angled crashes between the two vehicles involved in crashes were considered for this study. Data sources used for this research included agency crash databases such as FARS, NASS-GES, NASS-CDS, and CRSS.

The FARS 2008-2017 analysis reveals that the annual average of LPVs involved in side crashes with CTs was 192, of which approximately 23 percent resulted in side underrides. The annual average of occupant fatalities of LPVs involved in CT side crashes was 212, of which approximately 24 percent were attributed to side-underride crashes.

CDS data from 2006 to 2015 was used to estimate the delta V distributions associated with occupant injury severities when side-underride crashes occurred. The results indicated that minor injuries usually occurred around a delta V of 1 to 20 mph, while serious or fatal injuries occurred at higher speeds. The effects of speed limit, vehicle age, occupant age, belt use, and road surface conditions on occupant fatalities are also discussed in this study. Higher speed limits, non-belted occupants, vehicle age, occupant age, and wet or icy surface conditions all contributed to occupant injuries.

As noted in the Government Accountability Office's 2019 report on truck underride guards (GAO, 2019), previous evaluations of vehicle underride data have indicated that vehicle underride is underreported in FARS. To gauge the extent to which underreporting could affect estimates of side underrides, the results from the FARS analysis were considered in tandem with results from a review of available PCRs for front-to-side, two-vehicle LPV-CT trailer crashes identified in 2017 FARS data (184 cases, within which all side underrides reported in FARS are found). Overall, the PCR review found that 92 of the 184 cases involved vehicle underride of the light vehicle, while FARS coded only 52 of the 184 cases as vehicle underride (a difference of 77 percent to 94 percent, depending on how unknown underrides are classified). A similar range of differences is found when focusing on fatalities rather than underrides (59 underride fatalities in the FARS data versus 100 to 109 fatalities in the PCR review, or differences of 69 percent to 83 percent, depending on how fatalities in unknown underride cases are classified).

Of particular importance for the analysis of side guards is the subset of crashes below 40 mph, the design standard for the side guards considered in this analysis (i.e., the maximum impact speed at which the AngelWing side guard demonstrated protection during testing by the Insurance Institute for Highway Safety (IIHS). However, the sample of such cases within the PCR review is small enough to warrant caution in applying the corresponding estimate of the rate of underreporting. The PCR review identified over twice as many underrides and underride fatalities (12.8) as FARS (5) at speeds below 40 mph. Extending this view to include cases with unknown travel speed yields similar results: 20.9 underride fatalities in the PCR review versus 11 in FARS.

**Other Standards and AngelWing Side Underride Guard as an Option**

In the United States, only a rear impact guard is required for trailers and semitrailers with GVWRs of 4,536 kg or more. At the time of this writing, only one third-party-tested side underride guard system is known to be available for CTs that is intended to mitigate underrides and passenger compartment intrusion during an underride impact. This side underride guard is known as the AngelWing guard, manufactured by AirFlow Deflector. It is largely constructed of steel and is noted to have an off-the-shelf weight of 450 to 800 pounds depending on specific configuration (AirFlow Deflector, n.d./b; Seven Hills Engineering, LLC, 2020). In 2017 the IIHS conducted testing of the AngelWing side underride guard. In the evaluation, a midsize sedan struck the center of a 53-foot semitrailer at 35 mph. The first crash was conducted with the trailer equipped only with a fiberglass side skirt designed only to improve aerodynamics, and in the second crash the trailer had the AngelWing device installed. In the test using only the side skirt, the car struck the trailer and kept going. The impact sheared off part of the roof and the car became wedged underneath the trailer. In a similar real-world crash, the vehicle's occupants would likely have sustained fatal injuries. In the test involving the AngelWing guard, the guard bent when struck by the car, but the vehicle did not go underneath the trailer; had there been occupants in the vehicle, they would likely have sustained only minor injuries. A similar test was conducted later in 2017 at 40 mph, with similar results (IIHS, 2017b).

A similar countermeasure from Canadian firm PHSS Fortier (PHSS Fortier Lateral Protection, or LP) is comprised of belts of vinyl (PHSS Fortier, n.d.). The LP weighs approximately 540 pounds, and acts as a joint side guard and side skirt (i.e., it offers fuel economy improvements of approximately 4% over a baseline of no side skirt, but no fuel economy improvements over a baseline with a side skirt). The LP has been tested internally at impact speeds up to 35 mph (Radio Canada, 2019), but testing results equivalent to a third party such as IIHS testing are unavailable. Because the LP has only been tested up to 35 mph, it is unclear whether it would offer as much protection as the AngelWing guard, which has been tested to 40 mph. Pricing and effectiveness data for the LP are also unavailable. Thus, we do not use the LP in our analysis, other than to confirm the feasibility of side guard weights consistent with our selected lower-bound weight of 450 pounds.[1]

[1] We also examined a prototype side guard from Wabash National, which decided not to develop the device. In turn, we decided not to pursue the Wabash prototype as a representative side guard for this analysis.

**Benefits**

We calculate the benefits of equipping CT trailers with side guards in calendar year (CY) 2022 by estimating the improvement in safety (i.e., number of fatalities and serious injuries avoided) through the use of side guards (based on the known specifications of the AngelWing side guard) for all new CT trailers entering the fleet in CY 2022. In turn, we estimate the monetary equivalent of the estimated improvement in safety and multiplying these values by their corresponding estimated economic costs.

Table ES-1 summarizes the total number of fatalities and serious injuries avoided if the entire CT trailer fleet were equipped with side guards. These estimates were derived by multiplying target population estimates by the side guard effectiveness estimates.

*Table ES-1. Estimated Annual Mitigated Fatalities and Serious Injuries Due to Full Adoption of CT Trailer Side Guards*

| Underreporting Factor | Effectiveness – Fatalities | Effectiveness – Serious Injury | Mitigated Fatalities | Mitigated Serious Injuries |
|---|---|---|---|---|
| 78% | 97% | 85% | 17.2 | 69.1 |

Based on these inputs, we estimate that full adoption of CT trailer side guards would lead to an annual reduction of approximately 17 fatalities with an underreporting factor of 78 percent and 97-percent effectiveness up to 40 mph (approximately 69 serious injuries based on 85% effectiveness up to 40 mph).

For this analysis, we assume that side guard requirements would apply only to new CT trailers. We scale the estimates from Table ES-1 (i.e., representing an entire CT trailer fleet equipped with side guards) to apply to the estimated number of new CT trailers that would: (1) enter the fleet in CY 2022; and (2) be eligible to be equipped with side guards. For the purposes of this analysis, we consider the baseline number of affected trailers to be the entire CT trailer fleet, less special purpose trailers, including heavy equipment haulers, log haulers, auto transporters, livestock trailers and temporary living quarters (i.e., fifth-wheel trailers and campers). We assume that all side underrides occur in collisions with the subset of trailers considered in this analysis (e.g., there are no side underrides involving heavy equipment haulers).

We apply an estimate of 15.25 years for average CT trailer lifetimes in our calculations of lifetime impacts. This estimate reflects an assumption that CT trailers are used at constant rates (VMT per year) until they are retired from service. Thus, we project that 260,000 CT trailers that could be equipped with side guards will be sold in 2022, and that these trailers will remain in the fleet until 2038, on average. The 260,000 CT trailers represent approximately 3.9 percent of the total CT trailer fleet (260,000/6,600,000 = 0.039). Thus, on an assumption that only a negligible number of new trailers would be equipped with side guards voluntarily (if this assumption is violated, the implications of the analysis would not change, only the absolute estimates of benefits and costs), we assume that the number of fatalities and serious injuries that could be mitigated per year through the use of side guards on new CT trailers in 2022 is equal to 3.9 percent multiplied by the estimates in Table ES-1 above.

*Table ES-2. Estimated Annual Mitigated Fatalities and Serious Injuries Due to the Adoption of CT Trailer Side Guards on All Eligible New CT Trailers in CY 2022*

| Underreporting Factor | Effectiveness – Fatalities | Effectiveness – Serious Injury | Mitigated Fatalities | Mitigated Serious Injuries |
|---|---|---|---|---|
| 78% | 97% | 85% | 0.7 | 2.7 |

We estimate that equipping all new CT trailers in 2022 with side guards would lead to an annual reduction of approximately 1 (0.7) fatality with an underreporting factor of 78 percent and 97-percent effectiveness up to 40 mph (approximately 3 serious injuries at 85% effectiveness up to 40 mph).

These estimates do not account for the potential effects of advanced driver assistance technologies (ADAS) such as automatic emergency braking (AEB), blind spot detection, and lane keeping technologies, which could reduce the volume of potential side-underride crashes independently of the presence of side guards. ADAS is expected to help mitigate underrides, either through avoiding collisions (e.g., lane keep assist helping a vehicle to avoid errantly drifting in a manner increasing the probability of a collision with a trailer) or mitigating impact speed sufficiently to avoid underride within a collision (e.g., AEB reducing vehicle speed prior to impact with a trailer). If ADAS were to have any mitigating effect on side underride frequency, the target population of side underride fatalities and serious injuries relevant to this analysis would be reduced. It is also possible that AEB might reduce some higher impact speeds below the 40-mph threshold and thus increase the target population. It is not clear what the net impact would be. Note, however, that AEB is primarily effective at lower speeds, so it is likely that the net impact would be a reduction in the target population.

NHTSA does not yet have sufficient data to account for this effect, but it is reasonable to expect the proliferation of ADAS to reduce the risk of crashes that could result in side underride. That is, as the share of vehicles in the light-duty fleet equipped with ADAS increases, there would likely be fewer side underrides independently of the presence of side guards, because ADAS would help to mitigate LPV-CT collisions in at least some cases. In turn, side guards would mitigate fewer side underrides because there would be fewer to affect in any case.

Table ES-3 presents the estimated discounted lifetime safety benefits in 2020 dollars when side guards are equipped on all eligible new CT trailers in 2022:

*Table ES-3. Estimated Discounted Lifetime Safety Benefits Due to Adoption of CT Trailer Side Guards for All Eligible New CT Trailers in CY 2022 (Central Scenario, 78% Underreporting Factor, in Millions of 2020 Dollars)*

| Discount Rate | Lifetime Safety Benefits |
|---|---|
| 3% | $165.9 |
| 7% | $128.5 |

Equipping all eligible new CT trailers with side guards in 2022 is estimated to generate approximately $170 million in lifetime safety benefits each year at a 3-percent discount rate ($130 million at a 7% discount rate). This represents a benefit of approximately $640 per trailer at a 3-percent discount rate ($490 per trailer at a 7% discount rate).

These estimates do not account for the potential effects of ADAS such as AEB, blind spot detection, and lanekeeping technologies, which could reduce the volume of potential side-underride crashes independently of the presence of side guards. NHTSA does not yet have sufficient data to account for this effect, but it is reasonable to expect the proliferation of certain

ADAS to reduce the risk of crashes that could result in side underride. That is, as the share of vehicles in the fleet equipped with ADAS increases, there would likely be fewer side underrides independently of the presence of side guards, because ADAS would help to mitigate LPV-CT collisions in at least some cases. In turn, side guards would mitigate fewer side underrides because there would be fewer to affect in any case.

**Costs**

We apply information on the AngelWing as our basis for the price and weight (with supporting information from the LP and Wabash prototype on weight) of side guards sold in 2022. Initial hardware cost for the AngelWing was listed at $2,897 (with volume discounts available) at the time of data collection, which includes the side guards, cross members, mounting brackets and related hardware and installation instructions. We acknowledge that broad adoption of side guards would likely lead to considerable changes in the market for side guards, and thus it is feasible that the market would experience downward price pressure due to increasing returns to scale and competition from other potential suppliers. However, we do not have sufficient information available to project any particular impact on prices, and thus apply the unadjusted price of $2,897 for this analysis. Alternative side guard costs are considered in the sensitivity analysis.

Installation is stated to require less than 2 hours for two people (AirFlow Deflector, n.d./a). According to the Bureau of Labor Statistics (2021a), the national median hourly wage for automotive body and related repairers was $21.80 as of May 2020. The Bureau of Labor Statistics (2021b) estimates that wages represent approximately 70 percent of total employer costs for employee compensation; in turn, we estimate median total employee compensation for automotive repair workers to be $31.14 (=$21.80/0.7). We assume an average of 1½ hours per installer per trailer (to account for efficiency gains with experience and across larger operations), with two people installing side guards per trailer, or 3 labor hours per trailer; this yields a total labor cost of $93.42 per trailer (=$31.14 per hour x 3 hours per trailer). Given these figures, the total initial cost for outfitting new commercial combination trailers is shown in the following table.

*Table ES-4. Estimated Costs of Installing CT Trailer Side Guards on All Eligible New CT Trailers in 2022 (2020 Dollars)*

| | **Cost** |
|---|---|
| Side Guard Hardware Cost | $2,897 |
| Average Labor Cost per Side Guard | $93 |
| Average Cost per Trailer | $2,990 |
| **Total Cost for 260,000 Trailers (in millions)** | **$777.5** |

The average total cost of installing a side guard on a CT trailer is estimated to be $2,990. Across the estimated 260,000 new trailers that would be equipped in 2022, the total cost associated with side guard installation is estimated to be approximately $778 million. These estimated cost impacts do not include any additional costs associated with reinforcing trailers to accommodate side guards and any associated changes to trailer loading patterns. We acknowledge that any such costs, which could be substantial, would add to total hardware and installation costs. However, we do not have sufficient information available to inform an estimate of these additional costs.

The total incremental fuel cost depends on baseline fuel economy, the incremental weight increase, and the discount rate applied. With an estimated ratio of one Class 8 semi-truck per two trailers, we estimate that the equivalent of 130,000 additional trucks would carry CT trailers that were equipped with side guards in 2022.

*Table ES-5. Total Incremental Fuel Cost for Trucks Carrying Trailers with Mandatory Side Guards (Eligible New Trailers in 2022, 2020 Dollars)*

| | Weight Increase (Pounds) | Total Incremental Fuel Cost (in Millions) | | |
|---|---|---|---|---|
| | | Undiscounted | 3% Disc. Rate | 7% Disc. Rate |
| **Central Case: 40% of Eligible New CT Trailers in 2022 Equipped With Side Skirts** | **450** | **$296.3** | **$245.0** | **$195.2** |
| | **800** | **$515.4** | **$426.3** | **$339.7** |

The effects of equipping side guards on all eligible new CT trailers in 2022 on incremental lifetime fuel costs are insensitive to assumptions regarding the share of trailers equipped with side skirts. For our central analysis, requiring side guards is estimated to increase lifetime fuel costs by between approximately $250 million and $430 million at a 3-percent discount rate (between $200 million and $340 million at a 7% discount rate).

Overall cost impacts are presented in Table ES-6.

*Table ES-6. Total Lifetime Costs for CTs Hauling Eligible Trailers Equipped With Side Guards in 2022 (260,000 Trailers Equipped, in Millions of 2020 Dollars)*

| Cost Measure | 450-Pound Side Guard | 800-Pound Side Guard |
|---|---|---|
| Hardware and Installation Costs | $777.5 | $777.5 |
| Incremental Fuel Costs – 3% Discount Rate | $245.0 | $426.3 |
| Incremental Fuel Costs – 7% Discount Rate | $195.2 | $339.7 |
| **Total Costs – 3% Discount Rate** | **$1,022.5** | **$1,203.8** |
| **Total Costs – 7% Discount Rate** | **$972.7** | **$1,117.2** |

Under a side guard requirement, total costs for new trailers in 2022 are estimated to increase by between $1.02 billion and $1.20 billion at a 3-percent discount rate (between $970 million and $1.12 billion at a 7% discount rate). Incremental fuel costs represent between approximately one-fourth and two-fifths of estimated total costs, depending on side guard weight and discount rate.

Importantly, these estimated cost impacts do not include additional costs that accrue due to incremental wear and tear on equipped trailers. Side guards impose non-uniform loads on trailer floors, which adds stresses that decrease trailer lifetimes in the absence of repair. We did not identify data to aid in the estimation of these repair costs, but they are likely to be non-zero, on average. Side guards may also strike or become tangled with road structures and loading area components, leading to additional repair costs or restricted access to destinations altogether.

A related, unquantified cost involves restrictions on trailer axle configurations. The rear axles of trailers are commonly able to be moved fore and aft to adjust to loading conditions (chiefly, laden versus unladen). If side guards share a key attribute of the AngelWing – a braced structure underneath the trailer – it would be unclear how rear axles could be adjusted. Losing this capability would add to operating costs to an unknown degree.

### Net Benefits and BCRs

Net benefits represent the difference between total benefits and total costs. Similarly, BCRs represent the scale of total benefits relative to total costs. In regulatory analysis, net benefits are used as absolute measures of the returns offered by a particular policy alternative (in monetary terms), while BCRs are used as relative measures of how much better off society would be if a policy alternative were enacted. A positive value for net benefits and BCR greater than one both indicate that measurable societal benefits are higher than measurable societal costs under the policy alternative; a negative net benefit and a BCR less than one both indicate that measurable societal costs exceed measurable societal benefits.

In this analysis, the benefits are comprised of the total discounted safety impact of equipping CT trailers with side underride guards, while the costs are comprised of the hardware costs, installation costs, and incremental fuel costs associated with the added weight to trailers. Net benefits across the scenarios considered above are presented in Table ES-7.

*Table ES-7. Estimated Total Benefits, Total Costs, Net Benefits, by Scenario (Equipping 260,000 Eligible New CT Trailers With Side Guards in 2022, in Millions of 2020 Dollars)*

| **Scenario** | **3% Discount Rate** | **7% Discount Rate** |
|---|---|---|
| ***Total Benefits:*** | | |
| Central Case | $165.9 | $128.5 |
| ***Total Costs:*** | | |
| Low Cost Estimate: 450-Pound Side Guard Weight | $1,022.5 | $972.7 |
| High Cost Estimate: 800-Pound Side Guard Weight | $1,203.8 | $1,117.2 |
| ***Net Benefits (equals total benefits less total costs):*** | | |
| Low Cost Estimate, Central Case | -$856.7 | -$844.2 |
| High Cost Estimate, Central Case | -$1,037.9 | -$988.7 |

Estimated net benefits range from approximately -$1.04 billion to -$860 million at a 3-percent discount rate (from -$990 million to -$844 million at a 7% discount rate). Thus, under our central assumptions, side guards are not estimated to generate benefits greater than the corresponding costs. The sensitivity analysis presented in Section VI considers the effects of changes in cost assumptions, along with the effects of a larger target population using the upper-bound underreporting factor from the FARS-PCR analysis.

Table ES-8 presents the estimated benefit-cost ratios (BCRs), which enable an alternative comparison of the relative benefit across scenarios:

*Table ES-8. Estimated BCRs by Scenario*

| **Scenario** | **3% Discount Rate** | **7% Discount Rate** |
|---|---|---|
| Low Cost Estimate, Central Case | 0.16 | 0.13 |
| High Cost Estimate, Central Case | 0.14 | 0.12 |

For the central analysis, the estimated BCRs are between approximately 0.12 and 0.16 (i.e., total benefits are estimated to be between one-eighth and one-sixth of total costs).

### Cost-Effectiveness

Cost-effectiveness represents a measure of the average monetary cost per unit of change (benefit). In regulatory analyses for safety policies, cost-effectiveness generally measures the average estimated change in total costs per unit improvement in safety (e.g., cost per life saved). A policy alternative can be considered cost-effective if the estimated cost per unit increase is less than an appropriate benchmark. For example, a proposed safety standard could be considered cost-effective if the average cost per life saved equivalent (i.e., combining lives saved and injuries avoided, weighted by the relative values of injuries to fatalities) under the proposed standard were less than the comprehensive economic cost of a fatality (approximately $12 million in 2020 dollars). That is, the proposed standard would yield safety benefits at a lower cost than the benchmark value for those benefits.

In this analysis, CT trailer side guards can be considered cost-effective if the estimated lifetime cost per side guard is less than an appropriate benchmark. Thus, CT trailer side guards would be cost-effective if the estimated average cost per incremental fatality equivalent is less than the comprehensive economic cost of a fatality. Cost-effectiveness is calculated in this analysis by dividing total lifetime discounted costs by equivalent lives saved. Equivalent lives saved are equal to the total discounted safety benefits divided by the comprehensive economic cost of a fatality (e.g., if the estimated safety benefits for injury mitigation were equal to 10 times the comprehensive economic cost of a fatality, the injury mitigation benefits would be represented as equivalent to 10 lives saved). Alternatively, one can represent equivalent lives saved as equal to: (the sum of discounted lives saved) + (the sum of injuries avoided, weighted by the relative values of injuries to fatalities).

Cost-effectiveness estimates for the scenarios considered above are presented in Table ES-9.

*Table ES-9. Estimated Cost-Effectiveness by Scenario (in Millions of 2020 Dollars per Equivalent Life Saved)*

| Scenario | 3% Discount Rate | 7% Discount Rate |
|---|---|---|
| Low Cost Estimate, Central Case | $73.5 | $90.3 |
| High Cost Estimate, Central Case | $86.6 | $103.7 |

Consistent with the above comparisons of benefits and costs, the estimated measures of costs per equivalent life saved are six to nine times larger than the $12 million estimated comprehensive economic cost of a fatality.

### Sensitivity Analysis

The analytical inputs specified in the central analysis (i.e., underreporting factor, hardware cost, changes in CT travel demand due to capacity constraints associated with side guards, side guard effectiveness) are the best representations of these values NHTSA could develop based on available information. There is uncertainty in the analytical inputs, however. In this sensitivity analysis, we explore alternative values for these inputs to identify the extent to which the relationship between benefits and costs associated with a side guard requirement changes as the inputs change.

The estimated benefits of requiring CT side guards are affected by assumptions on the underreporting factor, changes in CT travel demand due to capacity constraints associated with side guards, and side guard effectiveness. The corresponding estimated costs are affected by assumptions on hardware cost and changes in CT travel demand due to capacity constraints associated with side guards. The values selected for inputs in the sensitivity analysis are likewise based on the range of available information. For cases where we did not have a justification for a specific value to test (e.g., changes in VMT), we exercised engineering judgment.

Increasing the assumed underreporting factor from 78 percent to 155 percent yields the following estimates of lifetime safety benefits:

*Table ES-10. Estimated Discounted Lifetime Safety Benefits Due to Adoption of CT Trailer Side Guards for All Eligible New CT Trailers in CY 2022 (by Equipped Cohort, Sensitivity Case With 155% Underreporting Factor, in Millions of 2020 Dollars)*

| Discount Rate | Lifetime Safety Benefits |
|---|---|
| 3% | $238.1 |
| 7% | $184.5 |

Equipping all eligible new CT trailers with side guards in 2022 is estimated to generate approximately $240 million in lifetime safety benefits each year at a 3-percent discount rate with an underreporting factor of 155 percent ($180 million at a 7% discount rate). This represents a benefit of approximately $920 per trailer at a 3-percent discount rate ($710 per trailer at a 7% discount rate). Consistent with the estimated annual impacts, these estimates are approximately 44 percent larger than the corresponding estimates at a 78-percent underreporting factor.

Thus, after applying the highest potential underreporting factor derived from the FARS-PCR review, benefits increase relative to our central case, but are still much lower than estimated costs.

NHTSA does not have sufficient information to estimate the impact of a side guard requirement on CT travel demand (i.e., the increase in vehicle miles traveled [VMT] due to capacity or operating constraints associated with the use of side guards). Using the information cited in Section IV.C. as a guide (i.e., less than 10% of CT loads are above 73,000 pounds), here we consider a sensitivity case in which CT VMT increases by 5 percent under a side guard requirement. The estimated impacts of this change in VMT are not constant over time. That is, during the first years of a side guard requirement, much of the additional VMT could be accommodated by legacy CTs that are not equipped with side guards. In later years, most or all of the additional VMT would be accommodated by CTs that are equipped by side guards, due to a steady increase in the share of CTs with side guards over time.

For this sensitivity analysis, we assume that: in the first year of a side guard requirement, 90 percent of incremental CT VMT would involve CTs that are not equipped with side guards; and that by 2038, all incremental CT VMT would involve CTs that are equipped with side guards. We assume no other changes in CT travel demand. Under these assumptions, the estimated annual safety benefits of a side guard requirement would be approximately 5 percent to 9.5 percent, or approximately $360,000 to $690,000 lower. This is not a large effect relative to the other elements considered in the sensitivity analysis, but it does demonstrate how operational constraints could lead to constraints on safety benefits.

In the central analysis, we assume that side guards would be sold at the assumed baseline price for the AngelWing side guard, $2,897 per unit. Under a side guard requirement for all new CT trailers, it is reasonable to expect at least some degree of downward price pressure due to factors such as competition and manufacturing efficiencies (i.e., economic returns to scale). NHTSA does not have sufficient information to assume any particular level of price reduction for side guards if they were required; rather, for this sensitivity case, we consider a 20-percent reduction in hardware costs, to $2,318 per unit (a reduction of $579 per unit).

*Table ES-11. Estimated Costs of Installing CT Trailer Side Guards on All Eligible New CT Trailers in 2022 (Sensitivity Case: 20% Reduction in Hardware Costs, 2020 Dollars)*

| | **Cost** |
|---|---|
| Side Guard Hardware Cost | $2,318 |
| Average Labor Cost per Side Guard | $93 |
| Average Cost per Trailer | $2,411 |
| **Total Cost for 260,000 Trailers ($ mil.)** | **$626.9** |

A 20-percent reduction in hardware costs would reduce annual hardware costs by an estimated $151 million to $603 million. With no assumed change in installation costs ($93 per trailer), total annual hardware and installation would be an estimated $626.9 million, versus $777.5 in the central analysis.

Returning to the theme of potential changes in CT VMT discussed in Section VI.A., we consider a sensitivity case in which CT trailer VMT increase by 5 percent due to capacity and operational constraints under a side guard requirement. Compared to the safety impacts of this change, the potential cost impacts are more complex. Not only are there fuel consumption impacts to consider, but also all other relevant operational costs (e.g., driver wages, incremental maintenance, administration).

While the central analysis focuses on incremental costs of carrying new side guard mass across all VMT, the additional fuel cost impacts in this sensitivity case involve the incremental costs of carrying all CT mass – side guard included – across the 5 percent increment of VMT. The resulting estimates of incremental fuel costs dominate all other impact measures in both the central analysis and the sensitivity analysis: If a side guard requirement led to a 5-percent increase in CT VMT, the lifetime fuel costs associated with the increase in VMT are estimated to be approximately $2.5 billion at a 3-percent discount rate ($2.0 billion at a 7% discount rate). This represents a fuel cost impact approximately 5 to 10 times as large as the incremental fuel costs associated with side guard weight.

Furthermore, additional CT VMT would necessitate additional operating costs that do not apply to the baseline CT VMT considered in the central analysis. According to Williams and Murray (2020), fuel costs represented approximately one-fourth of total average marginal trucking costs from 2015 to 2019. Based on this relationship, the total lifetime operational cost impacts (less Federal and State fuel taxes) for a given year of CT trailers associated with a 5-percent increase in CT VMT would be estimated to be on the order of $10 to $15 billion, depending on the discount rate. These estimates are purely speculative but underscore the potential for operational cost impacts to outweigh potential safety impacts by a wide margin.

With the estimates above, we are able to examine the sensitivity cases introduced in this section. The results are summarized in the following table.

*Table ES-12. Estimated Total Benefits, Total Costs, Net Benefits, by Sensitivity Case (Equipping 260,000 Eligible New CT Trailers With Side Guards in 2022, in Millions of 2020 Dollars)*

| Sensitivity Case | 3% Discount Rate | 7% Discount Rate |
|---|---|---|
| ***Total Benefits:*** | | |
| *Central Case: 78% Underreporting Factor* | *$165.9* | *$128.5* |
| 155% Underreporting Factor | $238.1 | $184.5 |
| ***Total Costs:*** | | |
| *Central Case: 450-Pound Side Guard* | *$1,022.5* | *$972.7* |
| *Central Case: 800-Pound Side Guard* | *$1,203.8* | *$1,117.2* |
| 20% Lower Hardware Costs, 450-Pound Side Guard | $871.9 | $822.1 |
| 20% Lower Hardware Costs, 800-Pound Side Guard | $1,053.2 | $966.5 |
| 20% Lower Hardware Costs, 450-Pound Side Guard, 5% Increase in VMT | $3,322.3 | $2,774.4 |
| 20% Lower Hardware Costs, 800-Pound Side Guard, 5% Increase in VMT | $3,512.6 | $2,926.1 |
| 450-Pound Side Guard, 5% Increase in VMT | $3,472.9 | $2,925.1 |
| 800-Pound Side Guard, 5% Increase in VMT | $3,663.3 | $3,076.7 |
| ***Net Benefits for Selected Sensitivity Cases (equals total benefits less total costs):*** | | |
| *Central Case: 450-Pound Side Guard* | *-$856.7* | *-$844.2* |
| *Central Case: 800-Pound Side guard* | *-$1,037.9* | *-$988.7* |
| 155% Underreporting Factor, 450-Pound Side Guard | -$784.4 | -$788.3 |
| 155% Underreporting Factor, 800-Pound Side Guard | -$965.7 | -$932.7 |
| 78% Underreporting Factor, 20% Lower Hardware Costs, 450-Pound Side Guard | -$706.0 | -$693.6 |
| 78% Underreporting Factor, 20% Lower Hardware Costs, 800-Pound Side Guard | -$887.3 | -$838.0 |
| 155% Underreporting Factor, 20% Lower Hardware Costs, 800-Pound Side Guard | -$815.0 | -$782.0 |
| Best-Case Scenario: 155% Underreporting Factor, 20% Lower Hardware Costs, 450-Pound Side Guard | -$633.8 | -$637.6 |

In all sensitivity cases (including additional permutations of the benefit and cost measures in the above table), net benefits are negative. In the best-case scenario across the assumptions considered (i.e., 155% underreporting factor and 20% lower hardware costs), estimated lifetime net benefits for an entire cohort of new CT trailers are approximately -$630 million at a 3% discount rate (-$640 million at a 7% discount rate). Across the sensitivity cases considered, hardware costs tend to be the predominant driver of negative net benefits, but the effect of side guard weight on incremental fuel costs is also a critical factor. Allowing for incremental CT travel due to operational constraints associated with side guards would compound incremental fuel cost impacts considerably, making fuel consumption the primary cost consideration.

### Summary

The cost-benefit analysis presented in this document indicates that equipping CT trailers with side underride guards would mitigate fatalities (and would likely also mitigate serious injuries) in LPV occupants associated with side underrides, but that the costs of doing so would exceed the benefits conditional on the assumptions and data limitations in the analysis. Equipping a new trailer with side guards is estimated to generate approximately $640 in lifetime discounted safety benefits at a 3-percent discount rate under the central range of assumptions evaluated (approximately $490 per trailer at a 7% discount rate).

These estimates reveal that one equivalent life would be saved (at a value of approximately $11.9 million) per approximately 18,700 trailers at a 3-percent discount rate under the central assumptions (per approximately 24,100 trailers at a 7% discount rate). The total discounted lifetime costs of equipping new trailers with side guards are estimated to be between approximately $3,930 and $4,630 per trailer at a 3-percent discount rate (between approximately $3,740 and $4,300 per trailer at a 7% discount rate), or six to eight times as large as the corresponding estimated safety benefits.

The analysis considered a range of input assumptions to account for uncertainty in the size of the target population, hardware costs, and fuel consumption impacts. Across all combinations of input assumptions considered, the estimated costs of equipping trailers with side guards exceed the estimated benefits. There is uncertainty in the assumptions that could lead to higher benefit estimates in light of additional information. The target population of fatalities and serious injuries could increase if: (1) the baseline level of relevant fatalities and serious injuries is much larger than estimated based on the FARS data and the PCR review; or (2) CT trailer side guards had some protective effect at impact speeds above 40 mph. The PCR review offered a thorough analysis of one year's LPV-CT crashes that could have resulted in side underride at impact speeds up to 40 mph, and established a meaningful estimate of the rate of underreporting side underrides in FARS. By basing our estimated target population on the underreporting factor from the PCR review, we are confident that we have represented the target population accurately. Furthermore, the sensitivity analysis allowed for a much larger underreporting factor, and found that the estimated benefits were still much smaller than the estimated costs associated with a side guard requirement.

Because side underride occurs predominantly at impact speeds above 40 mph, protective effects above 40 mph could generate a large incremental improvement above the safety benefits estimated in this analysis. However, we do not have information available on the degree to which side guards may offer a safety improvement beyond their 40-mph test limit. As such, any estimated benefits above 40 mph would be purely speculative. Similarly, the results of this study reflect existing side guard designs. It is possible that future designs may: mitigate side underride at higher speeds (increasing safety benefits); have lower hardware costs (reducing lifetime costs); or weigh less (reducing lifetime costs). However, we do not have any data to support assuming these characteristics in place of our baseline assumptions.

There are also unquantified factors that would be expected to reduce net benefits further. As discussed above, the safety benefits may be smaller than estimated due to decreases in crash risks associated with ADAS (e.g., reduced frequency of impacts with trailers due to technologies such as blind spot monitoring and lane keep assist, reduced impact speeds due to AEB), leading to a smaller baseline level of side underride fatalities and serious injuries. Cost impacts may also be larger than estimated due to: incremental travel due to axle weight and space constraints (e.g., loss of carrying capacity due to the presence of reinforcing structure may shift some cargo to new truck trips that would not otherwise have taken place); and incremental operating costs associated with repair due to trailer damage caused by the use of side guards (e.g., wear and tear associated with additional overall weight and additional stresses around reinforcing structure).

The analysis in this document supports the value of mitigating LPV-CT trailer crashes and resulting fatalities and serious injuries. The central finding is not that there is no safety issue, but rather that a hardware-based solution presents logistical barriers due to hardware costs and the expected weight of side guards. Based on the this, we conclude that alternative approaches to mitigating LPV-CT trailer crashes warrant further attention. As a focal example, ADAS represents a countermeasure that could reduce the frequency of LPV-CT trailer crashes, fatalities, and serious injuries.

# I. Introduction

## A. Background

A side underride occurs in a collision where the front end of a vehicle strikes the side of another (generally larger or taller) vehicle, and slides under the chassis of the side-struck vehicle. Underride is a possible outcome when a smaller vehicle strikes the side of a larger vehicle such as a single-unit truck (SUT) and trailer, which generally have a higher ride height than a passenger car. In some severe underride crashes, the sides of the trailers enter the passenger compartments of light-duty vehicles. This condition is called passenger compartment intrusion (PCI). PCI collisions can result in passenger vehicle occupant injuries and fatalities when the occupant of a light-duty vehicle strikes the side of the trailer. However, underride can be mitigated if the front end of the smaller vehicle in a side crash engages the structural elements of the side of a larger vehicle. When an underride is prevented, the occupants of the striking vehicle are potentially subjected to reduced injury and fatality risks due to the lack of PCI (i.e., consistent with frontal collisions not involving PCI).

Federal Motor Carrier Safety Regulation (FMCSR) 49 CFR 393.86(b), Rear Impact Guards and Rear End Protection, has been in effect since 1953. This regulation requires a heavy truck engaged in interstate commerce be equipped with a rear-end device designed to prevent underride in the event of a rear-end collision by a passenger car, light truck, or light-duty van.

In 1996 NHTSA published FMVSS Nos. 223 and 224; both standards went into effect in 1998. These standards were intended to reduce injuries and fatalities resulting from the collision of passenger vehicles into the rear ends of heavy trailers and semi-trailers. FMVSS No. 224 established the requirement that most new trailers and semi-trailers with GVWRs over 10,000 pounds be equipped with rear underride guards, while FMVSS No. 223 specifies the performance requirements of such guards (49 CFR Part 571, 1996).

A similar regulation had been considered in 1991 during the preliminary regulatory evaluation for rear underride guards; at that time side underride guards were found not to be cost-effective (NHTSA, 1991). More recently, the IIHS and other consumer advocate groups have petitioned NHTSA to reconsider similar requirements for side-underride guards for heavy trucks. These groups have pointed to serious injuries and fatalities resulting from side-underride collisions of LPVs with heavy SUTs and CTs.

On July 10, 2014, NHTSA published a grant of a petition for rulemaking submitted by Marianne Karth and the Truck Safety Coalition to improve underride crash protection. NHTSA stated in the notice that it was granting the petitioners' request with respect to rear impact guards and would initiate rulemakings on this issue. NHTSA also noted that it was still evaluating the petitioners' request to improve side guards and front override guards and would issue a separate decision on those aspects of the petitions at a later date.

According to data from FARS, an average of 212 fatalities per year resulted from front-to-side crashes of LPVs with heavy trucks from 2008 to 2017. Many of these fatalities occurred at impact speeds above the maximum speed that side underride guards have been successfully demonstrated to prevent underride (40 mph).

With respect to rear impact guards, NHTSA published an Advanced Notice of Proposed Rulemaking on July 23, 2015 (49 CFR Part 571, 2015) requesting comment on NHTSA's estimated cost and benefits of requirements for underride guards on SUTs, and for retroreflective material on the rear and sides of the vehicles to improve the conspicuity of the vehicles to other motorists. Additionally, NHTSA published a notice of proposed rulemaking (NPRM) on December 16, 2015 (NHTSA-2015-0118, RIN: 2127-AL58) proposing to adopt requirements of Transport Canada's standard for underride guards on trailers, which require rear impact guards to provide sufficient strength and energy absorption to protect occupants of compact and subcompact passenger cars impacting the rear of trailers at 56 km/h (35 mph).

NHTSA studied side underride crashes between LPVs and CTs, within an initial analysis of a side-underride guard system designed to mitigate the effects of an LPV with a GVWR of 10,000 pounds or less colliding with the side of the trailer of a CT with a GVWR up to 80,000 pounds. In such cases, the focus of the analysis reviewed in this document, side underride occurs when the front of an LPV slides under the side of the CT trailer. In the most detrimental cases, trailer design allows the LPV to underride so far that the trailer's side crushes the striking vehicle's A-pillars, windshield, or roof area and allows it to enter the passenger compartment intrusion.

A side underride guard system (i.e., side guards) is designed to minimize or prevent PCI. In this cost-benefit analysis, we evaluate the potential safety benefits that side guards would offer through mitigated underride fatalities and serious injuries in front-to-side LPV-CT collisions, and compare these benefits to the costs of purchasing, installing, and traveling with side guards over the lifetime of a CT trailer. To achieve this, we: (1) project the number of side underride fatalities that could be mitigated through the use of side guards; (2) estimate the share of fatalities and serious injuries identified in (1) that would be mitigated through the use of side guards; (3) estimate side guard hardware and installation costs; and (4) estimate the incremental fuel consumption that would be associated with the additional weight of side guards, given potential improvements to CT fuel economy over the lifetime of a CT trailer.

In addition to hardware, installation, and fuel costs, there are likely to be incremental CT repair costs associated with side guard usage due to additional stress placed on trailers by side guards. NHTSA does not have sufficient information on these costs to quantify them, but repair costs may represent an important share of overall cost impacts. Furthermore, for cases where the incremental mass and volume of side guards and their supporting structure restrict a CT's ability to carry a desired volume of cargo, the use of side guards would lead to incremental CT trips, with large incremental fuel costs and negative safety impacts. NHTSA does not have sufficient information on impacts associated with decreased cargo capacity to quantify them in this analysis, but we acknowledge that these impacts could increase the costs and decrease the benefits of side guards considerably.

The GAO (2019) report on underrides noted that single-unit trucks (i.e., rigid or straight trucks) are disparate in structure, making it difficult to develop a standard and corresponding technology to mitigate underrides involving SUTs. The report added that an industry expert they consulted was unaware of any plans to manufacture underride guards for SUTs due to how much SUTs vary in structure. Furthermore, the report confirmed that underride fatalities involving SUTs are less common than corresponding cases involving CTs, despite the fact the SUTs represent the majority of the heavy-vehicle fleet. Thus, CT trailers represent the most meaningful opportunity to evaluate the relative benefits of implementing a design standard for side underride protection that would be applied to a significant and relatively homogeneous component of the heavy vehicle fleet. For these reasons, this analysis focuses on CT trailers rather than including SUTs.

## B. Information and Actions Resulting in the Agency to Reevaluate Side Underride Protection Requirements

### *B.1 2017 Insurance Institute for Highway Safety Testing*

In 2017 the IIHS conducted testing of a device designed to protect against side underrides, known as the AngelWing manufactured by AirFlow Deflector (IIHS, 2017a). In the evaluation, a midsize sedan struck the center of a 53-foot semitrailer at 35 mph. The first crash was conducted with the trailer equipped with a fiberglass side skirt designed only to improve aerodynamics, and in the second crash the trailer had the AngelWing device installed. In the test using only the side skirt, the car struck the trailer and kept going. The impact sheared off part of the roof, and the car became wedged underneath the trailer. In a similar real-world crash, the vehicle's occupants would likely have sustained fatal injuries. In the test involving the AngelWing guard, the guard bent when struck by the car, but the car did not go underneath the trailer. This allowed the seat belt and air bags to restrain the test dummy; in a real-world crash, occupants of the LPV would likely have sustained only minor injuries. A similar test was conducted later in 2017 at 40 mph, with similar results (IIHS, 2017b).

### *B.2 2013 University of Michigan Transportation Research Institute Study for NHTSA*

A University of Michigan Transportation Research Institute study used data from the 2008-2009 Large Truck Crash Causation Survey (LTCCS) to examine 411 heavy truck-passenger vehicle crashes for front- or side-underride involvement. The LTCCS included a limited sample of serious crashes for which detailed investigations were available. Some underride was identified in 53.9 percent of these crashes, and PCI was found in 44.2 percent. In particular, passenger vehicle impacts with the side of the trailer involved underride 68.9 percent of the time, with passenger compartment intrusion occurring 48.5 percent of the time (Blower & Woodroofe, 2013).

# II. Safety Problem

NHTSA, the Government Accountability Office, the Federal Motor Carrier Safety Administration (FMCSA), and other agencies have been conducting research for better understanding of underride crashes (Morgan, 2001; Blower et al., 2012; Blower & Woodrooffe, 2013; Padmanaban, 2013; Bligh et al., 2018). An underride crash occurs when an LPV slides under a heavy truck, including a CT. These crashes involve an elevated risk of LPV compartment intrusion and, in turn, occupant fatalities and serious injuries. The proposed mandatory installation of side underride guards on CTs could prevent underrides in LPV-CT collisions, and thereby reduce occupant fatalities and serious injuries. The effectiveness of side underride guards in mitigating underride crashes will be studied in the context of this analysis. Data sources used for this study included agency crash databases such as FARS, National Automotive Sampling System, General Estimate System (NASS-GES) and Crashworthiness Data System (NASS-CDS), and CRSS.

This section presents findings from NHTSA analyses of side-underride crashes involving CTs and LPVs, to define the scale of fatalities and injuries that could be affected by the use of side guards on CT trailers (i.e., guards placed along the lower left and right of CTs to mitigate the risk of side underride). The analyses include NHTSA research on fatal LPV-CT crashes across data sources, and an in-depth review of PCRs of recent fatal LPV-CT crashes reported in FARS in 2017.

## A. FARS, GES, CRSS, and CDS Study

NHTSA recently conducted research on side-underride crashes involving CTs and LPVs to gain better understanding of side-underride crashes. NHTSA used FARS data from 2008-2017 to identify annual national counts of fatalities in side-underride crashes; only side impacts, sideswipes, and angled crashes involving one CT and one LPV were considered for this study. GES data from 2011 to 2015 and CRSS data from 2016 and 2017 provided the general patterns of occupant injuries when side-crashes between side-damaged CTs and frontal-damaged LPVs occurred. CDS data from 2006 to 2015 was used to estimate the delta V distributions associated with occupant injury severities when side-underride crashes occurred. The effects of speed limit, vehicle age, occupant age, belt use, and road surface conditions on occupant fatalities are also discussed in this analysis. The results presented in this section establish points of reference in estimating safety impacts associated with broad adoption of side underride guards.

### *A.1 Frontal- or Top-Damaged LPVs in Collisions With Side-Damaged or Undercarriage-Damaged CTs*

Table 1 shows the number of frontal- or top-damaged LPVs involved in side-underride crashes or other interaction crashes with side-damaged or undercarriage CTs, for front-side, sideswipe, and angled crashes, as reported by FARS:

*Table 1. Counts of Two-Vehicle Fatal LPV-CT Front-Side Crashes With Side or Bottom CT Damage (FARS, 2008-2017)*

| | Year | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Underride Status** | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | **Total** |
| No Underride | 134 | 147 | 155 | 126 | 157 | 156 | 154 | 144 | 146 | 153 | 1,472 |
| MOTOR VEHICLE IN TRANSPORT | | | | | | | | | | | |
| Underride With PCI | 25 | 22 | 23 | 14 | 18 | 21 | 26 | 23 | 26 | 28 | 226 |
| Underride Without PCI | 3 | 7 | 4 | 5 | 6 | 6 | 2 | 6 | 4 | 4 | 47 |
| Underride With Unknown PCI | 19 | 10 | 9 | 15 | 13 | 16 | 15 | 20 | 15 | 28 | 160 |
| MOTOR VEHICLE NOT IN TRANSPORT | | | | | | | | | | | |
| Intrusion and Vehicle Not in Motion | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Underride With Unknown PCI | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Override by Motor Vehicle in Transport | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 2 |
| Unknown | 1 | 3 | 2 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 15 |
| **Total** | **182** | **190** | **194** | **164** | **196** | **200** | **198** | **194** | **192** | **214** | **1,924** |

Among 1,924 LPVs that crashed into CT side regions in the sample (including 19 cases with vehicles not in transport), 435 (23%, including two vehicles not in transport) were involved in side-underride crashes, with 226 known PCIs. Thus, an annual average of 44 LPV-CT side underrides were reported by FARS during the 10-year period reviewed above. LPV occupant fatalities not associated with underride represent a range of impact locations for LPVs crashing with CTs, including the cab/tractor, between the cab/tractor and the kingpin/fifth wheel, and between the rear trailer wheels and the back end of the trailer. Additional LPV occupant fatalities in Table 1 are associated with impacts preceding the impact with the trailer (e.g., a crash with a vehicle other than the CT), and events following the impact with the trailer (e.g., ricochet into another vehicle, fixed object, or off-road location). A side guard would not be expected to reduce fatality risk for these events.

### A.2 LPV Occupant Injuries in Side-Underride Crashes

Side-underride crashes are associated with a high risk of severe injuries to LPV occupants in LPV collisions with CTs, and there are several factors that may contribute to occupant injuries. These factors include travel speed (or an observable proxy such as speed limit), occupant age, vehicle age, road conditions, and occupant belt use, among others. This study examined the effects of speed limit, vehicle age, occupant age, occupant belt use and road surface conditions on occupant injuries in LPV collisions with CTs that could lead to side underride.

Table 2 shows that side underrides accounted for approximately 24 percent (499) of LPV-occupant fatalities in crashes with CTs, where LPVs crashed into the side regions of CTs, CTs sustained side or undercarriage damage, and LPVs received frontal or top damage. Over half of side-underride occupant fatalities were associated with compartment intrusions (260 out of 499, with the status of intrusion unknown for another 190).

*Table 2. LPV Occupant Fatalities in LPV-CT Front-Side Crashes With Side or Bottom CT Damage (FARS 2008-2017)*

| | **Year** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Underride Status** | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | **Total** |
| No Underride | 146 | 161 | 169 | 132 | 182 | 166 | 163 | 160 | 163 | 162 | 1,604 |
| MOTOR VEHICLE IN TRANSPORT | | | | | | | | | | | |
| Underride With Compartment Intrusion | 29 | 26 | 24 | 15 | 23 | 27 | 30 | 25 | 30 | 31 | 260 |
| Underride Without Compartment Intrusion | 3 | 7 | 4 | 5 | 6 | 7 | 2 | 6 | 5 | 4 | 49 |
| Underride With Unknown Compartment Intrusion | 24 | 11 | 10 | 16 | 16 | 19 | 22 | 23 | 16 | 33 | 190 |
| MOTOR VEHICLE NOT IN TRANSPORT | | | | | | | | | | | |
| Intrusion and Vehicle Not in Motion | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Underride With Unknown Compartment Intrusion | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Override by Motor Vehicle in Transport | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 2 |
| Unknown | 1 | 3 | 2 | 3 | 1 | 1 | 2 | 1 | 1 | 1 | 16 |
| **Total** | 203 | 209 | 210 | 172 | 229 | 220 | 219 | 215 | 215 | 231 | 2,123 |

The annual level of reported fatalities in LPV-CT side underrides ranged from 36 to 68 from 2008 through 2017, with an annual average of 50 fatalities.

The patterns of occupant injury severity are distinct for occupants who experienced side-underride crashes versus occupants who did not experience side-underride crashes. Table 3 presents counts of side-underride versus no side-underride crashes.

*Table 3. Annual Average LPV Occupant Injury Severity by Underride Status in LPV-CT Front-Side Crashes With Side or Bottom CT Damage (FARS 2008-2017)*

| | Injury Severity | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Underride Status** | Not Injured | Possibly Injured | Minor Injury | Serious Injury | Fatal Injury | Injured, Unknown Severity | Unknown Injury | **Total** |
| No Underride | 1,330 | 282 | 318 | 346 | 1,604 | 6 | 8 | 3,894 |
| Underride With PCI | 210 | 27 | 28 | 45 | 260 | 3 | 2 | 575 |
| Underride Without PCI | 45 | 6 | 10 | 4 | 49 | 0 | 0 | 114 |
| Underride With Unknown PCI | 168 | 18 | 23 | 20 | 190 | 0 | 1 | 420 |
| Intrusion and Vehicle Not in Motion | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 2 |
| Underride With Unknown PCI and Vehicle Not in Motion | 1 | 0 | 4 | 0 | 1 | 0 | 0 | 6 |
| Override by Motor Vehicle in Transport | 1 | 0 | 0 | 0 | 2 | 0 | 0 | 3 |
| Unknown | 13 | 0 | 5 | 2 | 16 | 0 | 0 | 36 |
| **Total** | 1,769 | 333 | 388 | 417 | 2,123 | 9 | 11 | 5,050 |

Differences in injury severity may arise due to differences in crash energy (i.e., higher speeds are associated with both higher injury risk and higher underride risk) and risk profiles as a function of underride, independent of crash energy (i.e., the potential to experience life-threatening injuries increases under PCI).

### A.3 GES and CRSS Summary of CT and LPV Side Crashes

GES and CRSS data contain much more detailed information of injuries, minor injuries, and serious injuries associated with various types of persons, vehicles and crash types than FARS data. However, GES/CRSS provide no information of underride crashes. Nevertheless, the GES and CRSS data enable a comparison of LPV-occupant injury outcomes across crashes between side- or undercarriage-damaged CTs and frontal- or top-damaged LPVs, as shown in Table 4.

*Table 4. LPV Occupant Injury Severity by Year in LPV-CT Front-Side Crashes With Side or Bottom CT Damage (GES 2011-2015 and CRSS 2016-2017)*

| | Injury Severity | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | Not Injured | Possibly Injured | Minor Injury | Serious Injury | Fatal Injury | Injured, Unknown Severity | Unknown Injury | **Total** |
| 2011 | 25,494 | 2305 | 2891 | 726 | 73 | 910 | 528 | 32,928 |
| 2012 | 25,525 | 2334 | 1844 | 631 | 113 | 50 | 852 | 31,348 |
| 2013 | 22,868 | 2554 | 1457 | 394 | 269 | 97 | 740 | 28,380 |
| 2014 | 31,089 | 2769 | 1537 | 744 | 119 | 0 | 531 | 36,790 |
| 2015 | 34,295 | 2471 | 2196 | 495 | 25 | 201 | 1686 | 41,369 |
| 2016 | 34,995 | 1104 | 2930 | 647 | 260 | 0 | 2244 | 42,179 |
| 2017 | 37,939 | 4833 | 2456 | 861 | 118 | 0 | 1126 | 47,333 |
| **Total** | 212,205 (81.51%) | 18,369 (7.06%) | 15,311 (5.88%) | 4,498 (1.73%) | 977 (0.38%) | 1,258 (0.48%) | 7,706 (2.96%) | 260,326 |
| **Average** | 30,315 | 2,624 | 2,187 | 643 | 140 | 180 | 1,101 | 37,190 |

The FARS crash data in Table 2 indicated that the annual average of occupant fatalities of LPVs involved in crashes that could result in side underride is 212, of which approximately 24 percent were victims of side-underride crashes. Table 4 indicates that approximately 84 percent occupants were either uninjured or had unknown injury severity. Seriously or fatally injured occupants account for approximately 2 percent of cases, while occupants sustaining minor injuries or possibly injured occupants account for approximately 13 percent of cases.

## *A.4 Occupant Fatalities and Effects of Speed Limit, Belt Use, Occupant Age, Vehicle Age and Road Surface Condition*

When an LPV crashes into or under the side of a CT, several factors may contribute to the occupant injuries simultaneously. These factors include: degree of underride, crash energy (estimated in terms of delta V or speed limit), occupant age, vehicle age, road conditions, and others. This study explored the effects of these factors on occupant injuries.

### A.4.a Side Underride Fatalities as a Function of Speed Limit

Table 5 indicates that most occupant fatalities occurred under speed limits between 41 and 65 mph (i.e., travel speeds above the highest impact speed at which the IIHS demonstrated the effectiveness of the AngelWing). Travel speed is highly correlated with posted speed limits, and hence posted speed limits may serve as a useful proxy for actual travel or impact speed (for cases with no or limited pre-crash braking) and its relationship with injury severity in potential side-underride crashes.

*Table 5. LPV Occupant Fatalities in LPV-CT Collisions With Potential Side Underride, by Speed Limit and Underride Status (FARS 2008-2017)*

| Speed Limit (mph) | No Underride | Underride With PCI | Underride Without PCI | Underride With Unknown PCI | PCI and Vehicle Not in Motion | Underride With Unknown PCI and Vehicle Not in Motion | Override by Vehicle in Transport | Unknown Underride Status | Total |
|---|---|---|---|---|---|---|---|---|---|
| **Unknown** | 76 | 7 | 4 | 11 | 0 | 0 | 0 | 0 | 98 |
| **20 ~ 30** | 47 | 5 | 0 | 16 | 0 | 0 | 0 | 0 | 68 |
| **31 ~ 40** | 133 | 37 | 7 | 19 | 0 | 0 | 0 | 0 | 196 |
| **41~50** | 278 | 64 | 12 | 35 | 0 | 0 | 1 | 3 | 393 |
| **55** | 609 | 98 | 15 | 64 | 1 | 1 | 1 | 7 | 796 |
| **60** | 71 | 7 | 0 | 10 | 0 | 0 | 0 | 1 | 89 |
| **65** | 205 | 33 | 6 | 21 | 0 | 0 | 0 | 5 | 270 |
| **70** | 117 | 5 | 5 | 8 | 0 | 0 | 0 | 0 | 135 |
| **75** | 62 | 4 | 0 | 6 | 0 | 0 | 0 | 0 | 72 |
| **80** | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| **Total** | **1,604** | **260** | **49** | **190** | **1** | **1** | **2** | **16** | **2,123** |

The FARS data indicate that most side underride fatalities occur at speed limits exceeding 40 mph. Among the 260 side underride fatalities with PCI, 211 (81%) occurred at speed limits above 40 mph. Extending this comparison to the 450 side underride fatalities with observed or unknown PCI, at least 355 (79%) occurred at speed limits above 40 mph. Thus, an important share of side underride fatalities appears to involve travel speeds exceeding the maximum impact speed at which the AngelWing side guard demonstrated protection during IIHS testing. NHTSA does not have data on how well posted speed limits represent impact speeds within the FARS data. However, the police crash report review discussed in Section II.B found that the proportion of side underride fatalities occurring at impact speeds below 40 mph is estimated to be consistent with the proportion of side underride fatalities in FARS occurring on roads with posted speed limits up to 40 mph.

Approximately 8 underride fatalities per year (84 over 10 years) were reported as occurring on roads with speed limits below 40 mph. Approximately 2 reported side underride fatalities per year took place on a road with an unknown speed limit (22 over 10 years). Overall, 8 to 11 side underrides occurred per year on roads with speed limits of 40 mph or below from 2008-2017.

This indicates that the scope of side underrides for which CT trailer side guards could have a safety-enhancing effect may be restricted to an important degree. A review of police reports for FARS cases examined this relationship in further detail and is summarized in the Section II.B.

### A.4.b Effect of Restraint Use

Restraint use is extremely important for occupant safety. Table 6 indicates that at least 32 percent of occupants who died in crashes of an LPV into the side of a CT where the LPV sustained frontal or top damage and the CT sustained side or undercarriage damage failed to use restraints.

*Table 6. LPV Occupant Fatalities in LPV-CT Collisions With Potential Side Underride, by Seat Belt Use Status (FARS 2008-2017)*

| Belt Use Status | No Underride | Underride With PCI | Underride Without PCI | Underride With Unknown PCI | PCI and Vehicle Not in Motion | Underride With Unknown PCI and Vehicle Not in Motion | Override by Vehicle in Transport | Unknown Underride Status | Total |
|---|---|---|---|---|---|---|---|---|---|
| **Used Belt** | 865 | 154 | 29 | 123 | 0 | 1 | 2 | 9 | 1,183 (55.7%) |
| **Did Not Use Belt** | 547 | 70 | 15 | 46 | 1 | 0 | 0 | 4 | 683 (32.2%) |
| **Unknown** | 192 | 36 | 5 | 21 | 0 | 0 | 0 | 3 | 257 (12.1%) |
| **Total** | **1,604** | **260** | **49** | **190** | **1** | **1** | **2** | **16** | **2,123** |

This is similar to the seat belt usage behavior among side underride fatalities in the police crash report review discussed in the following section (28% unbelted).

## B. Police Crash Report Review of FARS Cases

NHTSA's above analysis of the FARS data enables comparisons of crash outcomes with and without side underride. In principle, one could use these comparisons to estimate the effectiveness of CT trailer side guards in mitigating fatalities associated with side underride. However, there is a critical limitation to the FARS data in an analysis of side guard effectiveness: The data do not include a random sample of non-fatal crashes for comparison. Rather, the data are constrained to include only cases with fatal outcomes, regardless of underride status. The analysis of the FARS data is valuable in understanding the scale of side underride fatalities and factors leading to differences in fatality and injury risk, especially potential travel speed. To extend the FARS analysis into a meaningful estimate of side guard effectiveness, it is necessary to identify two additional factors: the degree to which side underride fatalities are underreported in FARS; and evidence on the changes to fatality and injury risk that would occur when mitigating side underride for a given collision (e.g., for the same impact speed for the same vehicles). This section addresses these two factors.

### *B.1 Potential Underreporting of Side Underride Fatalities in FARS*

As noted in GAO's 2019 report on truck underride guards, previous evaluations of vehicle underride data have indicated that vehicle underride is under reported in FARS. For example, Padmanaban (2013) estimated that the actual number of underrides is approximately three times as large as the number reported in FARS. Padmanaban followed a similar process to NHTSA's review of police crash reports (PCRs) described below, in which PCRs for crashes between LPVs and CTs that could have resulted in side underride (but were not classified in FARS data as side underrides) were reviewed. However, the crash data analyzed by Padmanaban are out of date, going as far back as 1994; reporting standards for FARS records with respect to capturing side underride have improved considerably since the 1990s. Furthermore, the procedure for identifying underrides in Padmanaban does not allow for non-underrides that were incorrectly classified as underrides, which would lead to inflated estimates of underreporting. Thus, while Padmanaban's estimate of underreporting is considerably higher than NHTSA's corresponding estimate, it is likely that Padmanaban presents a higher level of underreporting than would representative of the more recent data considered in this analysis. Another recent study (Brumbelow, 2012) found a somewhat higher estimate of underreporting for side underride fatalities (a factor of 3.7), but the study was based on a very small sample.

NHTSA collected supplemental data within the "Trucks in Fatal Accidents" (TIFA) database for the years 2008 and 2009 to accurately determine rear underride crashes and the associated fatalities (Blower & Woodrooffe, 2013). NHTSA used the 2008 and 2009 TIFA and supplemental data in the December 2015 NPRM to upgrade FMVSSs No. 223, Rear impact guards, and No. 224, Rear impact protection, to determine the economic impacts of the proposal (NHTSA, 2015).

The details provided in the supplemental TIFA data for the years 2008 and 2009 enabled determining accurate annual estimates of crashes into the rear of trucks and truck-trailers resulting in vehicle underride and the number of fatalities associated with such crashes. Because TIFA is no longer operational, it is not possible to conduct a similar data collection for vehicle crashes into the side of trucks and truck-trailers. As an alternative, NHTSA conducted reviews of the PCRs to better understand the frequency of side-underride crashes and associated fatalities.

To develop a better understanding of vehicle underride into the side of trucks, NHTSA conducted a review of PCRs of all two-vehicle crashes involving a light vehicle impacting the side of a truck-trailer in 2017 FARS. The review was conducted by eight NHTSA engineers. Each case was randomly assigned to two engineers for review and a methodology was developed for the review to improve consistency.

Each reviewer analyzed each assigned PCR, which included the coded elements, PCR narrative, interviews, scene diagrams, photographs (if available), and summaries of the accident and coded the following for each case.

- Make, model, and year of the LPV and type of CT
- Impact location on the side of the CT
- Pre-collision maneuver of the LPV and CT
- Impact angle
- Impact speed
- Driver and front passenger restraint status and whether air bags deployed

- Driver and front passenger fatality status
- Number of fatalities in the light vehicle and total number of occupants in the LPV
- Whether underride and PCI occurred on the LPV
- Whether side guards on the trailer would have helped to prevent the LPV fatality

Rather than estimating specific impact speeds, which would be subject to relatively high uncertainty, the PCR review focused on whether the available evidence for a crash indicates that the crash occurred at an impact speed above 40 mph. This choice was made to align subsequent analyses, such as this benefit-cost analysis, with the expected design speed for side underride guards of 40 mph. That is, the target population includes all side underride fatalities at impact speeds up to 40 mph, and the PCR review identified the subset of side underride fatalities at impact speeds up to 40 mph with the greatest accuracy available conditional on the evidence.

The PCR review team made a determination of whether a given impact speed was above 40 mph based on: posted speed; the narrative and crash diagrams in the police report (including braking evidence); witness reports; and photographs of the vehicles and the crash scene, if available. This information was generally sufficient to assess whether a crash occurred at an impact speed above 40 mph. We acknowledge that there is uncertainty in at least some of the evidence evaluated to establish impact speed status. Travel speeds are higher than speed limits, on average, which would lead to a tendency for impact speeds in crashes without braking to be in excess of the posted speed limit. Conversely, sufficient pre-crash braking would reduce impact speeds below the speed limit. The PCR review accounted for both of these factors at the individual crash level, and thus these factors are internalized to the extent the evidence allowed in our estimation of the target population. Regarding remaining uncertainty in impact speed status, we do not have evidence that any errors are more likely to be biased in a particular direction.

Padmanaban (2013) reportedly followed a similar procedure, but the particular criteria applied to determine underride status in the PCR review are not fully known; the study cites a review of PCRs including “the narrative, scene diagram, and police officers’ information”. A key difference from the NHTSA PCR review is that Padmanaban assigned all FARS underrides as underrides, while the NHTSA review allowed for FARS underrides to be re-specified as non-underrides (4 out of 53 cases of underride reported in FARS were re-classified as non-underrides in the NHTSA PCR review).

Impact velocity was estimated using estimated speed (if available), posted speed limit, evidence of braking, and witness interviews. The assessment of whether underride occurred was based on a holistic evaluation of the information available, including type of CT and LPV, pre-impact maneuvers of the vehicles, scene diagrams, damage to the vehicles, impact location, impact angle, impact speed, and final position of the vehicles. For example, if there was evidence that, post-crash, the LPV was under the CT, or that it drove underneath the trailer and stopped on the other side, it was considered an underride. If there was evidence of top damage of the LPV or compartment intrusion, PCI was noted for the LPV. Ultimately, the determination of underride status was subjective, but the process was designed to be as objective as feasible.

The determination of underride or no underride from this review process was further evaluated by experienced special crash investigators and concurred upon. We acknowledge that there is remaining uncertainty in the designation of underride status due to incomplete information. The total number of side underrides determined in the analysis is NHTSA’s best estimate conditional on the available information. In the cost-benefit analysis detailed below, we consider the impacts of potential underestimation of total national side underrides through sensitivity analyses including scenarios with higher levels of side underrides consistent due to underreporting.

### B.2 Comparison of Reported Fatal Side Underride Crashes: PCRs Versus FARS

In 2017 there were 203 cases in FARS of a two-vehicle crash involving an LPV (with a GVWR of 10,000 pounds or less) striking the side of a CT where the LPV sustained frontal or top damage, and the CT sustained side or undercarriage damage. The PCRs for the 203 cases were requested from the States, of which NHTSA received 188 cases. Among these, 4 cases were found not to meet the established criteria[2] and so were removed from further evaluation. This resulted in a total of 184 cases that were reviewed by eight NHTSA engineers.

Among the 184 PCRs reviewed, 8.7 percent (=16/184) of impacts to the light vehicle into the truck-trailer were at an estimated impact velocity less than 40 mph (the maximum impact speed at which the AngelWing side guard demonstrated protection during IIHS testing) as shown in Table 7.

*Table 7. Number and Percentage of Crashes Among the 184 PCRs Reviewed by Impact Velocity*

| | < 40 mph | > 40 mph | Undetermined |
|---|---|---|---|
| **Crashes** | 16 (8.7%) | 152 (82.6%) | 16 (8.7%) |

About 43 percent (=79/184) of the 184 crashes were intersection crashes, and 26.6 percent (=49/184) were those where the trailers were turning left. Among the 184 cases, 92 resulted in underride. Among side underride cases identified in the PCR review, most fatalities involved crashes on roads with estimated impact speeds above 40 mph, where the LPV driver failed to stop at an intersection and struck the side of a trailer of the CT that was either traveling through the intersection or making a left turn.

About 92 percent of the 184 cases (=170/184) reviewed (LPV crashes into the sides of trailers) were with only 1 occupant fatality in the LPV; 65 percent of the fatally injured occupants in the 184 cases were restrained, which is similar to the rate of belt use among FARS cases discussed above (approximately 63% of fatalities with known restraint status were belted).

There was agreement in the coding of underride in about 70 percent of the cases (128 of the 184 cases). The PCR review indicated 92 of the 184 cases with vehicle underride while FARS coded only 52 of the cases with vehicle underride. Therefore, FARS undercounted underride by 43% (1-52/92). There were 1.77 times (=92/52) as many underrides in this set of 184 FARS cases than coded in FARS. There were 44 cases where the PCR data were coded as "underride" while FARS coded these cases as "no underride." There were 9 cases where the PCR data were coded as "unknown underride" due to lack of sufficient information available in the PCR, while FARS coded 8 of these cases as "no underride" and one case as "underride." There were no cases where the FARS coding was "unknown underride" though such a category is available.

For the cases where the PCR review indicated that underride occurred, the information was obtained from the PCR narrative, crash information and diagrams, vehicle types and vehicle damage after the crash. In most cases, photographs of the incidents were not available. The

[2] In one case, the striking vehicle was not an LPV; in two cases, the side-struck vehicle was not a heavy truck; and in one case the LPV did not strike the side of a CT.

information in the PCR could be used by the FARS analyst to determine the occurrence of underride; but based on the above analysis, it appears the FARS analyst may not have used all the information provided in the PCR (especially the narrative and scene diagrams) to determine underride status.[3] There were cases where the PCR reported that the vehicle was underneath the trailer, the vehicle went under the trailer, and the trailer wheels ran over the vehicle, or the vehicle traveled right through the trailer and there were gouge marks on the roof of the vehicle; however, the FARS analyst coded many of these cases as "no underride."

Tables 8A and 8B present a comparison of the vehicle underride coding from the PCR review and that in FARS.

*Table 8A. Distribution of Vehicle Underride Coding for the 184 Cases From the PCR Review*

| Impact Speed | Source | No Underride | Underride | Unknown Underride | Potential Underride |
|---|---|---|---|---|---|
| All | PCR Review | 83 | 92 | 9 | 92-101 |
| All | FARS | 132 | 52 | 0 | 52 |
| < 40 mph | PCR Review | 3 | 12 | 1 | 12-13 |
| < 40 mph | FARS | 11 | 5 | 0 | 5 |
| < 40 mph or Unknown | PCR Review | 10 | 18 | 3 | 18-21 |
| < 40 mph or Unknown | FARS | 21 | 11 | 0 | 11 |

*Table 8B. Distribution of Fatalities Under the Vehicle Underride Coding for the 184 Cases From the PCR Review*

| Impact Speed | Source | No Underride | Underride | Unknown Underride | Potential Underride Fatalities |
|---|---|---|---|---|---|
| All | PCR Review | 87 | 100 | 9 | 100-109 |
| All | FARS | 136 | 59 | 0 | 59 |
| < 40 mph | PCR Review | 4 | 12 | 1 | 12-13 |
| < 40 mph | FARS | 11 | 5 | 0 | 5 |
| < 40 mph or Unknown | PCR Review | 11 | 19 | 3 | 19-22 |
| < 40 mph or Unknown | FARS | 21 | 11 | 0 | 11 |

Overall, the PCR review found that at least 92 of the 184 cases involved vehicle underride of the LPV while FARS coded only 52 of the 184 cases as vehicle underride (a difference of 77 percent to 94 percent, depending on how unknown underrides are counted). A similar range of differences is found when focusing on fatalities rather than underrides (59 underride fatalities in

[3] See Appendix B for a discussion of the PCR review process.

the FARS data versus 100 to 109 fatalities in the PCR review, or **differences of 69% to 85%**, depending on how unknown underrides are counted).

The presence of cases with unknown underride status obscures the results, however. Nine cases in the PCR review had unknown underride status. Consistent with Padmanaban (2013), we assigned the unknown cases proportionally to the share of underrides among known cases for each travel speed group in Table 11B. This yielded our final estimates of underreporting factors, as shown in Table 8C.

*Table 8C. Distribution of Fatalities Under the Vehicle Underride Coding for the 184 Cases From the PCR Review – Unknown Cases Redistributed*

| Impact Speed | Source | No Underride | Underride | Unknown Underride | Underrides (with Allocated Unknowns) | Underreporting Factor |
|---|---|---|---|---|---|---|
| All | PCR Review | 87 | 100 | 9 | 104.8 | 1.78 |
| All | FARS | 136 | 59 | 0 | 59 | |
| < 40 mph | PCR Review | 4 | 12 | 1 | 12.8 | 2.55 |
| < 40 mph | FARS | 11 | 5 | 0 | 5 | |
| < 40 mph or Unknown | PCR Review | 11 | 19 | 3 | 20.9 | 1.90 |
| < 40 mph or Unknown | FARS | 21 | 11 | 0 | 11 | |

After accounting for cases with unknown underride status, we estimate that the number of side underride fatalities within the cases considered in the PCR review was 78 percent higher than reported in FARS. Of particular importance for the analysis of CT trailer side guards is the subset of crashes below 40 mph. However, the sample of such cases within the PCR review is small enough to warrant caution in applying the corresponding estimate of the rate of underreporting. The PCR review identified over twice as many underrides and underride fatalities (12.8) as FARS (5) at speeds below 40 mph. Extending this view to include cases with unknown travel speed yields similar results: 20.9 underride fatalities in the PCR review versus 11 in FARS. Overall, the PCR review of crashes at speeds below 40 mph identified 90 percent to 155 percent more fatalities than FARS.

For the analysis of safety impacts later in this document, we will focus on the estimated underreporting factor based on the full sample of crashes in the PCR review due to a preference for using a larger sample size to identify a behavior (underreporting) that is plausibly independent of travel speed. Furthermore, the full-sample value is very close to the corresponding lower-bound value for crashes below 40 mph (78% versus 90%); thus, analytical results should be relatively insensitive to the selection of the lower-bound value.

The share of side underride fatalities identified with impact speeds below 40 mph in the PCR review is consistent with the closest corresponding share in FARS based on posted speed limit. In the PCR review, 19.9 percent of fatalities (20.9 out of 104.8) are estimated to have occurred at impact speeds below 40 mph, versus 18.6 percent of fatalities in the FARS data (11 out of 59) occurring on roads with speed limits at 40 mph or below.

NHTSA is confident in the results of its PCR review and has chosen to apply the results to the central scenarios in this cost-benefit analysis. However, NHTSA also acknowledges the value of considering higher underreporting factors due to factors that could be associated with additional underreporting for this analysis. In particular, some degree of uncertainty in impact speed (e.g., lower speed at time of impact versus reported speed at the first critical event, general inaccuracy in reported speeds) could result in additional underreporting of side underrides at impact speeds at or below 40 mph. Thus, we consider the upper-bound value 155 percent for the underreporting factor from the PCR review in the sensitivity analysis presented in Section VI.

### C. Effectiveness of CT Trailer Side Guards Based on PCR-FARS Analysis

To estimate the effect of a side guard requirement on safety outcomes, it is necessary to apply an estimate of the effectiveness of CT trailer side guards in mitigating fatalities and serious injuries. The appropriate effectiveness measure for this analysis aligns with the target population in the analysis. That is, we must identify a useful measure of effectiveness in mitigating fatalities and serious injuries specifically in the types of crashes that resulted in those fatalities and injuries. The PCR review confirmed that side underrides almost always occur where a side guard would be located (i.e., between the fifth wheel/kingpin and the rear axles). The target population only includes side underrides rather than all fatalities in LPV-CT front-to-side impacts, and hence we assume that the entire target population could be affected by the use of side guards.

Following from this assumption, the remaining key qualifications to consider for side guard effectiveness are: (1) the failure rate of side guards; and (2) the latent risk of fatality and serious injury when a side guard successfully transforms what would have been an underride into what we assume to be a frontal collision. The only relevant information we have available regarding side guard failure rates is that the AngelWing has been tested successfully up to 40 mph; in turn, we assume a zero-percent failure rate in preventing underride for vehicles that strike the side guards at impact speeds of 40 mph or less. We describe our process for estimating latent fatality and serious injury risk below.

We apply a NHTSA analysis (Wang, 2021)[4] of fatality risk in frontal collisions as a function of delta V to estimate latent fatality risk for LPV-CT collisions involving side guards in our target population. That is, we acknowledge that, for at least some cases where an LPV strikes a side guard and side underride is mitigated, a fatality would still result.

The NHTSA analysis centered on logistic regressions incorporating Crashworthiness Data System (CDS) records on over 10 million occupants in frontal collisions in 2010-2015. The logistic regression for fatality risk in frontal collisions indicates that fatality risk in frontal collisions is roughly half as large as estimated by Joksch[5] in 1993. This relationship is consistent with improvements in vehicle design and the implementation of safety countermeasures during the 1990s and 2000s. Importantly, both representations of fatality risk in frontal collisions indicate that the risk of a frontal collision resulting in a fatality is: below one percent at a delta V

[4] Wang, J.-S. (2021). *MAIS (05/08) Injury Probability Curves as Functions of Delta-V*. Washington, DC: National Highway Traffic Safety Administration.

[5] Joksch, H. C. (1993). Velocity change and fatality risk in a crash: A rule of thumb. *Accident Analysis and Prevention*, *Vol. 25*, No. 1, pp. 103-4.

of 20 mph; near or below 3 percent at a delta V of 30 mph (1.3% per Wang); and near or below 10 percent at a delta V of 40 mph (6.0% per Wang).

There are two more related inputs required to map fatality risk estimates to a summary estimate to apply in this analysis, however. First, we need to identify the extent to which delta V differs from impact speed in LPV-CT trailer collisions. Second, we need to account for variability in impact speeds across the relevant collisions.
Delta V in a collision can differ from impact speed due to factors including energy absorption by the vehicle structure and induced rotation (i.e., changes in the directional component of velocity). In an evaluation of frontal-offset crashes, Nolan et al. (1998) acknowledge that delta V is equivalent to impact speed for full frontal-width collisions with rigid objects. In isolation, we find the steel structure of the AngelWing side guard to be substantially consistent with a rigid object, and thus collisions between (the entire frontal area of) an LPV into an equipped CT trailer would be equivalent to frontal-width collisions with rigid objects. However, it is reasonable that the directionality of any movement of the trailer could induce some rotation to the striking LPV. For this analysis, we maintain an assumption that delta V is equivalent to impact speed, based on observed outcomes in NHTSA analyses of crashes at speeds below 40 mph (including the PCR review). For comparison purposes, below we also present estimates of fatality risk where delta V is 80 percent of the magnitude of impact speed (i.e., 20% of the momentum of the LPV is manifested in changes to the direction of travel). The value of 80 percent was selected as an approximation of the midpoint of relevant values presented in Nolan et al.

Although we maintain the assumption that side guards would be effective in preventing side underride in collisions up to a design standard of 40 mph (i.e., the maximum impact speed at which the AngelWing was tested successfully by the IIHS), the estimates in Wang (2021) (and corroborated in Joksch, 1993) offer a physical basis quantifying how underride fatalities are more likely to occur as impact speed increases (i.e., up to, and beyond, 40 mph). For this analysis, we assume that side underride fatality risk increases with impact speed as presented in Wang, and delta V equals 100 percent of impact speed. Table 9 presents the estimated fatality risk in mitigated side underrides for different impact speeds and delta V.

*Table 9. Estimated Absolute Fatality Risk in Mitigated Side Underrides by Impact Speed (Fatality Risk Estimates From Wang, 2021)*

| **Travel Speed (mph)** | **Delta V (mph, 80% of Impact Speed)** | **Fatality Risk** | **Delta V (mph, 100% of Impact Speed)** | **Fatality Risk** |
|---|---|---|---|---|
| 5 | 4 | 0.0% | 5 | 0.0% |
| 10 | 8 | 0.0% | 10 | 0.0% |
| 15 | 12 | 0.1% | 15 | 0.1% |
| 20 | 16 | 0.2% | 20 | 0.3% |
| 25 | 20 | 0.3% | 25 | 0.6% |
| 30 | 24 | 0.5% | 30 | 1.3% |
| 35 | 28 | 1.0% | 35 | 2.8% |
| 40 | 32 | 1.8% | 40 | 6.0% |
| *45* | *36* | *3.3%* | *45* | *12.2%* |
| *50* | *40* | *6.0%* | *50* | *23.4%* |
| **Estimated Mean Risk (0-40 mph)** | | **0.9%** | | **3.0%** |

There is a threshold amount of kinetic energy required for a given LPV-CT collision to result in side underride. Kinetic energy increases quadratically with velocity. Thus, underrides are increasingly more likely to take place as impact speeds increase; for the range of impact speeds considered in this analysis, underrides are more likely to occur closer to 40 mph than 0 mph. In turn, underrides mitigated by side guards would essentially become frontal collisions at speeds closer to 40 mph than 0 mph.

This relationship is represented in our estimation of the mean latent fatality risk in mitigated side underrides. Information on the distribution of impact speeds in our target population is limited (i.e., we have confidence in the maximum impact speed of 40 mph, but do not have direct knowledge about the relative frequencies of other impact speeds). In the absence of further information on impact speeds, we estimate the average fatality risk among mitigated side underrides in our target population to be equal to one-half of the corresponding fatality risk in a 40-mph impact (i.e., a 3.0% average risk based on a 6.0% risk at 40 mph and no risk at 0 mph). Wang's analysis offers a meaningful basis to confirm whether this assumption is consistent with the expectation that side underride fatalities are more likely to occur closer to 40 mph than to 0 mph, by identifying the delta V in Wang's analysis associated with the estimated mean risk. In this case, the estimated mean risk of 3.0 percent at a delta V equal to impact speed represents an average impact speed of between 35 and 36 mph. Repeating the process for an alternative assumption of delta V equal to 80 percent of impact speed yields a similar result, with an average estimated risk of 0.9 percent corresponding to an average estimated impact speed of approximately 34 mph. Thus, we confirm that our estimated mean fatality risk is consistent with a target population in which fatal side underrides have impact speeds that are generally clustered between 30 and 40 mph.

A second factor to account for in estimating side guard effectiveness within our target population of crashes is seat belt usage. Based on the 2010-2015 NOPUS and NHTSA's BELT USE regression model, approximately 69 percent of occupants killed in all fatal crashes are estimated to have been restrained by seat belts during the years evaluated in Wang (2021), Applying Kahane's (2015) estimate that unbelted occupants are approximately twice as likely as belted occupants to die in frontal collisions, we estimate that our overall estimate of 3.0% fatality risk in mitigated side underrides represents a 2.3% risk for the 69 percent of belted occupants in the CDS data, and a 4.6% risk for the 31 percent of unbelted occupants. The PCR review confirmed that approximately 72 percent of occupants killed in side underrides were restrained by seat belts, which is close to the 69 percent share in the CDS data. In turn, substituting a 72-percent belted share from the PCR review in place of the 69-percent share from the CDS analysis does not change the overall estimate of a 3.0% fatality risk in mitigated side underrides.

We subtract the estimated fatality risk in mitigated side underrides to yield our estimate of side guard effectiveness, **97% effectiveness in mitigating fatalities in our target population**. For the broader set of LPV-CT front-to-side impacts resulting in fatalities, side guards would be estimated to be considerably less effective, because of the large share of such impacts that occur where a side guard would not be located.

Repeating this process for serious injuries (e.g., traumatic, but non-fatal, injuries associated with PCI), we weight the corresponding injury risk curves for MAIS3, MAIS4, and MAIS5 injuries from Wang (2021) by their frequency in 2011-2015 General Estimates System (GES) data: 73 percent, 19 percent, and 8 percent, respectively. This yields an estimated 15-percent risk of serious injury in mitigated side underrides, and thus an estimated **85% effectiveness in**

**mitigating serious injury in our target population**. This represents a general relationship for safety countermeasures in which effectiveness in mitigating injuries is lower than effectiveness in mitigating fatalities.

It is highly plausible that a considerable share of mitigated side underride fatalities and serious injuries would result in minor injuries instead, rather than no injuries at all. Thus, it is feasible that side guards could mitigate fewer minor injuries than the minor injuries that would arise when mitigating fatalities and serious injuries. Hence, we assume no net effect of CT trailer side guards on minor injuries. However, the costs associated with minor injury are much lower than the corresponding costs of fatalities and serious injuries, and thus estimates of safety benefits are insensitive to the role of minor injuries.

# III. Benefits

As reviewed above, the predominant safety issue is the extent to which fatalities in LPV-CT collisions resulting in side underride, especially those resulting in PCI, could be mitigated through the use of CT trailer side guards. PCI is associated with high rates of injury and fatality for occupants of LPVs, due to both the dangerous nature of PCI itself, along with the higher levels of energy that may be associated with crashes with PCI (i.e., the higher the speed of impact, the more likely PCI is to occur and the more dangerous the impact, in general). The benefits of requiring installation of side impact guards on CT trailers are defined in this analysis as the decrease in occupant fatalities and injuries in LPVs resulting from the use of side guards. To estimate the benefits of requiring CTs to be equipped with side impact guards, we estimated the annual number of occupant fatalities and injuries in LPVs that experience underrides when crashing into the side of CTs at impact speeds up to 40 mph, and then multiplied these estimates by our estimated measure of side guard effectiveness in mitigating fatalities and serious injuries. The resulting estimates represent the number of mitigated side underride fatalities and serious injuries in impacts at speeds less than or equal to 40 mph. A sensitivity analysis also considers scenarios where the target population of crashes is based on a higher underreporting factor of 155 percent.

## A. Target Population

### *A.1 Fatalities*

From 2008 to 2017 FARS reported 1,924 LPVs involved in fatal crashes into the sides of CTs, for an annual average of 192 crashes. Among these total crashes, 435 LPVs were involved in side-underride crashes, for an annual average of 44 crashes. Among these fatalities, 84 were reported as occurring on roads with speed limits below 40 mph (8.4 per year, on average). Another 22 reported side underride fatalities per year took place at unknown speed limits (2.2 per year, on average). Overall, FARS reports that 8 to 11 side underrides occurred per year on roads with speeds limits of 40 mph or below from 2008 to 2017.

The target population of fatalities considered for estimating benefits in this analysis includes all LPV-occupant fatalities in front-to-side crashes with CTs on roads with speed limits up to 40 mph that result in side underride. In estimating benefits, we assume that side impact guards would mitigate fatalities and injuries (with an estimated effectiveness of 97% for our target population) in LPV impacts into the sides of CTs at impact speeds up to 40 mph, consistent with the design standard for AngelWing side guards.

The 8-to-11 annual average fatalities described above do not represent the full target population, due to the underreporting issue discussed in Section II.B. For the central analysis, we identified a possible range of underreporting factors and chose to apply a value of **78 percent (i.e., we assume that the true number of relevant side underride fatalities is equal to 1.78 times the baseline value from FARS).** For the sensitivity analysis, we consider a higher value of 155 percent using the upper bound measure from the FARS-PCR review, to reflect the potential for additional underreported underride fatalities that could be mitigated by side guards.

The FARS data and PCR reviews confirmed the estimated low share of total side underrides involving estimated travel speeds of 40 mph or below. The PCR review estimated that only 19.9 percent of side underride fatalities in the review occurred at impact speeds below 40 mph.

Similarly, across the review of FARS records of side underrides with reported speed limits, only 18 percent of side underrides involved travel on roads with speed limits of 40 mph or below (to gauge the predominant share of fatalities at highway and freeway travel speeds, only 35% involved reported travel speeds of 50 mph or below). While these estimates are close to one another, we prefer the value from the PCR review, because: (1) the review involved expert determination of impact speed status above or below 40 mph; and (2) the estimate based on FARS data focuses on posted speed limits rather than impact speed.

Taking these factors into account, we estimate our target population of annual side underride fatalities at impact speeds up to 40 mph to be equal to: the annual average of all side underride fatalities in the 2010-19 FARS data (50), multiplied by the estimated share of side underride fatalities below 40 mph from the PCR review (19.9%), multiplied by the estimated underreporting factor (1.78), or 17.7 fatalities. Note that, for sensitivity analysis, we also consider an alternative target population value of 25.4 annual fatalities (=50*0.199*2.55) using the 155-percent underreporting factor.

*Table 10. Estimated Target Population of Annual Fatalities in Side-Underride Crashes at or Below 40 mph*

| Measure | Fatalities |
|---|---|
| All LPV-CT Front-Side Crashes (from FARS) | 212 |
| LPV-CT Side Underrides (from FARS) | 50 |
| Share of LPV-CT Side Underrides at Impact Speeds Below 40 mph (from PCR Review) | 19.9% |
| **Target Population: LPV-CT Side Underrides, 40 mph or Below, 78% Underreporting Factor** | **17.7** |
| **Target Population, Sensitivity Case: LPV-CT Side Underrides 40 mph or Below, 155% Underreporting Factor** | **25.4** |

For the central analysis, we estimate that CT trailer side guards would potentially affect approximately 18 fatalities each year if the entire CT fleet were equipped with side guards. For the sensitivity analysis, we consider alternatives where CT trailer side guards could potentially affect up to 25 fatalities per year if the entire fleet were equipped.

### *A.2 Injuries*

The GES and CRSS data discussed in the previous section contain information on injuries and injury severity such as possible injury, minor injury, and serious injury associated with occupants, vehicles and crash types. However, the data do not provide information specific to underride crashes. For this analysis, we apply this relationship to our estimates of the target population of fatalities, to derive estimates of the target population of serious (MAIS 3-5) injuries.

*Table 11. Estimated Target Population of Annual Serious Injuries in Side Underride Crashes at or Below 40 mph (Based on GES/CRSS Ratio of Serious to Fatal Injury of 4.6:1)*

| Measure | Serious Injuries |
|---|---|
| All LPV-CT Front-Side Crashes | 974 |
| LPV-CT Side Underrides | 230 |
| LPV-CT Side Underrides 40 mph or Below | 46 |
| **Target Population: LPV-CT Side Underrides 40 mph or Below, 78% Underreporting Factor** | **81** |
| **Target Population, Sensitivity Case: LPV-CT Side Underrides 40 mph or Below, 155% Underreporting Factor** | **117** |

For the central analysis, we estimate that CT trailer side guards would potentially affect approximately 81 serious injuries each year if the entire CT fleet were equipped. We also consider sensitivity cases where side guards would potentially affect up to 117 serious injuries each year if the entire CT fleet were equipped.

As mentioned in the section on effectiveness above, we assume no net effect of CT trailer side guards on minor injuries, and thus minor injuries are not within the target population of injuries.

## B. Benefit Analysis

We calculate the benefits of equipping CT trailers with side guards in calendar year (CY) 2022 by estimating the improvement in safety (i.e., number of fatalities and serious injuries avoided) through the use of side guards (based on the known specifications of the AngelWing side guard) for the for all new CT trailers entering the fleet in CY 2022. In turn, we estimate the monetary equivalent of the estimated improvement in safety and multiplying these values by their corresponding estimated economic costs.

We begin by estimating the total number of fatalities and serious injuries avoided if the entire CT trailer fleet were equipped with side guards. These estimates are found by multiplying the target population values from Tables 10 and 11 by the side guard effectiveness estimates from Section II.B.

*Table 12. Estimated Annual Mitigated Fatalities and Serious Injuries Due to Full Adoption of CT Trailer Side Guards*

| Underreporting Factor | Effectiveness – Fatalities | Effectiveness – Serious Injury | Mitigated Fatalities | Mitigated Serious Injuries |
|---|---|---|---|---|
| 78% | 97% | 85% | 17.2 | 69.1 |
| 155% | 97% | 85% | 24.7 | 99.3 |

Based on these inputs, we estimate that full adoption of CT trailer side guards would lead to an annual reduction of approximately 17 fatalities with an underreporting factor of 78 percent and 97-percent effectiveness up to 40 mph (approximately 69 serious injuries based on 85% effectiveness up to 40 mph).

For this analysis, we assume that side guard requirements would apply only to new CT trailers. Although it would be feasible to retrofit existing trailers, there are at least three key practical concerns with retrofitting. First, such an approach would represent a large burden for some owners of trailers that have depreciated only partially. That is, there is a range of trailer age for which it would be unreasonably expensive both to retrofit a trailer and to scrap the same trailer.

Second, the logistics of ramping up side guard production and distribution at such a scale, only to ramp back down to an annual maintenance level are further impractical. Third, the expected lifetimes of existing trailers are shorter than new trailers, imposing a greater challenge in achieving a sufficient safety impact for the cost of installing and using side guards. Thus, for this analysis we focus on eligible new CT trailers in 2022 (i.e., side guards would be installed on 260,000 new trailers in 2022).

We scale the estimates from Table 12 (i.e., representing an entire CT trailer fleet equipped with side guards) to apply to the estimated number of new CT trailers that would: (1) enter the fleet in CY 2022; and (2) be eligible to be equipped with side guards. For the purposes of this analysis, we consider the baseline number of affected trailers to be the entire CT trailer fleet, less special purpose trailers, including heavy equipment haulers, log haulers, auto transporters, livestock trailers and temporary living quarters (i.e., fifth-wheel trailers and campers). We assume that all side underrides occur in collisions with the subset of trailers considered in this analysis (e.g., there are no side underrides involving heavy equipment haulers).

The total number of CTs in the fleet in 2018 was approximately 2.9 million in 2018, per the Bureau of Transportation Statistics (BTS, 2020a); applying the average annual growth rate for CTs reported by BTS for 2013-2018 (approximately 3%), we estimate that there will be approximately 3.3 million CTs in the fleet in 2022. A presentation by the American Trucking Association indicated that there were approximately 2.8 million CTs and 5.6 million CT trailers, or two trailers per registered CT, in 2010 (Scott, 2010). Applying the ratio of CTs to trailers from Scott, we estimate that there will be approximately 6.6 million CT trailers in the fleet in 2022.

Prior NHTSA research showed that approximately 70 percent of trailers manufactured each year fall into a category that would be affected by the adoption of side guards (Blower & Woodroffe, 2013). According to this formula, there were an average of approximately 234,000 new CT trailers manufactured each year from 2015 to 2018 that would require side underride guards; applying a similar 3-percent growth rate to 2022 yields an estimate of approximately 260,000 manufactured trailers in 2022 that would be in the scope of this analysis.

Hooper and Murray (2017) report an average CT trailer lifetime of 12.7 years, which is consistent with 10-to-15-year lifetimes commonly referred to on industry websites. An alternative means of estimating the average CT trailer lifetime is to apply the ratio of the total trailer fleet to new trailer sales, making an adjustment for demand for trailers to satisfy new freight demand. BTS (2020a) shows annual growth of ton-miles of freight close to zero from 2013 to 2018, so we choose to leave out an adjustment for freight demand growth in this calculation. In turn, our alternative estimate for average CT trailer lifetimes is equal to (0.7[6] x 6,600,000) divided by 260,000, or 17.8 years.

We apply the simple average of the above estimates, 15.25 years, for average CT trailer lifetimes in our calculations of lifetime impacts. This estimate reflects an assumption that CT trailers are used at constant rates (VMT per year) until they are retired from service. Thus, we project that 260,000 CT trailers that could be equipped with side guards will be sold in 2022, and that these trailers will remain in the fleet until 2038, on average. The 260,000 CT trailers represent approximately 3.9 percent of the total CT trailer fleet (260,000/6,600,000 = 0.039). Thus, on an

[6] 0.7 represents the 70 percent of trailers manufactured each year that would be affected by the adoption of side guards.

assumption that only a negligible number of new trailers would be equipped with side guards voluntarily (if this assumption is violated, the implications of the analysis would not change, only the absolute estimates of benefits and costs), we assume that the number of fatalities and serious injuries that could be mitigated per year through the use of side guards on new CT trailers in 2022 is equal to 3.9 percent multiplied by the estimates in Table 13 above.

*Table 13. Estimated Annual Mitigated Fatalities and Serious Injuries Due to the Adoption of CT Trailer Side Guards on All Eligible New CT Trailers in CY 2022*

| Underreporting Factor | Effectiveness – Fatalities | Effectiveness – Serious Injury | Mitigated Fatalities | Mitigated Serious Injuries |
|---|---|---|---|---|
| 78% | 97% | 85% | 0.7 | 2.7 |

We estimate that equipping all new CT trailers in 2022 with side guards would lead to an annual reduction of approximately 1 (0.7) fatality with an underreporting factor of 78 percent and 97-percent effectiveness up to 40 mph (approximately 3 serious injuries at 85% effectiveness up to 40 mph).

These estimates do not account for the potential effects of ADAS) such as AEB, blind spot detection, and lanekeeping technologies, which could reduce the volume of potential side-underride crashes independently of the presence of side guards. ADAS is expected to help mitigate underrides, either through avoiding collisions (e.g., lane keep assist helping a vehicle to avoid errantly drifting in a manner increasing the probability of a collision with a trailer) or mitigating impact speed sufficiently to avoid underride within a collision (e.g., AEB reducing vehicle speed prior to impact with a trailer). If ADAS were to have any mitigating effect on side underride frequency, the target population of side underride fatalities and serious injuries relevant to this analysis would be reduced. It is also possible that ADAS might reduce some higher impact speeds below the 40-mph threshold and thus increase the target population. It is not clear what the net impact would be. Note, however, that ADAS is primarily effective at lower speeds, so it is likely that the net impact would be a reduction in the target population.

NHTSA does not yet have sufficient data to account for this effect, but it is reasonable to expect the proliferation of ADAS to reduce the risk of crashes that could result in side underride. That is, as the share of vehicles in the light-duty fleet equipped with ADAS increases, there would likely be fewer side underrides independently of the presence of side guards, because ADAS would help to mitigate LPV-CT collisions in at least some cases. In turn, side guards would mitigate fewer side underrides because there would be fewer to affect in any case.

The safety impacts in Table 13 can be represented in monetary terms by multiplying the impacts by corresponding values based on comprehensive economic costs of injury. The comprehensive value of societal impacts from fatalities and injuries includes a variety of cost components. Table 14 summarizes the cost components and corresponding unit costs in 2020 dollars. As shown, the cost components included medical, EMS, market productivity, household productivity, insurance administration, workplace, legal, congestion, travel delay, and the intangible value of physical pain and loss of quality of life (i.e., quality-adjusted life-years, QALYs). The unit costs were revised from those published in the agency's 2015 report (Blincoe et al., 2015). Blincoe et al. reported unit costs in 2010 dollars. To convert them to 2020 dollars, the analysis derived adjustment factors from two types of economic indices for adjustment factors: two series of non-seasonally adjusted Consumer Price Index (CPI) and the Employment Cost Index (ECI) from the Bureau of Economic Analysis. CPI series that were used for deriving adjustment factors include

CUUR0000SA0 (All Items, Urban Consumers, U.S. All City Average) and CUUR0000SAM2 (Medical Care Services, Urban Consumers, U.S. All City Average). The ECI used is the series CIU1010000000000I (Total Compensation, Civilian workers, All Industries and Occupations). Each adjustment factor is the ratio of the index value in 2020 to that in 2010.

Note that instead of using a direct adjustment, the value of QALY was derived based on the formula shown in the last row of Table 14 adjusting the value of statistical life (VSL) to reflect after-tax wages and household productivity. This is an accounting mechanism that prevents double-counting of these factors, which are hypothetically considered to be inherently included in VSL estimates. The current established DOT VSL is $11.6 million (in 2020 dollars) which was based on the most current 2021 DOT Guidance on VSL (DOT, 2021).

*Table 14. Comprehensive Unit Costs of Injury for Evaluating Crashworthiness Countermeasures (2020 Dollars)*

| Components | PDO | MAIS0 | MAIS1 | MAIS2 | MAIS3 | MAIS4 | MAIS5 | Fatal |
|---|---|---|---|---|---|---|---|---|
| Medical | $0 | $0 | $3,739 | $15,299 | $64,947 | $182,093 | $513,315 | $15,117 |
| EMS | $71 | $45 | $129 | $264 | $496 | $999 | $1,020 | $1,076 |
| Market Prod. | $0 | $0 | $3,424 | $24,318 | $80,820 | $176,891 | $424,096 | $1,172,349 |
| Household Prod. | $75 | $57 | $1,083 | $8,926 | $28,500 | $47,158 | $119,849 | $364,180 |
| Ins. Adm. | $228 | $171 | $3,933 | $5,557 | $18,332 | $33,666 | $86,497 | $33,778 |
| Workplace | $78 | $58 | $428 | $3,321 | $7,256 | $7,991 | $13,932 | $14,802 |
| Legal | $0 | $0 | $1,410 | $3,997 | $14,791 | $31,806 | $98,644 | $127,003 |
| QALYs | $0 | $0 | $30,606 | $479,493 | $1,071,207 | $2,713,724 | $6,049,769 | $10,201,971 |
| **Total** | $452 | $331 | $44,752 | $541,175 | $1,286,349 | $3,194,328 | $7,307,122 | $11,930,276 |

The key comprehensive economic costs to consider in this analysis are the costs of fatalities and serious injuries. Per Table 14, the estimated comprehensive economic cost of a fatality is approximately $11.9 million (in 2020 dollars). There are MAIS levels that correspond to serious, non-fatal injury. For this analysis, we estimate the costs of serious injuries associated with side underrides by weighting the corresponding economic comprehensive costs of MAIS 3, MAIS 4, and MAIS 5 injuries by their estimated relative frequencies among front-to-side LPV-CT crashes. Among all such crashes in 2011-2015 General Estimates System (GES) records, MAIS 3 injuries represented 76.4% of all MAIS 3-MAIS 5 injuries; MAIS 4 and MAIS 5 injuries represented the other 17.2% and 6.3% of injuries, respectively. GES and FARS data classify injury severity (variable name INJ_SEV) using the KABCO injury scale. KABCO values were translated to MAIS values using NHTSA's KABCO-to-MAIS translator.

*Table 15. KABCO-to-MAIS Translator*

| MAIS | Police-Reported Injury Severity System | | | | | |
|---|---|---|---|---|---|---|
| | O | C | B | A | K | U |
| | No Injury | Possible Injury | Non Incapacita-ting | Incapacita-ting | Fatality | Injured, Severity Unknown |
| 0 | 0.92535 | 0.23431 | 0.08336 | 0.03421 | 0.00000 | 0.21528 |
| 1 | 0.07257 | 0.68929 | 0.76745 | 0.55195 | 0.00000 | 0.62699 |
| 2 | 0.00198 | 0.06389 | 0.10884 | 0.20812 | 0.00000 | 0.10395 |
| 3 | 0.00008 | 0.01071 | 0.03187 | 0.14371 | 0.00000 | 0.03856 |
| 4 | 0.00000 | 0.00142 | 0.00619 | 0.03968 | 0.00000 | 0.00442 |
| 5 | 0.00003 | 0.00013 | 0.00101 | 0.01775 | 0.00000 | 0.01034 |
| Killed | 0.00000 | 0.00025 | 0.00128 | 0.00458 | 1.00000 | 0.00046 |
| Total | 1.00001 | 1.00000 | 1.00000 | 1.00000 | 1.00000 | 1.00000 |

Source: 1982-1986 Old NASS; 2000-2008 CDS

Because the GES data include cases that are consistent with side underride but may not involve underride (i.e., there is no underride variable available for filtering GES data), we also evaluated front-to-side LPV-CT crashes classified in FARS specifically as underrides. Among these crashes, MAIS 3 injuries represented 72.9 percent of all MAIS 3- MAIS 5 injuries, while MAIS 4 and MAIS 5 injuries represented the other 19.0 percent and 8.0 percent of injuries, respectively. This strong degree of agreement in relative frequencies of MAIS 3 through MAIS 5 injuries across GES and FARS cases confirms the representativeness of the estimated relative frequencies. Because the GES data represent an unrestricted sample of crash data (i.e., the FARS data involve only fatal crashes), we chose to apply the GES-based values in estimating the comprehensive economic costs of serious injury in this analysis: approximately $2.0 million in 2020 dollars.[7] In turn, we estimate the safety benefits of equipping all eligible new CT trailers in CY 2022 with side guards as shown in Table 16, which presents estimated benefits for the primary scenario of a 78-percent underreporting factor and 97-percent effectiveness in mitigating fatalities and 85-percent effectiveness in mitigating serious injuries up to 40 mph.

*Table 16. Estimated Annual Safety Benefits Due to Equipping All Eligible New CT Trailers With Side Guards in CY 2022: Central Scenario, 78-Percent Underreporting Factor (Millions of 2020 Dollars)*

| Safety Impact | Benefit |
|---|---|
| Fatality Reduction | $8.1 |
| Serious Injury Reduction | $5.4 |
| Total Safety Impact | $13.5 |

Equipping all eligible new CT trailers with side guards in 2022 is estimated to generate approximately $13.5 million in benefits per year with an underreporting factor of 78 percent, 97-percent effectiveness in mitigating fatalities up to 40 mph, and 85-percent effectiveness in mitigating serious injuries up to 40 mph.

[7] Applying the same procedure when using the FARS-based estimates of relative frequencies yields a similar estimate of $2.1 million.

To estimate BCRs and net benefits, it is necessary to represent benefits as the lifetime discounted sum of annual safety impacts associated with the adoption of CT trailer side guards. For this analysis, we assume an average trailer lifetime of 15.25 years and a constant usage rate of 89,278 VMT/year (see the cost impacts section for more discussion on CT trailer VMT). New trailers equipped with side guards would be associated with safety benefits for their full lifetime. Applying the above estimates of annual safety impacts across a 15.25-year lifetime for new trailers yields the following estimate of lifetime discounted safety benefits associated with the adoption of CT trailer side guards:

*Table 17. Estimated Discounted Lifetime Safety Benefits Due to Adoption of CT Trailer Side Guards for All Eligible New CT Trailers in CY 2022 (Central Scenario, Millions of 2020 Dollars)*

| Discount Rate | Lifetime Safety Benefits |
|---|---|
| 3% | $165.9 |
| 7% | $128.5 |

Equipping all eligible new CT trailers with side guards in 2022 is estimated to generate approximately $170 million in lifetime safety benefits each year at a 3-percent discount rate ($130 million at a 7% discount rate). This represents a benefit of approximately $640 per trailer at a 3-percent discount rate ($490 per trailer at a 7% discount rate).

*Table 18. Estimated Discounted Lifetime Safety Benefits Due to Adoption of CT Trailer Side Guards for All Eligible New CT Trailers in CY 2022 (per Trailer, Central Scenario, 2020 Dollars)*

| Discount Rate | Lifetime Safety Benefits |
|---|---|
| 3% | $638 |
| 7% | $494 |

## C. Uncertainty and Unquantified Benefits

There is uncertainty in the assumptions that could lead to higher benefit estimates in light of additional information. The target population of fatalities and serious injuries could increase if: (1) the baseline level of relevant fatalities and serious injuries is much larger than estimated based on the FARS data and the PCR review; or (2) CT trailer side guards had some protective effect at impact speeds above 40 mph. The PCR review offered a thorough analysis of one year's LPV-CT crashes that could have resulted in side underride at impact speeds up to 40 mph, and established a meaningful estimate of the rate of underreporting side underrides in FARS. By basing our estimated target population on the underreporting factor from the PCR review, we are confident that we have represented the target population accurately. Furthermore, the sensitivity analysis allowed for a much larger underreporting factor, and found that the estimated benefits were still much smaller than the estimated costs associated with a side guard requirement.

Because side underride occurs predominantly at impact speeds above 40 mph, protective effects above 40 mph could generate a large incremental improvement above the safety benefits estimated in this analysis. However, we do not have information available on the degree to which side guards may offer a safety improvement beyond their 40-mph test limit. As such, any estimated benefits above 40 mph would be purely speculative. Similarly, the results of this study reflect existing side guard designs. It is possible that future designs may mitigate side underride at higher speeds, increasing safety benefits. However, we do not have any data to support changing our baseline assumptions regarding effectiveness.

As mentioned above, the estimated benefits impacts do not account for the potential effects of ADAS such as AEB and lane keep assist. ADAS is expected to help mitigate underrides, either through avoiding collisions (e.g., lane keep assist helping a vehicle to avoid errantly drifting in a manner increasing the probability of a collision with a trailer) or mitigating impact speed sufficiently to avoid underride within a collision (e.g., AEB reducing vehicle speed prior to impact with a trailer). If ADAS were to have any mitigating effect on side underride frequency, the target population of side underride fatalities and serious injuries relevant to this analysis would be reduced. It is also possible that AEB might reduce some higher impact speeds below the 40-mph threshold and thus increase the target population. It is not clear what the net impact would be. Note, however, that AEB is primarily effective at lower speeds, so it is likely that the net impact would be a reduction in the target population.

# IV. Cost Impacts

## A. Side Underride Guard Installation Costs

### *A.1 Estimated Population of Affected Trailers*

As described in the benefits section above, for the purposes of this analysis, we consider the baseline number of affected trailers to be the entire CT trailer fleet, less special purpose trailers, including heavy equipment haulers, log haulers, auto transporters, livestock trailers and temporary living quarters (i.e., fifth-wheel trailers and campers). Based on available estimates and assumptions regarding growth in demand for trailers and volumes of trailers relative to tractors, we estimate that there will be approximately 6.6 million CT trailers in the fleet in 2022. Based on NHTSA research (Blower & Woodroffe, 2013) on the share of trailers that could be equipped with side guards (and which are likewise prone to underride), we project that approximately 260,000 new CT trailers that could be equipped with side guards will be sold in 2022.

We apply an estimated 15.25-year average trailer lifetime, based on a simple average of the 12.7-year average trailer lifetime reported by Hooper and Murray (2017) and the ratio of CT trailers that could be equipped with side guards to projected new eligible CT trailer sales in 2022 (17.8 years). Thus, we project that 260,000 CT trailers that could be equipped with side guards will be sold in 2022, and that these trailers will remain in the fleet until approximately 2038, on average.

### *A.2 Initial Hardware and Labor Cost*

At this time, only one side underride guard that has been confirmed in third-party (IIHS) testing to be capable of preventing or mitigating light vehicle underride at impact speeds up to 40 mph is known to be available commercially in the United States (the AngelWing). A similar countermeasure from Canadian firm PHSS Fortier (n.d.) is comprised of several belts of vinyl. The PHSS weighs approximately 540 pounds, and acts as a joint side guard and side skirt (i.e., it offers fuel economy improvements of approximately 4 percent over a baseline of no side skirt, but no fuel economy improvements over a baseline with a side skirt). The LP has been tested internally at impact speeds up to 35 mph (Radio Canada, 2019), but testing results equivalent to a third-party such as IIHS testing are unavailable. Pricing and effectiveness data for the LP are also unavailable. Critically, information is unavailable regarding differences in the rate of damage to trailers equipped with the LP relative to other trailers; the low ground clearance of the LP relative to the AngelWing raises the potential for the LP to strike objects or infrastructure at a relatively high rate, leading to incremental costs associated with trailer damage. Thus, we do not use the LP in our analysis, other than to confirm the feasibility of side guard weights consistent with our selected lower-bound weight of 450 pounds.

We apply information on the AngelWing as our basis for the price and weight (with supporting information from the LP and Wabash prototype on weight) of side guards sold in 2022. Initial hardware cost for the AngelWing was listed at $2,897 (with volume discounts available) at the time of data collection, which includes the side guards, cross members, mounting brackets and related hardware and installation instructions. We acknowledge that broad adoption of side guards would likely lead to considerable changes in the market for side guards, and thus it is feasible that the market would experience downward price pressure due to increasing returns to scale and competition from other potential suppliers. However, we do not have sufficient information available to project any particular impact on prices, and thus apply the unadjusted price of $2,897 for this analysis. Alternative side guard costs are considered in the sensitivity analysis.

Installation is stated to require less than 2 hours for two people (AirFlow Deflector, n.d./a). According to the Bureau of Labor Statistics (2021a), the national median hourly wage for automotive body and related repairers was $21.80 as of May 2020. The Bureau of Labor Statistics estimates that wages represent approximately 70 percent of total employer costs for employee compensation (Bureau of Labor Statistics, 2020b); in turn, we estimate median total employee compensation for automotive repair workers to be $31.14 (=$21.80/0.7). We assume an average of 1½ hours per installer per trailer (to account for efficiency gains with experience and across larger operations), with two people installing side guards per trailer, or 3 labor hours per trailer; this yields a total labor cost of $93.42 per trailer (=$31.14 per hour x 3 hours per trailer). Given these figures, the total initial cost for outfitting new commercial combination trailers is shown in the following table.

*Table 19. Estimated Costs of Installing CT Trailer Side Guards on All Eligible New CT Trailers in 2022 (2020 Dollars)*

| | **Cost** |
|---|---|
| Side Guard Hardware Cost | $2,897 |
| Average Labor Cost per Side Guard | $93 |
| Average Cost per Trailer | $2,990 |
| **Total Cost for 260,000 Trailers ($ mil.)** | **$777.5** |

The average total cost of installing a side guard on a CT trailer is estimated to be $2,990. Across the estimated 260,000 new trailers that would be equipped in 2022, the total cost associated with side guard installation is estimated to be approximately $778 million. These estimated cost impacts do not include any additional costs associated with reinforcing trailers to accommodate side guards and any associated changes to trailer loading patterns. We acknowledge that any such costs, which could be substantial, would add to total hardware and installation costs. However, we do not have sufficient information available to inform an estimate of these additional costs.

The following section discusses fuel economy impacts associated with side guards. A component of that topic is relevant to hardware costs, because the analysis considers two technology-focused strategies firms could implement in response to a side guard requirement. The first strategy would be to equip new trailers with fuel-saving aerodynamic fairings (i.e., side skirts), which can improve fuel economy by approximately 5 percent (Wood, 2012). Although approximately 40 percent of new trailers are equipped with side skirts (Sharpe & Roeth, 2014), it is feasible that additional trailers would be equipped with side skirts (either purchased separately or in a package with side guards) in an effort to offset expected increases in fuel consumption due to the additional weight of side guards. In such cases, side skirts would add approximately $600 to $1,500 in hardware and installation costs, based on available price estimates for side skirts.

## B. Fuel Economy Impact

The additional weight of a side underride guard would increase the amount of fuel consumed by a CT. For this analysis, we considered two external sources of estimates of the effects of changes in vehicle mass (or payload) on CT fuel economy:  a study by ICF International (2009); and a study by the Institute for Internal Combustion Engines and Thermodynamics (2011). The ICF International study estimates that each 1,000-pound mass reduction for heavy vehicles with GVWR above 60,000 pounds (i.e., a class within which CTs reside) yields a 1.1-percent increase in fuel economy. The ICCT study yields a similar result, with a 2,500-kilogram mass decrease yielding a 5.8-percent increase in fuel economy (i.e., equivalent to a 1.1-percent increase in fuel economy).

With strong agreement across these two sources, we apply an estimate of a 1.1-percent increase in CT fuel consumption per 1,000-pound mass increase to estimate the impact that the incremental mass of side guards would have on CT fuel economy. We assume that the average in-use weight of a loaded heavy CT is 55,000 pounds (Petersen, 2013).

The Federal Highway Administration reports average CT fuel economy of approximately 6 mpg (FHWA, n.d.). This value represents a lower-bound for CT fuel economy that does not reflect potential improvements in fuel economy through technological improvements independent of side guards (e.g., efficient engines, lower-rolling-resistance tires, side skirts, aerodynamic improvements). In turn, NHTSA finds the value of 6 mpg to be lower than the likely average CT fuel economy over the lifetime of CT trailers that enter the fleet in 2022. That is, across the estimated average lifetimes of trailers new CT trailers equipped with side guards in 2022 (i.e., from 2022 to 2035 or 2040), it is reasonable to expect that average CT fuel economy will exceed 6 mpg due to technological advancements that could be adopted either independently of side guards or in conjunction with side guards (e.g., development of packages that include side guards and fuel-saving technologies such as side skirts).

For this analysis we assume that the CT fleet will incorporate some measure of technological advancements that improve fuel economy over the interval that CT trailers entering the fleet in 2022 would remain in the fleet. NHTSA has limited information available to inform assumptions on the rate at which CT fuel economy would improve. However, the Energy Information Administration (EIA, 2021a) projects that overall freight truck fuel economy will increase by approximately 30 percent from 2022 to 2040.[8] The EIA forecast incorporates information on potential technological developments, and thus serves as a useful basis in projecting average CT fuel economy. We apply the projected rates of technological development from the EIA forecast in projecting average CT fuel economy for future years to 2038 (i.e., the projected year where the full CT trailer fleet would be equipped with side guards based on side guards becoming mandatory in 2022) and beyond using the annual rates of change in freight truck fuel economy from the EIA forecast (e.g., in 2040, CT trailers are projected to have fuel economy equal to 30% above a current baseline value of 6 mpg, or 7.8 mpg).

It is important to clarify that our estimates of baseline fuel economy implicitly account for the freight transportation industry's adoption of fuel-saving technologies such as side skirts over time. Specifically, within the general trend of improving fuel economy forecast by the EIA, we assume that the share of new CTs equipped with side skirts will increase from an initial value of

[8] According to Table 7 (Transportation Sector Key Indicators and Delivered Energy Consumption) of *Annual Energy Outlook 2021*, freight truck fuel economy is projected to increase from 7.4 mpg in 2022 to 9.5 mpg in 2040.

40 percent in 2022 to a value of 90 percent by 2038.[9] We assume that 30 percent of the overall CT trailer fleet is equipped with side skirts or equivalent technology; this represents a minor increase above the value of 25 percent cited in Sharpe and Roeth (2014), to account for the effects of new, equipped trailers replacing retired, unequipped trailers from 2014 to the present. Based on this assumption and our assumed fleetwide average CT fuel economy of 6 mpg in 2022, we calculate that CTs equipped with side skirts in 2022 have an average fuel economy of 6.21 mpg, while unequipped CTs have an average fuel economy of 5.91 mpg. We apply these values in concert with the annual EIA projections of improvements in fuel economy and an assumed linear trend in side skirt usage to estimate separate values for fuel economy for CTs with side skirts and CTs without side skirts for each year in the analysis.

We did not identify any expected path for side guards to incorporate fuel-saving technology independently from side skirts, and hence do not allocate any fuel-saving impacts to side guards directly. Rather, we assume that fuel-saving technologies such as side skirts will be adopted consistent with the rates implicit within EIA forecasts, and that side guards will impact fuel economy separately from such technologies through the effects of increasing CT trailer mass.

The joint side skirt-guard nature of some side guard designs (e.g., the PHSS Fortier design) offers a convenient mechanism for adopting fuel-saving technology and underride-mitigation technology. However, firms have access to side skirts presently, and thus mandating side guards does not offer an incremental improvement to baseline CT fuel economy outside of the potential outcome where decision-makers choose to adopt fuel-saving technology specifically in response to side guard requirements. Furthermore, NHTSA would not likely have the authority to require fuel-saving technology within any rulemaking focused on mitigating side underride fatalities.

Ultimately, we have used these relationships to inform our projections of the impacts of side guards on incremental fuel consumption, determining that the net impact of side guards on fuel consumption would likely follow a path along which fuel consumption would increase conditional on baseline fuel economy. As the use of fuel-saving technologies increases in the fleet consistent with EIA forecasts, the fuel consumption penalty due to carrying the additional weight of side guards that we measure decreases.

The weight of the side underride guard is 450 to 800 pounds, depending on the specific configuration (AirFlow Deflector, n.d./a). We apply this range of side guard weight to estimate fuel consumption impacts.

We estimate the average effect of CT trailer side guards on annual CT fuel consumption and fuel costs by estimating fuel consumed with and without side guards for the estimated average distance travelled by a CT in a year, conditional on the share of CTs in the fleet equipped with side guards. Our estimate of average distance travelled by a CT in a year is equal to a projection of total annual CT VMT, divided by our estimated number of CTs (2.1 million). The Bureau of Transportation Statistics (2020b) reports that CTs travelled approximately 168 billion miles in 2013 and approximately 184 billion miles in 2018, with an annual average growth rate of 1.8 percent over that period. Applying that growth rate to the 2018 value yields an estimate of 2020 CT VMT of approximately 187 billion. Dividing this value by 2.1 million CTs yields an estimate of annual average CT VMT equal to 89,278.

[9] See a comment by a senior researcher at the International Council for Clean Transportation in trucks.com (Adler, 2018).

We begin an evaluation of the effects of CT trailer side guards on CT fuel consumption and fuel costs by comparing these impacts on trailers equipped with side skirts versus trailers without side skirts. The overall fleet average of 6 mpg assumed above incorporates a mix of trailers with and without side skirts; thus, it is useful to gauge whether the use of side skirts would lead to notably different cost impacts. We estimate average fuel economy with and without side skirts by calibrating the overall average of 6 mpg relative to an assumed share of 30 percent of trailers equipped with side skirts, and an assumed share of new CT trailers being equipped with side guards growing linearly from 40 percent in 2022 to 90 percent in 2038. Based on these assumptions, CTs carrying trailers without side guards or side skirts would have an average fuel economy of 5.91 mpg in 2022, increasing to 7.19 mpg by 2037 based on the EIA projection. CTs carrying trailers with 450-pound side guards but without side skirts would have an average fuel economy of 5.89 mpg in 2022 (5.86 mpg for 800-pound side guards), increasing to 7.15 mpg in 2037 (7.12 mpg for 800-pound side guards). This represents incremental lifetime fuel consumption of 913 gallons for a 450-pound side guard (1,588 gallons for an 800-pound side guard), based on 89,278 VMT per year over a 15.25-year lifetime.

Even with side skirts equipped, fuel economy is affected to a highly similar degree through the use of side guards. CTs equipped with side skirts but no side guards are estimated to have an average fuel economy of 6.21 mpg in 2022, increasing to 7.55 mpg in 2037 based on the EIA projection. CTs carrying trailers equipped with 450-pound side guards and side skirts would have an average fuel economy of 6.18 mpg in 2022 (6.16 mpg for 800-pound side guards), increasing to 7.51 mpg in 2037 (7.48 mpg for 800-pound side guards). This represents incremental lifetime fuel consumption of 869 gallons for a 450-pound side guard (1,512 gallons for an 800-pound side guard). Intuitively, the presence of side skirts only reduces incremental fuel consumption by the proportional improvement offered by side skirts: approximately 5 percent (44 gallons for a 450-pound side guard, 76 gallons for an 800-pound side guard).

*Table 20. Comparison of Incremental Fuel Impacts With and Without Side Skirts*

| | **No Side Skirt or Side Guard** | **No Side Skirt, with Side Guard** | **With Side Skirt, No Side Guard** | **With Side Skirt and Side Guard** |
|---|---|---|---|---|
| Fuel Economy, 2022 (mpg) | 5.91 | 5.86-5.89 | 6.21 | 6.16-6.18 |
| Fuel Economy, 2037 (mpg) | 7.19 | 7.12-7.15 | 7.55 | 7.48-7.51 |
| Incremental Lifetime Fuel Consumption (gallons) | | 913-1,588 | | 869-1,512 |
| Incremental Lifetime Fuel Cost, 3% Discount Rate[10] | | $1,922-$3,343 | | $1,830-$3,184 |
| Incremental Lifetime Fuel Cost, 7% Discount Rate[11] | | $1,531-$2,663 | | $1,458-$2,537 |

The differences in estimated incremental lifetime fuel cost (net of Federal and State taxes, which are classified as transfers in this analysis rather than costs) with and without side skirts are quite

[10] Fuel cost based on projected prices of diesel fuel from the reference case of *Annual Energy Outlook 2021* (EIA, 2021b).
[11] Fuel cost based on projected prices of diesel fuel from the reference case of *Annual Energy Outlook 2021* (EIA, 2021b).

small, between $73 under low cost assumptions at a 7-percent discount rate and $159 under high cost assumptions at a 3-percent discount rate. Thus, the presence of side skirts in isolation does not appear to be a predominant factor for influencing cost impacts. That is, equipping the two new CT trailers that would be carried by a focal truck with side skirts would mitigate between $73 and $195 in lifetime discounted fuel costs associated with side guards; the estimated fuel cost savings are far lower than the expected costs of side skirts (assumed to be an average cost of $800 per trailer in this analysis). Thus, we do not expect the existence of a side guard requirement to induce decision-makers to equip CT additional CT trailers with side skirts, except in edge cases where an additional $73-$159 is sufficient to change purchasing decisions.

For the central analysis, we assume that 40 percent of new CT trailers in 2022 would be equipped with side skirts. We calculate lifetime incremental fuel costs as the change in fuel costs associated with carrying a fleet of 260,000 such trailers over their lifetimes, relative to the corresponding fuel costs for a baseline fleet of trailers that are not equipped with side guards.

*Table 21. Lifetime Fuel Economy Impact of CT Trailer Side Guards, 40 Percent of Eligible New Trailers in 2022 Equipped With Side Skirts (per Truck Carrying Eligible New Trailers, 2020 Dollars)*

| | | ***450-Pound Side Guard Weight*** | | | ***800-Pound Side Guard Weight*** | | |
|---|---|---|---|---|---|---|---|
| **Year** | **Fuel Price^ ($/gal.)** | **Undiscounted** | **3% Discount Rate** | **7% Discount Rate** | **Undiscounted** | **3% Discount Rate** | **7% Discount Rate** |
| 2022 | $2.05 | $152.77 | $150.53 | $147.69 | $265.79 | $261.89 | $256.95 |
| 2023 | $2.26 | $166.46 | $159.24 | $150.40 | $289.60 | $277.04 | $261.65 |
| 2024 | $2.36 | $171.85 | $159.61 | $145.11 | $298.98 | $277.69 | $252.46 |
| 2025 | $2.42 | $174.27 | $157.14 | $137.52 | $303.18 | $273.38 | $239.25 |
| 2026 | $2.48 | $176.64 | $154.64 | $130.28 | $307.32 | $269.04 | $226.65 |
| 2027 | $2.53 | $178.28 | $151.53 | $122.89 | $310.17 | $263.63 | $213.79 |
| 2028 | $2.59 | $178.38 | $147.20 | $114.91 | $310.33 | $256.08 | $199.91 |
| 2029 | $2.62 | $178.62 | $143.11 | $107.54 | $310.76 | $248.97 | $187.09 |
| 2030 | $2.72 | $181.43 | $141.12 | $102.08 | $315.65 | $245.52 | $177.60 |
| 2031 | $2.75 | $181.69 | $137.21 | $95.54 | $316.09 | $238.70 | $166.21 |
| 2032 | $2.79 | $180.53 | $132.36 | $88.72 | $314.08 | $230.28 | $154.35 |
| 2033 | $2.81 | $180.19 | $128.26 | $82.76 | $313.49 | $223.15 | $143.98 |
| 2034 | $2.83 | $177.91 | $122.95 | $76.36 | $309.51 | $213.90 | $132.86 |
| 2035 | $2.84 | $177.02 | $118.77 | $71.01 | $307.96 | $206.63 | $123.54 |
| 2036 | $2.85 | $176.16 | $114.75 | $66.04 | $306.47 | $199.64 | $114.90 |
| 2037* | $2.89 | $44.29 | $28.01 | $15.52 | $77.06 | $48.73 | $27.00 |
| **Total** | | **$2,279** | **$1,885** | **$1,502** | **$3,965** | **$3,279** | **$2,613** |

^Fuel price is net of average federal and state taxes of $0.5669 per gallon, as estimated by the Energy Information Administration (2022). *Based on an assumed average trailer lifetime of 15.25 years. Fuel consumption in each year is scaled to match the rate of change in freight truck fuel economy in *Annual Energy Outlook 2021* (EIA, 2021).

We estimate that, on average, trucks carrying CT trailers entering the fleet with side guards in 2022 would incur an additional $1,885-$3,279 in fuel costs over the lifetime of the trailers at a 3-percent discount rate ($1,502-$2,613 at a 7% discount rate). Total incremental fuel cost is estimated by multiplying the estimated incremental lifetime fuel costs by the number of applicable vehicles.[12] With an estimated ratio of one Class 8 semi-truck per two trailers, we

[12] The estimated number of applicable vehicles is from Mazareanu (2020).

estimate that an equivalent of 130,000 additional trucks would carry eligible trailers that would be equipped with side guards in 2022.

*Table 22. Total Incremental Fuel Cost for Trucks Carrying Trailers With Mandatory Side Guards (Eligible New Trailers in 2022, 2020 Dollars)*

| | Weight Increase (Pounds) | Total Incremental Fuel Cost ($ mil.) | | |
|---|---|---|---|---|
| | | Undiscounted | 3% Discount Rate | 7% Discount Rate |
| **Central Case: 40% of Eligible New CT Trailers in 2022 Equipped with Side Skirts** | **450** | **$296.3** | **$245.0** | **$195.2** |
| | **800** | **$515.4** | **$426.3** | **$339.7** |

The effects of equipping side guards on all eligible new CT trailers in 2022 on incremental lifetime fuel costs are insensitive to assumptions regarding the share of trailers equipped with side skirts. For our central analysis, requiring side guards is estimated to increase lifetime fuel costs by between approximately $250 million and $430 million at a 3-percent discount rate (between $200 million and $340 million at a 7% discount rate).

## C. Weight-Out and Other Costs

When adding weight to a freight vehicle for any reason, it is possible that the vehicle would be able to carry less cargo due to maximum load restrictions (i.e., the vehicle would experience weight-out). In turn, the reduction in cargo capacity would represent a cost in terms of lost revenue (forgone business) or increased operating costs (additional truck trips to carry the same amount of cargo).

The EPA estimates the typical weight of an unladen Class 8 tractor-trailer combination is approximately 36,000 pounds, while payloads typically do not exceed 40,000 pounds. While 80,000 pounds is the load limit for Class 8 trucks, over 90 percent of loaded tractor-trailers weigh less than 73,000 pounds (Petersen, 2013). As such, even the heaviest configuration of the AngelWing represents only about 1 percent of the total allowable loaded weight for a CT. Because loaded CTs predominantly weigh less than 73,000 pounds, the addition of 450 to 800 pounds from the AngelWing is not expected to have a material effect upon the amount of cargo such a vehicle is able to carry (Worth & Guerrero, 2016).

However, the inclusion of side guards could cause individual axle weight limits to be exceeded for a given truckload. To offset this, it would be necessary to add axles to the vehicle configuration, which would add hardware costs, installation costs (for each time an axle would be added to a trailer), and maintenance costs. In addition, refrigerated trailers are more likely than other trailers to be loaded to capacity, which would make refrigerated freight travel more likely to experience weight-related constraints when requiring side guards. We do not have sufficient information to estimate how often additional axles would be required or how often additional refrigerated freight trips would be required due to weight-related constraints when CTs are equipped with side guards, but we acknowledge that the associated costs would likely be non-zero across the fleet.

In the absence of distinct information on the extent to which the incremental weight of side guards would affect the amount of cargo carried by individual Class 8 CTs, we assume no change in VMT as a result of less cargo being carried per vehicle in our central analysis. Revenue and traffic congestion would be similarly unaffected under the central assumption.

Critically, if the assumption regarding weight-out does not hold, there would be incremental CT travel required to carry the remaining cargo that is unable to be carried due to side guard weight. Incremental travel could feasibly not only offset safety benefits from side guards but could also cause incremental fuel costs to be considerably larger than under our analysis. For example, while the incremental fuel costs associated with side guards are estimated to be on the order of one-half percent of baseline fuel costs, a required increase of CT travel equal to 5 percent (e.g., weight-out is binding for 5% of baseline CT VMT demand) would lead to approximately 10 times more additional incremental fuel costs.

Because the AngelWing guard is expected to require only approximately 3 person-hours or less of labor to install per unit, we do not anticipate any appreciable increase in employment levels for freight transport firms should the guard become required equipment for CTs. Increased employment could result among firms producing or distributing side guards; however, these employment impacts do not represent costs to freight transport firms beyond the share of side guard costs comprised of manufacturer labor cost.

Importantly, the above estimated cost impacts do not include additional costs that accrue due to incremental wear and tear on equipped trailers. Side guards impose non-uniform loads on trailer floors, which adds stresses that decrease trailer lifetimes in the absence of repair. We did not identify data to aid in the estimation of these repair costs, but they are likely to be non-zero, on average (see, for example, the two docket submissions by the Truck Trailer Manufacturers Association (Sims, 2016; Shelton 2006). Side guards may also strike or become tangled with road structures and loading area components, leading to additional repair costs or restricted access to destinations altogether.

A related unquantified cost involves restrictions on trailer axle configurations. The rear axles of trailers are commonly able to be moved fore and aft to adjust to loading conditions (chiefly, laden versus unladen). If CT trailer side guards share a key attribute of the AngelWing – a braced structure underneath the trailer – it would be unclear how rear axles could be adjusted. Losing this capability would add to operating costs to an unknown degree.

## D. Summary

Requiring side underride guards for Class 8 CT trailers is estimated to result in approximately $780 million in hardware and installation costs for eligible new CT trailers entering the fleet in 2022. Incremental lifetime fuel costs associated with side guard weight are estimated to increase by between approximately $250 million and $430 million at a 3-percent discount rate (between approximately $200 million and $340 million at a 7% discount rate). Due to limited available information, weight-out is assumed to result in no appreciable increase in costs or lost revenue in our central analysis (the sensitivity analysis considers changes in this assumption). These cost components comprise the elements of the total estimated cost impacts for a side-underride guard requirement in our central analysis, as shown in Table 23.

*Table 23. Total Lifetime Costs for CTs Hauling Eligible Trailers Equipped With Side Guards in 2022 (260,000 Trailers Equipped, Millions of 2020 Dollars)*

| Cost Measure | 450-Pound Side Guard | 800-Pound Side Guard |
|---|---|---|
| Hardware and Installation Costs | $777.5 | $777.5 |
| Incremental Fuel Costs – 3% Disc. Rate | $245.0 | $426.3 |
| Incremental Fuel Costs – 7% Disc. Rate | $195.2 | $339.7 |
| **Total Costs – 3% Discount Rate** | **$1,022.5** | **$1,203.8** |
| **Total Costs – 7% Discount Rate** | **$972.7** | **$1,117.2** |

Under a side guard requirement, total costs for new trailers in 2022 are estimated to increase by between $1.02 billion and $1.20 billion at a 3-percent discount rate (between $970 million and $1.12 billion at a 7% discount rate). Incremental fuel costs represent between approximately one-fourth and two-fifths of estimated total costs, depending on side guard weight and discount rate.

## E. Uncertainty and Unquantified Costs

It is possible that future designs may have lower hardware costs or weigh less than the AngelWing, either of which would reduce lifetime costs. However, we do not have any data to support assuming these characteristics in place of our baseline assumptions.

As discussed above, due to a lack of sufficient data, this analysis does not quantify any costs associated with increased CT trips due to forgone cargo capacity in equipped CT trailers. If such trips occurred, they would offset a portion of the safety benefits estimated in this analysis through the safety risks associated with incremental CT travel. Similarly, the analysis assumes that no CT trips involving the 70 percent of eligible CT trailers that could be equipped with side guards would be rendered infeasible due to access restrictions (e.g., ground clearance issues). If either of these factors are present, the costs associated with CT trailer side guards would increase.

Costs would also increase if the inclusion of side guards caused individual axle weight limits to be exceeded for a given truckload. To offset this, it would be necessary to add axles to the vehicle configuration, which would add hardware costs, installation costs (for each time an axle would be added to a trailer), and maintenance costs. The analysis also assumes that the design of CT trailer side guards would not accelerate factors such as metal fatigue for CT trailers. It is feasible that the presence of side guards could make side guards more prone to deformation, which would lead to additional repair costs or shorter trailer lifetimes. Both of these results would increase the costs associated with CT trailer side guards.

# V. Cost-Benefit and Cost-Effectiveness Analyses

With the benefits (safety impacts) and costs (trailer ownership and truck operating cost impacts) estimated, it is feasible to identify net benefits, benefit-cost ratios (BCRs), and cost-effectiveness measures associated with CT trailer side underride guard requirements. For the evaluation of safety-related policies, net benefits and BCRs measure absolute and relative benefits (i.e., benefits less costs, and benefits divided by costs), respectively. Cost-effectiveness measures the net cost per equivalent life saved (i.e., per equivalent fatality, in monetary terms).

## A. Cost-Benefit Analysis Overview

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

Impacts are converted from impact quantities (e.g., number of fatal crashes) into dollar values (e.g., our estimates of the comprehensive economic costs of fatalities and injuries) for comparison. Impacts often occur over many years, and to account for the greater value of the present impacts versus those further in the future, the future impacts are discounted so that the values of all years are treated as present values. Future values of each impact are discounted at 3 percent and 7 percent, consistent with the Office of Management and Budget's cost-benefit analysis guidelines (OMB, n.d.).

The total net benefit may be positive or negative. Additionally, a BCR can be calculated (total benefits divided by total costs) and used to categorize the option as being net beneficial (BCR>1), net neutral (BCR=1), or net negative (BCR<1). These two analysis outputs, net benefits and BCR, are used for comparative purposes.

The primary alternative of comparison is the case where no action is taken. Similarly, net benefits could be used in a comparison of all relevant alternatives (including the do-nothing case) to determine the most cost-effective option. A net positive cost-benefit analysis is not a decisive reason for pursuing an option, as other considerations may make the option untenable, such as monetary or legal constraints. Likewise, a net-negative cost-benefit analysis does not preclude a specific course of action, because policy objectives or uncertainty in future benefits and costs may outweigh expected negative net benefits.

## B. Net Benefits and BCRs

Net benefits are used as absolute measures of the returns offered by a particular policy alternative (in monetary terms) in regulatory analysis, while BCRs are used as relative measures of how much better off society would be if a policy alternative were enacted. A positive value for net benefits and a BCR greater than one both indicate that measurable societal benefits are higher than measurable societal costs under the policy alternative; a negative net benefit and a BCR less than one both indicate that measurable societal costs exceed measurable societal benefits.

In this analysis, the benefits are comprised of the total discounted safety impact of equipping CT trailers with side underride guards, while the costs are comprised of the hardware costs, installation costs, and incremental fuel costs associated with the added weight to trailers. Net benefits across the scenarios considered above are presented in Table 24.

*Table 24. Estimated Total Benefits, Total Costs, Net Benefits, by Scenario (Equipping 260,000 Eligible New CT Trailers With Side Guards in 2022, Millions of 2020 Dollars)*

| Scenario | 3% Discount Rate | 7% Discount Rate |
|---|---|---|
| ***Total Benefits:*** | | |
| Central Case | $165.9 | $128.5 |
| ***Total Costs:*** | | |
| Low Cost Estimate: 450-Pound Side Guard Weight | $1,022.5 | $972.7 |
| High Cost Estimate: 800-Pound Side Guard Weight | $1,203.8 | $1,117.2 |
| ***Net Benefits (equals total benefits less total costs):*** | | |
| Low Cost Estimate, Central Case | -$856.7 | -$844.2 |
| High Cost Estimate, Central Case | -$1,037.9 | -$988.7 |

Estimated net benefits range from approximately -$1.04 billion to -$860 million at a 3-percent discount rate (from -$990 million to -$844 million at a 7% discount rate). Thus, under our central assumptions, side guards are not estimated to generate benefits greater than the corresponding costs. The sensitivity analysis presented in Section VI considers the effects of changes in cost assumptions, along with the effects of a larger target population using the upper-bound underreporting factor from the FARS-PCR analysis.

Table 25 presents the estimated BCRs, which enable an alternative direct comparison of the relative benefit across scenarios and discount rates.

*Table 25. Estimated BCRs by Scenario*

| Scenario | 3% Discount Rate | 7% Discount Rate |
|---|---|---|
| Low Cost Estimate, Central Case | 0.16 | 0.13 |
| High Cost Estimate, Central Case | 0.14 | 0.12 |

For the central analysis, the estimated BCRs are between approximately 0.12 and 0.16 (i.e., total benefits are estimated to be between one-eighth and one-sixth of total costs).

## C. Cost-Effectiveness

Cost-effectiveness represents a measure of the average monetary cost per unit of change (i.e., benefit). In regulatory analyses for safety policies, cost-effectiveness generally measures the average estimated change in total costs per unit improvement in safety (e.g., cost per life saved). A policy alternative can be considered cost-effective if the estimated cost per unit increase is less than an appropriate benchmark. For example, a proposed safety standard could be considered cost-effective if the average cost per life saved equivalent (i.e., combining lives saved and injuries avoided, weighted by the relative values of injuries to fatalities) under the proposed standard were less than the comprehensive economic cost of a fatality (approximately $11.9 million in 2020 dollars). That is, the proposed standard would yield safety benefits at a lower cost than the benchmark value for those benefits.

In this analysis CT trailer side guards can be considered cost-effective if the estimated lifetime cost per side guard is less than an appropriate benchmark. Thus, CT trailer side guards would be cost-effective if the estimated average cost per incremental fatality equivalent is less than the comprehensive economic cost of a fatality. Cost-effectiveness is calculated in this analysis by dividing total lifetime discounted costs by equivalent lives saved. Equivalent lives saved are equal to the total discounted safety benefits divided by the comprehensive economic cost of a fatality (e.g., if the estimated safety benefits for injury mitigation were equal to 10 times the comprehensive economic cost of a fatality, the injury mitigation benefits would be represented as equivalent to 10 lives saved). Alternatively, one can represent equivalent lives saved as equal to: (the sum of discounted lives saved) + (the sum of injuries avoided, weighted by the relative values of injuries to fatalities).

Cost-effectiveness estimates for the scenarios considered above are presented in Table 26.

*Table 26. Estimated Cost-Effectiveness by Scenario (Millions of 2020 Dollars per Equivalent Life Saved)*

| **Scenario** | **3% Discount Rate** | **7% Discount Rate** |
|---|---|---|
| Low Cost Estimate, Central Case | $73.5 | $90.3 |
| High Cost Estimate, Central Case | $86.6 | $103.7 |

Consistent with the above comparisons of benefits and costs, the estimated measures of costs per equivalent life saved are six to nine times larger than the estimated comprehensive economic cost of a fatality.

# VI. Sensitivity Analysis

The central analysis detailed in the previous sections represents our preferred representation of the potential benefits and costs of a CT trailer side requirement taking effect in 2022. However, there is uncertainty in the analytical inputs specified in the central analysis (i.e., underreporting factor, hardware cost, changes in CT travel demand due to capacity constraints associated with side guards, side guard effectiveness).

In this sensitivity analysis we explore alternative values for these inputs to identify the extent to which the relationship between benefits and costs associated with a side guard requirement changes as the inputs change. The estimated benefits of requiring CT side guards are affected by assumptions on the underreporting factor, changes in CT travel demand due to capacity constraints associated with side guards, and side guard effectiveness. The corresponding estimated costs are affected by assumptions on hardware cost and changes in CT travel demand due to capacity constraints associated with side guards.

## A. Benefits

As discussed in Section III.A., increasing the underreporting factor from 78 percent to 155 percent (i.e., the upper-bound value from the FARS-PCR review) increases the target population of annual side underride fatalities from 17.7 to 25.4. Similarly, the target population of annual side underride serious injuries increases from 81 to 117 under an underreporting factor of 155 percent. At estimated effectiveness rates of 97 percent in mitigating fatalities and 85 percent in mitigating serious injuries, equipping the entire CT trailer fleet would mitigate 24.7 side underride fatalities (versus 17.2 at a 78% underreporting factor) and 99 serious injuries from side underride crashes (versus 69 at a 78% underreporting factor).

Focusing on the effects of equipping all eligible new CT trailers in 2022 (260,000 out of 6.6 million trailers), applying a 155-percent underreporting factor would result in an estimated reduction of 1.0 side underride fatalities (versus 0.7 at a 78% underreporting factor) and 3.9 serious injuries in side underride crashes (versus 2.7 at a 78% underreporting factor) in 2022. Applying the above estimated fatality and injury impact over an assumed 15.25-year average CT trailer lifetime, we estimate the following discounted lifetime safety benefits:

*Table 27. Estimated Discounted Lifetime Safety Benefits Due to Adoption of CT Trailer Side Guards for All Eligible New CT Trailers in CY 2022 (by Equipped Cohort, Sensitivity Case With 155% Underreporting Factor, Millions of 2020 Dollars)*

| Discount Rate | Lifetime Safety Benefits |
|---|---|
| 3% | $238.1 |
| 7% | $184.5 |

Equipping all eligible new CT trailers with side guards in 2022 is estimated to generate approximately $240 million in lifetime safety benefits each year at a 3-percent discount rate with an underreporting factor of 155 percent ($180 million at a 7% discount rate). This represents a benefit of approximately $920 per trailer at a 3-percent discount rate ($710 per trailer at a 7% discount factor). Consistent with the estimated annual impacts, these estimates are approximately 44 percent larger than the corresponding estimates at a 78-percent underreporting factor.

*Table 28. Estimated Discounted Lifetime Safety Benefits Due to Adoption of CT Trailer Side Guards for All Eligible New CT Trailers in CY 2022 (per Trailer, Sensitivity Case With 155% Underreporting Factor, 2020 Dollars)*

| Discount Rate | Lifetime Safety Benefits |
|---|---|
| 3% | $916 |
| 7% | $710 |

Thus, after applying the highest potential underreporting factor derived from the FARS-PCR review, benefits increase relative to our central case, but are still much lower than estimated costs.

NHTSA does not have sufficient information to estimate the impact of a side guard requirement on CT travel demand (i.e., the increase in vehicle miles traveled (VMT) due to capacity or operating constraints associated with the use of side guards). Using the information cited in Section IV.C. as a guide (i.e., less than 10 percent of CT loads are above 73,000 pounds), here we consider a sensitivity case in which CT VMT increases by 5 percent under a side guard requirement. The estimated impacts of this change in VMT are not constant over time. That is, during the first years of a side guard requirement, much of the additional VMT could be accommodated by legacy CTs that are not equipped with side guards. In later years, most or all of the additional VMT would be accommodated by CTs that are equipped by side guards, due to a steady increase in the share of CTs with side guards over time.

For this sensitivity analysis, we assume that: in the first year of a side guard requirement, 90 percent of incremental CT VMT would involve CTs that are not equipped with side guards; and that by 2038, all incremental CT VMT would involve CTs that are equipped with side guards. We assume no other changes in CT travel demand. Under these assumptions, the estimated annual safety benefits of a side guard requirement would be approximately 5 percent to 9.5 percent, or approximately $360,000 to $690,000 lower. This is not a large effect relative to the other elements considered in the sensitivity analysis, but it does demonstrate how operational constraints could lead to constraints on safety benefits.

## B. Costs

In the central analysis we assume that side guards would be sold at the assumed baseline price for the AngelWing side guard, $2,897 per unit. Under a side guard requirement for all new CT trailers, it is reasonable to expect at least some degree of downward price pressure due to factors such as competition and manufacturing efficiencies (i.e., economic returns to scale). NHTSA does not have sufficient information to assume any particular level of price reduction for side guards if they were required; rather, for this sensitivity case, we consider a 20-percent reduction in hardware costs, to $2,318 per unit (a reduction of $579 per unit).

*Table 29. Estimated Costs of Installing CT Trailer Side Guards on All Eligible New CT Trailers in 2022 (Sensitivity Case: 20-Percent Reduction in Hardware Costs, 2020 Dollars)*

| | Cost |
|---|---|
| Side Guard Hardware Cost | $2,318 |
| Average Labor Cost per Side Guard | $93 |
| Average Cost per Trailer | $2,411 |
| **Total Cost for 260,000 Trailers ($ mil.)** | **$626.9** |

A 20-percent reduction in hardware costs would reduce annual hardware costs by an estimated $151 million, to $603 million. With no assumed change in installation costs ($93 per trailer), total annual hardware and installation would be an estimated $626.9 million, versus $777.5 in the central analysis.

Returning to the theme of potential changes in CT VMT discussed in Section VI.A., we consider a sensitivity case in which CT trailer VMT increase by 5 percent due to capacity and operational constraints under a side guard requirement. Compared to the safety impacts of this change, the potential cost impacts are more complex. Not only are there fuel consumption impacts to consider, but also all other relevant operational costs (e.g., driver wages, incremental maintenance, administration).

While the central analysis focuses on incremental costs of carrying new side guard mass across all VMT, the additional fuel cost impacts in this sensitivity case involve the incremental costs of carrying all CT mass – side guard included – across the 5-percent increment of VMT. The resulting estimates of incremental fuel costs dominate all other impact measures in both the central analysis and the sensitivity analysis: If a side guard requirement led to a 5-percent increase in CT VMT, the lifetime fuel costs associated with the increase in VMT are estimated to be approximately $2.5 billion at a 3-percent discount rate ($2.0 billion at a 7% discount rate). This represents a fuel cost impact approximately 5 to 10 times as large as the incremental fuel costs associated with side guard weight.

Furthermore, additional CT VMT would necessitate additional operating costs that do not apply to the baseline CT VMT considered in the central analysis. According to Williams and Murray (2020), fuel costs represented approximately one-fourth of total average marginal trucking costs from 2015 to 2019. Based on this relationship, the total lifetime operational cost impacts (less Federal and State fuel taxes) for a given year of CT trailers associated with a 5-percent increase in CT VMT would be estimated to be on the order of $10-$15 billion, depending on the discount rate. These estimates are purely speculative but underscore the potential for operational cost impacts to outweigh potential safety impacts by a wide margin.

### C. Net Benefits, BCRs, and Cost-Effectiveness

With the estimates above, we are able to examine the sensitivity cases introduced in this section. The results are summarized in the following table:

*Table 30. Estimated Total Benefits, Total Costs, Net Benefits, by Sensitivity Case (Equipping 260,000 Eligible New CT Trailers With Side Guards in 2022, Millions of 2020 Dollars)*

| **Sensitivity Case** | **3% Discount Rate** | **7% Discount Rate** |
|---|---|---|
| ***Total Benefits:*** | | |
| *Central Case: 78% Underreporting Factor* | *$165.9* | *$128.5* |
| 155% Underreporting Factor | $238.1 | $184.5 |
| ***Total Costs:*** | | |
| *Central Case: 450-Pound Side Guard* | *$1,022.5* | *$972.7* |
| *Central Case: 800-Pound Side Guard* | *$1,203.8* | *$1,117.2* |
| 20% Lower Hardware Costs, 450-Pound Side Guard | $871.9 | $822.1 |
| 20% Lower Hardware Costs, 800-Pound Side Guard | $1,053.2 | $966.5 |
| 20% Lower Hardware Costs, 450-Pound Side Guard, 5% Increase in VMT | $3,322.3 | $2,774.4 |
| 20% Lower Hardware Costs, 800-Pound Side Guard, 5% Increase in VMT | $3,512.6 | $2,926.1 |
| 450-Pound Side Guard, 5% Increase in VMT | $3,472.9 | $2,925.1 |
| 800-Pound Side Guard, 5% Increase in VMT | $3,663.3 | $3,076.7 |
| ***Net Benefits for Selected Sensitivity Cases (equals total benefits less total costs):*** | | |
| *Central Case: 450-Pound Side Guard* | *-$856.7* | *-$844.2* |
| *Central Case: 800-Pound Side guard* | *-$1,037.9* | *-$988.7* |
| 155% Underreporting Factor, 450-Pound Side Guard | -$784.4 | -$788.3 |
| 155% Underreporting Factor, 800-Pound Side Guard | -$965.7 | -$932.7 |
| 78% Underreporting Factor, 20% Lower Hardware Costs, 450-Pound Side Guard | -$706.0 | -$693.6 |
| 78% Underreporting Factor, 20% Lower Hardware Costs, 800-Pound Side Guard | -$887.3 | -$838.0 |
| 155% Underreporting Factor, 20% Lower Hardware Costs, 800-Pound Side Guard | -$815.0 | -$782.0 |
| Best-Case Scenario: 155% Underreporting Factor, 20% Lower Hardware Costs, 450-Pound Side Guard | -$633.8 | -$637.6 |

In all sensitivity cases (including additional permutations of the benefit and cost measures in the above table), net benefits are negative. In the best-case scenario across the assumptions considered (i.e., 155% underreporting factor and 20% lower hardware costs), estimated lifetime net benefits for an entire cohort of new CT trailers are approximately -$630 million at a 3% discount rate (-$640 million at a 7% discount rate). Across the sensitivity cases considered, hardware costs tend to be the predominant driver of negative net benefits, but the effect of side guard weight on incremental fuel costs is also a critical factor. Allowing for incremental CT travel due to operational constraints associated with side guards would compound incremental fuel cost impacts considerably, making fuel consumption the primary cost consideration.

The estimated BCRs present benefits relative to costs for the sensitivity cases considered above.

*Table 31. Estimated BCRs by Sensitivity Case*

| Sensitivity Case | 3% Discount Rate | 7% Discount Rate |
|---|---|---|
| 155% Underreporting Factor, 450-Pound Side Guard | 0.23 | 0.19 |
| 155% Underreporting Factor, 800-Pound Side Guard | 0.20 | 0.17 |
| 78% Underreporting Factor, 20% Lower Hardware Costs, 450-Pound Side Guard | 0.19 | 0.16 |
| 78% Underreporting Factor, 20% Lower Hardware Costs, 800-Pound Side Guard | 0.16 | 0.13 |
| 155% Underreporting Factor, 20% Lower Hardware Costs, 800-Pound Side Guard | 0.23 | 0.19 |
| Best-Case Scenario: 155% Underreporting Factor, 20% Lower Hardware Costs, 450-Pound Side Guard | 0.27 | 0.22 |

In the best-case scenario estimated lifetime benefits are approximately 27 percent as large as estimated lifetime costs at a 3-percent discount rate (22% at a 7% discount rate). The estimated BCRs range from 0.16 to 0.23 across the other scenarios at a 3% discount rate (0.03 to 0.19 at a 7% discount rate).

Last, we present cost-effectiveness measures for the sensitivity cases considered in this section.

*Table 32. Estimated Cost-Effectiveness by Sensitivity Case*
*(Millions of 2020 Dollars per Equivalent Life Saved*

| Sensitivity Case | 3% Discount Rate | 7% Discount Rate |
|---|---|---|
| 155% Underreporting Factor, 450-Pound Side Guard | $51.2 | $62.9 |
| 155% Underreporting Factor, 800-Pound Side Guard | $60.3 | $72.2 |
| 78% Underreporting Factor, 20% Lower Hardware Costs, 450-Pound Side Guard | $62.7 | $76.3 |
| 78% Underreporting Factor, 20% Lower Hardware Costs, 800-Pound Side Guard | $75.7 | $89.7 |
| 155% Underreporting Factor, 20% Lower Hardware Costs, 800-Pound Side Guard | $52.8 | $62.5 |
| Best-Case Scenario: 155% Underreporting Factor, 20% Lower Hardware Costs, 450-Pound Side Guard | $43.7 | $53.2 |

## VII. Conclusion

The cost-benefit analysis presented in this document indicates that equipping CT trailers with side underride guards would mitigate fatalities (and would likely also mitigate serious injuries) in LPV occupants associated with side underrides, but that the costs of doing so would exceed the benefits conditional on the assumptions and data limitations in the analysis. Equipping a new trailer with side guards is estimated to generate approximately $640 in lifetime discounted safety benefits at a 3-percent discount rate under the central range of assumptions evaluated (approximately $490 per trailer at a 7% discount rate).

These estimates reveal that one equivalent life would be saved (at a value of approximately $11.9 million) per approximately 18,700 trailers at a 3-percent discount rate under the central assumptions (per approximately 24,100 trailers at a 7% discount rate). The total discounted lifetime costs of equipping new trailers with side guards are estimated to be between approximately $3,930 and $4,630 per trailer at a 3-percent discount rate (between approximately $3,740 and $4,300 per trailer at a 7% discount rate), or six to nine times as large as the corresponding estimated safety benefits.

The analysis considered a range of input assumptions to account for uncertainty in the size of the target population, hardware costs, and fuel consumption impacts. Across all combinations of input assumptions considered, the estimated costs of equipping trailers with side guards exceed the estimated benefits. There is uncertainty in the assumptions that could lead to higher benefit estimates in light of additional information. The target population of fatalities and serious injuries could increase if: (1) the baseline level of relevant fatalities and serious injuries is much larger than estimated based on the FARS data and the PCR review; or (2) CT trailer side guards had some protective effect at impact speeds above 40 mph. The PCR review offered a thorough analysis of one year's LPV-CT crashes that could have resulted in side underride at impact speeds up to 40 mph, and established a meaningful estimate of the rate of underreporting side underrides in FARS. By basing our estimated target population on the underreporting factor from the PCR review, we are confident that we have represented the target population accurately. Furthermore, the sensitivity analysis allowed for a much larger underreporting factor, and found that the estimated benefits were still much smaller than the estimated costs associated with a side guard requirement.

Because side underride occurs predominantly at impact speeds above 40 mph, protective effects above 40 mph could generate a large incremental improvement above the safety benefits estimated in this analysis. However, we do not have information available on the degree to which side guards may offer a safety improvement beyond their 40-mph test limit. As such, any estimated benefits above 40 mph would be purely speculative. Similarly, the results of this study reflect existing side guard designs. It is possible that future designs may: mitigate side underride at higher speeds (increasing safety benefits); have lower hardware costs (reducing lifetime costs); or weigh less (reducing lifetime costs). However, we do not have any data to support assuming these characteristics in place of our baseline assumptions.

There are also unquantified factors that would be expected to reduce net benefits further. As discussed above, the safety benefits may be smaller than estimated due to decreases in crash risks associated with ADAS (e.g., reduced frequency of impacts with trailers due to technologies such as blind spot monitoring and lane keep assist, reduced impact speeds due to AEB), leading to a smaller baseline level of side underride fatalities and serious injuries. Cost impacts may also be larger than estimated due to: incremental travel due to axle weight and space constraints (e.g., loss of carrying capacity due to the presence of reinforcing structure may shift some cargo to new truck trips that would not otherwise have taken place); and incremental operating costs associated with repair due to trailer damage caused by the use of side guards (e.g., wear and tear associated with additional overall weight and additional stresses around reinforcing structure).

The analysis in this document supports the value of mitigating LPV-CT trailer crashes and resulting fatalities and serious injuries. The central finding is not that there is no safety issue, but rather that a hardware-based solution presents logistical barriers due to hardware costs and the expected weight of side guards. Based on this finding, we conclude that alternative approaches to mitigating LPV-CT trailer crashes warrant further attention. As focal examples, ADAS represents a countermeasure that could reduce the frequency of LPV-CT trailer crashes, fatalities, and serious injuries.

## References


49 CFR Part 571, Docket No. 1–11, Notice 11, RIN 2127–AA43, Federal Motor Vehicle Safety Standards Rear Impact Guards; Rear Impact Protection, Federal Register, Vol. 61, No. 16 January 24, 1996.

49 CFR Part 571, 80 FR 60320, Docket No. NHTSA-2015-0070, October 6, 2015. Advance Notice of Proposed Rulemaking, Federal Motor Vehicle Safety Standards; Rear Impact Protection, Lamps, Reflective Devices, and Associated Equipment Single Unit Trucks

80 FR 78417. Rear Impact Guards, Rear Impact Protection. *Federal Register*, December 16, 2015, pp. 78417-60. https://thefederalregister.org/80-FR/78417

Adler, A. (2018, August 29). Fleets adopt trailer fuel-efficiency tech as Federal rules stall [Webpage]. Trucks.com. www.trucks.com/2018/08/29/fleets-adopt-trailer-fuel-efficiency-tech/

AirFlow Deflector Inc. (n.d./a). T*ruck side guards – Lateral underride protection devices; Meets all city, government, and insurance standards* (Web page). https://airflowdeflector.com/airflow-2/

AirFlow Deflector Inc. (n.d./b). *Angel Wing* [sic] *truck side guard. Tested by the IIHS to prevent side underride* (Web page). https://airflowdeflector.com/angelwing_underride-1/ [Angel Wing should be AngelWing, a trademarked name.]

Bligh, R. P., Dobrovolny, C. S., Akram, S., Abu-Odeh, N., & Kovar, J. (2018, April). *Computer modeling and evaluation of side underride protective device designs* (Report No. DOT HS 812 522). National Highway Traffic Safety Administration. www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/13611_supd_report_041118_v4-tag.pdf

Blincoe, L., Miller, T., Zaloshnja, E., & Lawrence, B. (2015, May). *The economic and societal impact of motor vehicle crashes, 2010 (Revised)* (Report No. DOT HS 812 013). National Highway Traffic Safety Administration. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812013

Blower, D., Woodrooffe, J., & Page, O. (2012, August). *Analysis of rear underride in fatal truck crashes, 2008* (Report No. DOT HS 811 652). National Highway Traffic Safety Administration. https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/811652.pdf

Blower, D., & Woodrooffe, J. (2013, March). Heavy-vehicle crash data collection and analysis to characterize rear and side underride and front override in fatal truck crashes (Report No. DOT HS 811 725). National Highway Traffic Safety Administration. https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/811725.pdf

Bureau of Labor Statistics. (2021a, March 31). *Occupational employment statistics: May 2020 National Occupational Employment and Wage Estimates, United States* (Web page). www.bls.gov/oes/current/oes_nat.htm#49-0000

Bureau of Labor Statistics. (2020b, September 17). *Employer costs for employee compensation summary* (Web page. Release No. USDL-20-1736). www.bls.gov/news.release/ecec.nr0.htm

Bureau of Transportation Statistics. (2020a, August 20). *Truck profile* (Web page). www.bts.gov/content/truck-profile

Bureau of Transportation Statistics. (2020b, September 18). *U.S. vehicle miles* (Web page). www.bts.gov/content/us-vehicle-miles

Department of Transportation. (2021, March). *Departmental guidance: Treatment of the value of preventing fatalities and injuries in preparing economic analyses* (Web page). www.transportation.gov/sites/dot.gov/files/2021-03/DOT%20VSL%20Guidance%20-%202021%20Update.pdf

Energy Information Administration. (2021a). *Annual energy outlook 2021: Table 7. Transportation sector key indicators and delivered energy consumption* (Web page). www.eia.gov/outlooks/aeo/data/browser/#/?id=7-AEO2021&cases=ref2021&sourcekey=0

EIA. (2021b). *Annual energy outlook 2021: Table 12. Petroleum and other liquids prices* (Web page). www.eia.gov/outlooks/aeo/data/browser/#/?id=12-AEO2021&cases=ref2021&sourcekey=0

EIA. (2022). *Federal and state motor fuels taxes[1]* [Excel spreadsheet]. www.eia.gov/petroleum/marketing/monthly/xls/fueltaxes.xls

Evans, L. (1994). Driver injury and fatality risk in two-car crashes versus mass ratio using Newtonian mechanics. *Accident Analysis and Prevention*, *Vol. 26,* No. 5, pp. 609-16.

Federal Highway Administration. (n.d.). *Annual vehicle distance traveled in miles and related data - 2017(1) by highway category and vehicle type* (Web page table in Office of Highway Policy Information, Highway Statistics Series). www.fhwa.dot.gov/policyinformation/statistics/2017/pdf/vm1.pdf

Federal Reserve Bank of St. Louis. (2020, July 30). *Gross domestic product (implicit price deflator)* (Web page. Report No. A191RD3A086NBEA). https://fred.stlouisfed.org/series/A191RD3A086NBEA

Government Accountability Office. (2019, March). *Truck underride guards: Improved data collection, inspections, and research needed* (Report to Congressional Requesters. Report No. GAO-19-264). https://www.gao.gov/assets/700/697585.pdf

Hooper, A. & Murray, D. (2017, October). *An analysis of the operational costs of trucking: 2017 update*. PAmerican Transportation Research Institute. https://truckingresearch.org/wp-content/uploads/2017/10/ATRI-Operational-Costs-of-Trucking-2017-10-2017.pdf

ICF International. (2009). *Opportunities to reduce greenhouse gas emissions from trucking.* Environmental Defense Fund.

Institute for Internal Combustion Engines and Thermodynamics (2011). *Evaluation of Fuel-efficiency improvements in the heavy-duty vehicle (HDV) sector from improved trailer and tire designs by application of a new test procedure* (Report No. I-24/2011 Hb-Em 18/11/679).

Insurance Institute for Highway Safety. (2017a, May 10). *IIHS tests show benefits of side underride guards for semitrailers*. www.iihs.org/iihs/news/desktopnews/iihs-tests-show-benefits-of-side-underride-guards-for-semitrailers

IIHS. (2017b, August 29). *Side guard on semitrailer prevents underride in 40 mph test*. https://www.iihs.org/iihs/news/desktopnews/side-guard-on-semitrailer-prevents-underride-in-40-mph-test

Joksch, H. C. (1993). Velocity change and fatality risk in a crash: A rule of thumb. *Accident Analysis and Prevention*, *Vol. 25*, No. 1, pp. 103-4.

Mazareanu, E. (2020). *Class 3-8 truck sales in the United States from 2001 to 2019* (Web page). Statista. www.statista.com/statistics/261416/class-3-8-truck-sales-in-the-united-states/

Morgan, T. (2001). *The effectiveness of retroreflective tapes on heavy trailers* (Report No. DOT HS 809 222). National Highway Traffic Safety Administration. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/809222

National Center for Statistics and Analysis. (2019, December). *Seat belt use in 2019 – Overall results* (Traffic Safety Facts Research Note. Report No. DOT HS 812 875). National Highway Traffic Safety Administration. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812875

National Highway Traffic Safety Administration. (1991). Preliminary Regulatory Evaluation – Combination Truck Rear Underride Guards, NHTSA Docket No. 1-11-n09, p. 15.

Nolan, J. M., Preuss, C. A., Jones, S. L., & O'Neill, B. (1998, May 31-June 4). *An update on the relationships between computed delta Vs and impact speeds for offset crash tests*. 16th International Technical Conference on the Enhanced Safety of Vehicles, Windsor, ON, Canada, pp. 1234-41.

Office of Management and Budget. (n.d.). Circular A-94 – Guidelines and discount rates for benefit-cost analysis of federal programs, memorandum for heads of executive departments and establishments. https://obamawhitehouse.archives.gov/sites/default/files/omb/assets/a94/a094.pdf

Padmanaban, J. (2013) Estimating side underride fatalities using field data. *Annals of Advances in Automotive Medicine*, *Vol. 57*, pp. 225-32.

Petersen, J. (2013, October 17). Data on class 8 tractor-trailer combination weights (Blog post). Seeking Alpha[α] https://seekingalpha.com/instablog/227454-john-petersen/2323012-data-on-class-8-tractor-trailer-combination-weights

Pickrell, T. M., Li. R., & Shova, K. C. (2016, September). *Occupant restraint use in 2015: Results from the NOPUS controlled intersection study* (Report No. DOT HS 812 330). National Highway Traffic Safety Administration. ww.crashstats.nhtsa.dot.gov/Api/Public/Publication/812330

Pickrell, T. M. and Ye, T.J. (2011, November). *Occupant restraint use in 2010: Results from the NOPUS controlled intersection study* (Report No. DOT HS 811 527). National Highway Traffic Safety Administration. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/811527

PHSS Fortier. (n.d.). *Our product – Lateral protection – Protection latérale* (Web page). https://protectionlaterale.ca/en/our-product-lateral-protection/

Porav, H., & Newman, P. (2018, November 4-7). *Imminent collision mitigation with reinforcement learning and vision*. 21st IEEE International Conference on Intelligent Transport Systems, Maui, Hawaii.

Radio Canada. (2019). *Lac-mégantic invention could save lives* (Web page). https://ici.radio-canada.ca/nouvelle/1127212/jupes-laterales-protection-vinyle-fortier-invention-lac-megantic

Scott, T. (2010, July 26). *Trucking in America* (PowerPoint) National Conference of State Legislators, Louisville, KY. www.ncsl.org/documents/transportation/TScott72610.pdf

Seven Hills Engineering, LLC. (2020). *Underride* (Web page). http://7he.us/underride/

Sharpe, B., & Roeth, M. (2014, February). *Costs and adoption rates of fuel-saving technologies for trailers in the North American on-road freight sector*. International Council on Clean Transportation.

Shelton, R. 2006, April). *Potential costs, safety benefits, and cost-effectiveness of side impact guards for truck trailers* [a.k.a. TTMA side impact exhibits A-D 2016-05-13], In Docket NHTSA-2015-0118). Truck Trailer Manufacturers Association. https://downloads.regulations.gov/NHTSA-2015-0118-0041/attachment_2.pdf

Sims, J. (2016, May 31). TTMA Side Impact Main Comment 2016-05-13. In Docket NHTSA-2015-0118). Truck Trailer Manufacturers Association. [Letter from Sims to NHTSA]. https://downloads.regulations.gov/NHTSA-2015-0118-0041/attachment_1.pdf

Trailer/Body Builders. (2017). *Wabash prototype: Side underride guard with aero skirt* (Web page). www.trailer-bodybuilders.com/trailers/article/21742324/wabash-prototype-side-underride-guard-with-aero-skirt

Trailer/Body Builders. (2020). *Trailer output report archive*, 1993-Present (Web portal). www.trailer-bodybuilders.com/page/trailer-output/trailer-output-report-archive

Wang, J.-S., & Blincoe, L. (2003, May). Belt use regression model – 2003 update (Report No. DOT HS 809 639). National Highway Traffic Safety Administration. https://permanent.fdlp.gov/websites/crashstats.nhtsa.dot.gov/pdf/lps99504.pdf

Williams, N., & Murray, D. (2020, November). *An analysis of the operational cost of trucking*. American Transportation Research Institute.

Wood, R. (2012). EPA Smartway verification of trailer undercarriage advanced aerodynamic drag reduction technology. *Journal of Commercial Vehicles*, Vol. 5, No. 2, pp. 607-15.

Worth, M., & Guerrero, A. (2016). *2016 freight quick facts report* (Report No. FHWA-HOP-16-083). Federal Highway Administration. https://ops.fhwa.dot.gov/publications/fhwahop16083/fhwahop16083.pdf

# Appendix A: SAS Code Used to Identify the Target Population

```
/* Step 1: Libnames and Data Sources  */

LIBNAME FARS17 "XXXXX";

data FARS17.accident_F; set accident_F; run;
data FARS17.vehicle_F; set vehicle_F; run;
data FARS17.person_F; set person_F; run;
data FARS17.ENH2017; set ENH2017; run;
data FARS17.Fanalysis; set Fanalysis; run;
data FARS17.Fanalysis_per; set Fanalysis_per; run;
data FARS17.sideCT_Fcar_ENH2017; set sideCT_Fcar_ENH2017; run;
data fars17.sideCT_Fcar_per17; set data sideCT_Fcar_per17; run;

/* data saving  data sideCT_Fcar_ENH2017;   */

/*  ***************  FARS Data  ***********  */

libname FARS2001 'L:\FARS\2001\';
libname FARS2002 'L:\FARS\2002\';
libname FARS2003 'L:\FARS\2003\';
libname FARS2004 'L:\FARS\2004\';
libname FARS2005 'L:\FARS\2005\';
libname FARS2006 'L:\FARS\2006\';
libname FARS2007 'L:\FARS\2007\';
libname FARS2008 'L:\FARS\2008\';
libname FARS2009 'L:\FARS\2009\';
libname FARS2010 'L:\FARS\2010\';
libname FARS2011 'L:\FARS\2011\';
libname FARS2012 'L:\FARS\2012\';
libname FARS2013 'L:\FARS\2013\';
libname FARS2014 'L:\FARS\2014\';
libname FARS2015 'L:\FARS\2015\';
libname FARS2016 'L:\FARS\2016\';
libname FARS2017 'L:\FARS\2017\';
libname FARS2018 'L:\FARS\2018\';

options nofmterr;
*options ls=150 pagesize=63 nofmterr formchar='|-E+OE+=|-/\<>*';

/* Step 2: ACC and VEH FARS data  **********************  */

data Accident_F  (keep=year state st_case fatals sp_limit VE_forms
splTYPE sp_limit vspd_lim man_coll harm_EV city month day hour
sur_cond surf_NEW road_fnc Vlan_NUM lan_num no_lanes lgt_COND weather weather1);
```

```
drop latitude longitude;
set     fars2001.accident(in=yr2001) fars2002.accident(in=yr2002) fars2003.accident(in=yr2003)
        fars2004.accident(in=yr2004) fars2005.accident(in=yr2005) fars2006.accident(in=yr2006)
        fars2007.accident(in=yr2007) fars2008.accident(in=yr2008) fars2009.accident(in=yr2009)
        fars2010.accident(in=yr2010) fars2011.accident(in=yr2011) fars2012.accident(in=yr2012)
        fars2013.accident(in=yr2013) fars2014.accident(in=yr2014) fars2015.accident(in=yr2015)
        fars2016.accident(in=yr2016) fars2017.accident(in=yr2017) fars2018.accident(in=yr2018);

if yr2001 then year=2001;      else if yr2002 then year=2002;
        else if yr2003 then year=2003; else if yr2004 then year=2004;
        else if yr2005 then year=2005; else if yr2006 then year=2006;
        else if yr2007 then year=2007; else if yr2008 then year=2008;
        else if yr2009 then year=2009; else if yr2010 then year=2010;
        else if yr2011 then year=2011; else if yr2012 then year=2012;
        else if yr2013 then year=2013; else if yr2014 then year=2014;
        else if yr2015 then year=2015; else if yr2016 then year=2016;
        else if yr2017 then year=2017;  else if yr2018 then year=2018;
run;

/*  step 3: VEH FARS Files */

data vehicle;
/* (keep=year mod_year myear_c state st_case veh_no body_c body_typ
make vin gvwr WGTCD_TR PWGTCD_TR vin_WGT WT_C vspd_lim impact1 impact2 p_crash1
veh_man UNDERIDE UNDER_C trav_sp drive_V J_Knife M_HARM SEQ1
RollOVER VSURCOND surf_NEW VNUM_LAN);
*/
set fars2001.vehicle(in=cy01) fars2002.vehicle(in=cy02) fars2003.vehicle(in=cy03)
   fars2004.vehicle(in=cy04) fars2005.vehicle(in=cy05) fars2006.vehicle(in=cy06)
   fars2007.vehicle(in=cy07) fars2008.vehicle(in=cy08) fars2009.vehicle(in=cy09)
   fars2010.vehicle(in=cy10) fars2011.vehicle(in=cy11) fars2012.vehicle(in=cy12)
   fars2013.vehicle(in=cy13) fars2014.vehicle(in=cy14) fars2015.vehicle(in=cy15)
   fars2016.vehicle(in=cy16) fars2017.vehicle(in=cy17) fars2018.vehicle(in=cy18);

if cy01 then year=2001;
else if cy02 then year=2002; else if cy03 then year=2003; else if cy04 then year=2004;
else if cy05 then year=2005; else if cy06 then year=2006; else if cy07 then year=2007;
else if cy08 then year=2008; else if cy09 then year=2009; else if cy10 then year=2010;
else if cy11 then year=2011; else if cy12 then year=2012; else if cy13 then year=2013;
else if cy14 then year=2014; else if cy15 then year=2015; else if cy16 then year=2016;
else if cy17 then year=2017; else if cy18 then year=2018;

/* define combination truck, or CT, see Manual NCSA 2019 Verified  */
if ( body_typ in (60 61 62 63 64 67 71 72 78 79) and (1 le tow_veh le 4) )
  or body_typ=66 then body_C =1;
```

```
/*** Single unit truck, or SU ***/
if body_typ in (60 61 62 63 64 67 71 72 78 79) and tow_veh in (0 5 9)
   then body_C =2;

/***** BUS ***/
if 50 le body_typ le 59 then body_c =3;              /* update NOV 2015  */

/*** PV light vehicle <=10, 000 lbs***/
if  (01 <= body_typ <=11) or (14 <= body_typ <=22)
     or (28 <= body_typ <= 41) or (45 <=body_typ <=49)
     or (24 <= body_typ <=25)
     or (body_typ=79 and tow_veh in (0 9))
then body_C =4;
                  /* Manual PV =01-11, 14-16, 19-22, 24(1), 25(2), 28-41, 45-49,
                  or (79 and tow_veh=0 or 9) or 17 (since 2010)
                        Verify again 2019 FEB     */
drive_V =.;
if (0< TRAV_SP<=30) OR (0< SPeed <=30) then drive_V= 1;  *'000-30';
else if (31<= TRAV_SP <=40) OR (31<= SPeed <=40)then drive_V= 2;   *'31-40';
else if (41<= TRAV_SP <=50) OR (41<= SPeed <=50)then drive_V= 3;   *'41-50';
else if (51<= TRAV_SP <=55) OR (51<= SPeed <=55)then drive_V= 4;   *'51-55';
else if (56<= TRAV_SP <=60) OR (56<= SPeed <=60)then drive_V= 5;    *'56-60';
else if (61<= TRAV_SP <=65) OR (61<= SPeed <=65)then drive_V= 6;    *'61-65';
else if (66<= TRAV_SP <=70) OR (66<= SPeed <=70)then drive_V= 7;    *'66-70';
else if (71<= TRAV_SP <=75) OR (71<= SPeed <=75)then drive_V= 8;       *''71-75';
else if (76<= TRAV_SP <=149 and TRAV_SP not in (98,99,998,999))
OR (76<= speed <=149 and speed not in (98,99,998,999)) then drive_V= 9;   *over 76 100-149';

if 0<=(year - MOD_year)<=2 then myear_c =1;
else if 3<=(year - MOD_year)<=5 then mYEAR_c =2;
else if 5<=(year - MOD_year)<=9 then mYEAR_c =3;
else if 10<=(year - MOD_year)<=20 then mYEAR_c =4;
else if 21<=(year - MOD_year)<=30 then mYEAR_c =5;
else mYear_c =.;

/* addtional ref for weight  */
            WT_c=.;
            if GVWR=1 or 1<=VIN_WGT <=9998 or WGTCD_TR in (1,2) or PWGTCD_TR in (1,2) then
WT_c=1;   /* light veh passenger car  */
            else if GVWR=2 or WGTCD_TR in (3,4,5,6) or PWGTCD_TR in (3,4,5,6) then WT_c=2;
/* middle WT  */
            else if GVWR=3 or WGTCD_TR in (7,8) or PWGTCD_TR in (7,8) then WT_c=3;     /* heavy
truck  */
run;

/* Person FARS Files */
```

```
data person_F (keep=year state st_case veh_no age AGE_c
sex sex_c rest_use belt_C Fatal_C seat_pos seat_c
inj_SEV per_TYP per_TYPE ejection ej_path);
set fars2001.person(in=cy01) fars2002.person(in=cy02) fars2003.person(in=cy03)
   fars2004.person(in=cy04) fars2005.person(in=cy05) fars2006.person(in=cy06)
   fars2007.person(in=cy07) fars2008.person(in=cy08) fars2009.person(in=cy09)
   fars2010.person(in=cy10) fars2011.person(in=cy11) fars2012.person(in=cy12)
   fars2013.person(in=cy13) fars2014.person(in=cy14) fars2015.person(in=cy15)
   fars2016.person(in=cy16) fars2017.person(in=cy17) fars2018.person(in=cy18);

if cy01 then year=2001; else if cy02 then year=2002; else if cy03 then year=2003;
else if cy04 then year=2004; else if cy05 then year=2005; else if cy06 then year=2006;
else if cy07 then year=2007; else if cy08 then year=2008; else if cy09 then year=2009;
else if cy10 then year=2010; else if cy11 then year=2011; else if cy12 then year=2012;
else if cy13 then year=2013; else if cy14 then year=2014; else if cy15 then year=2015;
else if cy16 then year=2016; else if cy17 then year=2017; else if cy18 then year=2018;

        if 11<=seat_pos <=19 then seat_c =1;
        else if 20<=seat_pos <=54 then seat_c =0;
        else seat_c =.;
        if sex =2 then sex_c =1;  /*female  */
        else sex_c =0;

        if 0<= age <=3 then age_c =1;
        else if 4<= age <=7 then age_c =2;
        else if 8<= age <=12 then age_c =3;
        else if 13<= age <=21 then age_c =4;
        else if 22<= age <=45 then age_c =5;
        else if 46<= age <=65 then age_c =6;
        else if 66<= age <=97 then age_c =7;
        else age_c =.;

        if rest_use in (0,7) then belt_c =1;        /* not used  */
        else if rest_use in (1,2,3,4,5,6,8,10,11,12,13) then belt_c=0;  /*use belt  */
        else belt_c=.;  /* 98,99, missing or unknown  */                /* use belt  */

*if inj_sev in (4,6) then fatal_c=1;
if inj_sev eq 4 then fatal_c=1;
else fatal_C=0;
*if per_typ in (1,2,9)  OR per_TYPE in (1,2,9);          /* driver and passenger */
run;

/* ***** Step 2: Sort and merge sort all 3 data files *****  */
proc sort data=person_F;
by year  state st_case veh_no; run;
proc sort data=accident_F;
```

```
by year  state st_case; run;
proc sort data=vehicle_F;
by year  state st_case veh_no; run;


/* ***** Step 3: Merge Data ***** */
data fanalysis;
merge vehicle_F(in=veh) accident_F(in=acc);          /* try 2 types of vehicle files  */
by year state st_case;
if veh and acc;                         /*   only VEH?? June 12  18  */
if year le 2009 then do;
      if 20<=SP_LIMIT <=30 then spltype=1;
                  else if 31 <=SP_LIMIT <=40 then spltype=2;
                  else if 41 <=SP_LIMIT <=50 then spltype=3;
                  else if SP_LIMIT=55 then spltype=4;
                  else if SP_LIMIT=60 then spltype=5;
                  else if SP_LIMIT=65 then spltype=6;
      else if SP_LIMIT=70 then spltype=7;
                  else if SP_LIMIT=75 then spltype=8;
      else if SP_LIMIT=80 then spltype=9;
                  else splTYPE= .;    /* missing  */
            end;

      else if year ge 2010 then do;
      if 20<= VSPD_LIM <=30 then spltype=1;
                  else if 31 <=VSPD_LIM <=40 then spltype=2;
                  else if 41 <=VSPD_LIM <=50 then spltype=3;
      else if VSPD_LIM=55 then spltype=4;
                  else if VSPD_LIM=60 then spltype=5;
                  else if VSPD_LIM=65 then spltype=6;
      else if VSPD_LIM=70 then spltype=7;
                  else if VSPD_LIM=75 then spltype=8;
         else if VSPD_LIM=80 then spltype=9;
                  else spltype= .;
         end;

         IF (sur_COND IN (2,3,4,5,6,7) or VSURCOND in (2,3,4,5,6,7,8,10,11)) THEN surf_C =1;
         ELSE IF (SUR_COND =1 or VsurCOND =1) THEN surf_C=0;    /* DRY VS. WORSE  */
         else surf_c =.;

         if 2001<= year <=2009 then surf_new = sur_COND;
         else if year >=2010 then surf_NEW = VsurCOND;

         if weather in (2,3,4,5,6,7) then weather_c=1;
         else if weather in (0,1)then weather_c=0;
```

```
        if (No_Lanes in (3,4,5,6,7) or VNUM_lan in (3,4,5,6,7)) then lane_c=1;
        else if No_Lanes in (1,2) or VNUM_lan in (1,2) then lane_c=0; else lane_c =.;

   if UNDERIDE = 0 then UNDER_c=0;
        else if  1<= UNDERIDE <=6 then under_c =1;
   else under_c =.;
                                  /* update NOV 2015  */
run;

proc sort data=Fanalysis;
by year  state st_case veh_no; run;

/*  ***** Step 4: Identify HEAVY  VEH CT and SU with side or undercarriage damage *****  */

data side_CT_F;
set Fanalysis;
        /*   side impacts only and 14 is undercarriage */
if impact1 in (2,3,4,8,9,10,14, 61,62,63,81,82,83);
if body_C in (1) and (2001<=year <=2018);  /* 1= CT, 2=SU choose body_C for CT, SU, and BUS here
*/
run;

data front_CT_F;
set Fanalysis;
        /*   side impacts only and 14 is undercarriage */
if impact1 in (11,12,1, 14);
if body_C in (1) and (2001<=year <=2018);  /* 1= CT, 2=SU choose body_C for CT, SU, and BUS here
*/
run;

data rear_CT_F;
set Fanalysis;
        /*   side impacts only and 14 is undercarriage */
if impact1 in (5,6,7, 14);
if body_C in (1) and (2001<=year <=2018);  /* 1= CT, 2=SU choose body_C for CT, SU, and BUS here
*/
run;

/*  ***** identify light veh with frontal or top damage *******  */
data vehicle_light_frontaL;
set Fanalysis;
light_body_TYP = body_TYP;
if (WT_c=1 or body_c=4) and (impact1 in (11,12,1, 13));
         /* frontal 11,12,1 and top damage 13*/
run;
```

```
/*  ***** identify light veh with rear or top damage *******  */
data vehicle_light_rear;
set Fanalysis;
light_body_TYP = body_TYP;
if (WT_c=1 or body_c=4) and (impact1 in (5,6,7, 13));
            /* frontal 11,12,1 and top damage 13 */
run;

/*  2017 examples  *****************  */
/* ********* 2017 examples 2 veh *****************  */

data sideCT_Fcar_couple;
    /* side/undecarriage damaged CT and fontal damaged car  */
merge side_CT_F (in=a) vehicle_light_frontal(in=b);
by year state st_case;                  *veh_no;
if a and b;
if man_COLL in (3,4,5,6,7,8,99) and (body_c =4 or WT_c=1) and ve_forms =2;

/* one year example CT and side-interactions only  */
title "smaller size: side damaged CT and frontal damaged car with Man_collisons angled";
run;

data frontCT_Fcar_couple;
    /* side/undecarriage damaged CT and fontal damaged car  */
merge front_CT_F (in=a) vehicle_light_frontaL(in=b);
by year state st_case;                  *veh_no;
if a and b;
if man_COLL in (2,99) and (body_c =4 or WT_c=1) and ve_forms =2;
/* one year example CT and front-front manners only  */
title "smaller size: side damaged CT and frontal damaged car with Man_collisons angled";
run;

data rearCT_Fcar_couple;
    /* side/undecarriage damaged CT and fontal damaged car  */
merge rear_CT_F (in=a) vehicle_light_frontaL(in=b);
by year state st_case;                  *veh_no;
if a and b;
if man_COLL in (1,99) and (body_c =4 or WT_c=1) and ve_forms =2;        /* one year example CT
and side-interactions only  */
title "smaller size: side damaged CT and frontal damaged car with Man_collisons angled";
run;

/* updating if CT hits car from behind   JULY 2019 */
data frontCT_rear_car_couple;
    /* side/undecarriage damaged CT and fontal damaged car  */
merge front_CT_F (in=a) vehicle_light_rear(in=b);
```

```
by year state st_case;                *veh_no;
if a and b;
if man_COLL in (1,99) and (body_c =4 or WT_c=1) and ve_forms =2;
/* one year example CT and front-rear manner only   2 veh only */
title "smaller size: side damaged CT and frontal damaged car with Man_collisons angled";
run;

/* Check 2017 status of underride and body type */
data fanalysis_per;           /* general case accident + Veh and person */
merge Fanalysis(in=a) person_F(in=b);
by year state st_case;                *veh_no;
if a and b;
run;
                                        data f_VEH_per;           /* general case accident + Veh
and person */
                                        merge vehicle_F(in=a) person_F(in=b);
                                        by year state st_case;                *veh_no;
                                        if a and b;
                                        run;

/* Special case : 2017 LPV and PERSON  */
data sideCT_Fcar_per;           /* specical case:  accident + Veh and person */
merge sideCT_Fcar_couple(in=a) person_F(in=b);
by year state st_case;                *veh_no;
if a and b;
run;

data frontCT_Fcar_per;           /* specical case:  accident + Veh and person */
merge frontCT_Fcar_couple(in=a) person_F(in=b);
by year state st_case;                *veh_no;
if a and b;
run;

data rearCT_Fcar_per;           /* specical case:  accident + Veh and person */
merge rearCT_Fcar_couple(in=a) person_F(in=b);
by year state st_case;                *veh_no;
if a and b;
run;

/* Updating CT hits cars  */
data frontCT_rear_car_per;           /* specical case:  accident + Veh and person */
merge frontCT_rear_car_couple(in=a) person_F(in=b);
by year state st_case;                *veh_no;
if a and b;
run;
```

```
/* Check status of underride and body type */
proc logistic data= sideCT_Fcar_per; /* descending;  */
   where (2008 <=YEAR <=2018);
   model fatal_c (descending) = UNDER_C  /outroc=roc;
   title "All data 2006-15 and model after 1996 relative hazard or risk study of two different conditions";
run;

proc logistic data= sideCT_Fcar_per; /* descending;  */
   where (2008 <=YEAR <=2018);
   model fatal_c (descending) = UNDER_C age_c  belt_c /outroc=roc;
   title "All data 2006-15 and model after 1996 relative hazard or risk study of two different conditions";
run;

proc freq data = frontCT_rear_car_couple;
tables underide*year /MISSING norow nocol nopercent;
title "front damaged CT and rear damaged Car with Man_collisons angled and only two veh";
where (body_c =4 or WT_c=1) and VE_FORms =2 and (2008<= year <=2018);
run;

proc freq data = frontCT_rear_car_per;  *fanalysis_per;
tables year*underide*inj_SEV /MISSING norow nocol nopercent;
title " front damaged CT and rear damaged Car  with Man_collisons angled and only two veh";
where (body_c =4 or WT_c=1) and inj_SEV in (4,6)
and per_TYP in (1,2, 9) and (2008<= year <=2018);
run;

proc freq data = frontCT_rear_car_per;  *fanalysis_per;
tables underide*inj_SEV /MISSING norow nocol nopercent;
title "front damaged CT and rear damaged Car   with Man_collisons angled and only two veh";
where (body_c =4 or WT_c=1) /* and inj_SEV in (4,6)  */
and per_TYP in (1,2, 9) and (2008<= year <=2018);
run;

/* Updating if CT hits multiple cars >=2   */
data frontCT_rear_car_couple3;
/* side/undercarriage damaged CT and frontal damaged car  */

merge front_CT_F (in=a) vehicle_light_rear(in=b);
by year state st_case;                  *veh_no;
if a and b;
if man_COLL in (1,99) and (body_c =4 or WT_c=1);  /* and ve_forms =2; */

/* One-year example CT and front-rear manner only and more than 2 veh */
title "Smaller size: side damaged CT and 2+ rear damaged car with Man_collisons";
run;
```

```
data frontCT_rear_car_per3;             /* specical case:  acciden + Veh and person */

merge frontCT_rear_car_couple3(in=a) person_F(in=b);
by year state st_case;                  *veh_no;
if a and b;
run;

/* Updating if CT hits multiple cars >=2   */

proc freq data = frontCT_rear_car_couple3;
tables underide*year /MISSING norow nocol nopercent;
title "front damaged CT and rear damaged Car with Man_collisons angled and only two veh";
where (body_c =4 or WT_c=1) and (2008<= year <=2018) and VE_FORms =2;
run;

proc freq data = frontCT_rear_car_couple3;
tables underide*year /MISSING norow nocol nopercent;
title "front damaged CT and rear damaged Car with Man_collisons angled and only two veh";
where (body_c =4 or WT_c=1) and (2008<= year <=2018); /* and VE_FORms =2; */
run;

proc freq data = frontCT_rear_car_per3;  *fanalysis_per;
tables year*inj_SEV /MISSING norow nocol nopercent;
title " front damaged CT and rear damaged Car  with Man_collisons angled and only two veh";
where (body_c =4 or WT_c=1) and inj_SEV in (4,6)
and per_TYP in (1,2, 9) and (2008<= year <=2018);
run;

proc freq data = frontCT_rear_car_per3;  *fanalysis_per;
tables underide*inj_SEV /MISSING norow nocol nopercent;
title "front damaged CT and rear damaged Car   with Man_collisons angled and only two veh";
where (body_c =4 or WT_c=1) /* and inj_SEV in (4,6)  */
and per_TYP in (1,2, 9) and (2008<= year <=2018);
run;


/* Rollover and Ejections  */
proc freq data = sideCT_Fcar_couple;
tables underide*year /MISSING norow nocol nopercent;
title "Table 2: smaller size: side damaged CT and frontal damaged car with Man_collisons angled and
only two veh";
where (body_c =4 or WT_c=1) and VE_FORms =2 and (2008<= year <=2018);
run;

proc freq data = sideCT_Fcar_per;  *fanalysis_per;
tables year*underide/MISSING norow nocol nopercent;
```

```
title "Table 2008-18 (12YRS): occupant fatalities side damaged CT and frontal damaged car with
Man_collisons angled and only two veh";
where (body_c =4 or WT_c=1) and inj_SEV in (4,6)
and per_TYP in (1,2, 9) and (2008<= year <=2018);
run;

proc freq data = sideCT_Fcar_per;  *fanalysis_per;
tables underide*inj_SEV /MISSING norow nocol nopercent;
title "Table 2006-17 (12YRS): occupant fatalities side damaged CT and frontal damaged car with
Man_collisons angled and only two veh";
where (body_c =4 or WT_c=1) /* and inj_SEV in (4,6)  */
and per_TYP in (1,2, 9) and (2008<= year <=2018);
run;

proc logistic data= sideCT_Fcar_per; /* descending;  */
  where (2008 <=YEAR <=2018);
  model fatal_c (descending) = UNDER_C age_c spltype belt_c seat_c  mYEAR_c
SURF_C/outroc=roc;
  title "All Data 2006-15 and model after 1996 relative hazard or risk study of two different conditions";
run;

/* Frontal- or rear-damaged CT */

proc freq data = frontCT_Fcar_couple;
tables underide*year /MISSING norow nocol nopercent;
title "Table 2: smaller size: front damaged CT and frontal damaged car with Man_collisons angled and
only two veh";
where (body_c =4 or WT_c=1) and VE_FORms =2 and (2008<= year <=2018);
run;

proc freq data = rearCT_Fcar_couple;
tables underide*year /MISSING norow nocol nopercent;
title "Table 2: smaller size: rear damaged CT and frontal damaged car with Man_collisons angled and
only two veh";
where (body_c =4 or WT_c=1) and VE_FORms =2 and (2008<= year <=2018);
run;

proc freq data = frontCT_Fcar_per;  *fanalysis_per;
tables year*underide*inj_SEV /MISSING norow nocol nopercent;
title "Table 2006-17 (12YRS): occupant fatalities front damaged CT and frontal damaged car with
Man_collisons angled and only two veh";
where (body_c =4 or WT_c=1) and inj_SEV in (4,6)
and per_TYP in (1,2, 9) and (2008<= year <=2018);
run;

proc freq data = rearCT_Fcar_per;  *fanalysis_per;
```

```
tables year*underide*inj_SEV /MISSING norow nocol nopercent;
title "Table 2006-17 (12YRS): occupant fatalities rear damaged CT and frontal damaged car with
Man_collisons angled and only two veh";
where (body_c =4 or WT_c=1) and inj_SEV in (4,6)
and per_TYP in (1,2, 9) and (2008<= year <=2018);
run;

proc freq data = frontCT_Fcar_per;  *fanalysis_per;
tables underide*inj_SEV /MISSING norow nocol nopercent;
title "Table 2008-17 (10YRS): occupant fatalities front damaged CT and frontal damaged car with
Man_collisons angled and only two veh";
where (body_c =4 or WT_c=1) /* and inj_SEV in (4,6)  */
and per_TYP in (1,2, 9) and (2008<= year <=2018);
run;

proc freq data = rearCT_Fcar_per;  *fanalysis_per;
tables underide*inj_SEV /MISSING norow nocol nopercent;
title "Table 2008-17 (10YRS): occupant fatalities rear damaged CT and frontal damaged car with
Man_collisons angled and only two veh";
where (body_c =4 or WT_c=1) /* and inj_SEV in (4,6)  */
and per_TYP in (1,2, 9) and (2008<= year <=2018);
run;


/* More rollovers and ejections  */

proc freq data = sideCT_Fcar_per;  *fanalysis_per;
tables belt_c*underide /MISSING norow nocol nopercent;
title "belt use effect occupant fatalities side damaged CT and frontal damaged car with Man_collisons
angled and only two veh";
where (body_c =4 or WT_c=1) and inj_SEV in (4,6)
and per_TYP in (1,2, 9) and (2008<= year <=2017);
run;

proc freq data = sideCT_Fcar_per;  *fanalysis_per;
tables seat_c*underide /MISSING norow nocol nopercent;
title "belt use effect occupant fatalities side damaged CT and frontal damaged car with Man_collisons
angled and only two veh";
where (body_c =4 or WT_c=1) and inj_SEV in (4,6)
and per_TYP in (1,2, 9) and (2008<= year <=2018);
run;

proc freq data = sideCT_Fcar_per;  *fanalysis_per;
tables spltype*underide /MISSING norow nocol nopercent;
title "spped limit effect occupant fatalities side damaged CT and frontal damaged car with
Man_collisons angled and only two veh";
```

```
where (body_c =4 or WT_c=1) and inj_SEV in (4,6)
and per_TYP in (1,2, 9) and (2008<= year <=2018);
run;
proc freq data = sideCT_Fcar_per;  *fanalysis_per;
tables surf_NEW*underide /MISSING norow nocol nopercent;
title "surf conditions: occupant fatalities side damaged CT and frontal damaged car with Man_collisons
angled and only two veh";
where (body_c =4 or WT_c=1) and inj_SEV in (4,6)
and per_TYP in (1,2, 9) and (2008<= year <=2018);
run;

proc freq data = sideCT_Fcar_per;  *fanalysis_per;
tables AGE_C*underide /MISSING norow nocol nopercent;
title "effect of occupant age occupant fatalities side damaged CT and frontal damaged car with
Man_collisons angled and only two veh";
where (body_c =4 or WT_c=1) and inj_SEV in (4,6)
and per_TYP in (1,2, 9) and (2008<= year <=2018);
run;

proc freq data = sideCT_Fcar_per;  *fanalysis_per;
tables mYEAR_C*underide /MISSING norow nocol nopercent;
title "Table 2008-17: veh_age effect occupant fatalities side damaged CT and frontal damaged car with
Man_collisons angled and only two veh";
where (body_c =4 or WT_c=1) and inj_SEV in (4,6)
and per_TYP in (1,2, 9) and (2008<= year <=2018);
run;

/* 2017   side/undercarriage damaged CT and frontal damaged car  */
data sideCT_Fcar_couple17;
merge side_CT_F (in=a) vehicle_light_frontaL(in=b);
by year state st_case;                  *veh_no;
if a and b;
if man_COLL in (3,4,5,6,7,8,99) and (body_c =4 or WT_c=1) and ve_forms =2 and year =2017;         /*
one year example CT and side-interactions only  */
title "smaller size: side damaged CT and frontal damaged car with Man_collisons angled";
run;

data sideCT_Fcar_per17;             /* special case:  accident + veh and person */
merge sideCT_Fcar_couple (in=a) person_F(in=b);
by year state st_case;                  *veh_no;
if a and b;
if (body_c =4 or WT_c=1) and per_TYP in (1,2, 9) and year =2017;  /* including injured and killed */
run;

/*  New data about 2017 *****  */
proc data data = sideCT_Fcar_per17;
```

```
by state st_case veh_no;run;

data enh2017;
set FARS17.enhanced17; run;

proc sort data=enh2017;
by state st_case veh_no;run;
proc sort data= person_F;
by state st_case veh_no;run;


    data enh2017RM;
                    merge ENH2017(in =a) person_F (in=b);
                    by state st_case veh_no;
                    if a and year =2017;
  if year le 2009 then do;
   if 20<=SP_LIMIT <=30 then spltype=1;
          else if 31 <=SP_LIMIT <=40 then spltype=2;
          else if 41 <=SP_LIMIT <=50 then spltype=3;
          else if SP_LIMIT=55 then spltype=4;
          else if SP_LIMIT=60 then spltype=5;
          else if SP_LIMIT=65 then spltype=6;
   else if SP_LIMIT=70 then spltype=7;
          else if SP_LIMIT=75 then spltype=8;
   else if SP_LIMIT=80 then spltype=9;
          else splTYPE= .;    /* missing  */
     end;
  else if year ge 2010 then do;
   if 20<= VSPD_LIM <=30 then spltype=1;
          else if 31 <=VSPD_LIM <=40 then spltype=2;
          else if 41 <=VSPD_LIM <=50 then spltype=3;
   else if VSPD_LIM=55 then spltype=4;
          else if VSPD_LIM=60 then spltype=5;
          else if VSPD_LIM=65 then spltype=6;
   else if VSPD_LIM=70 then spltype=7;
          else if VSPD_LIM=75 then spltype=8;
    else if VSPD_LIM=80 then spltype=9;
          else spltype= .;
     end;
    *IF inj_sev in (4,6) THEN fatal_C =1;
    IF inj_sev eq 4 THEN fatal_C =1;
    ELSE fatal_c = 0;    /* death vs. others  */

    IF rest_use in (0,7) then belt_C =1;  /* risky  */
    ELSE belt_c =0;    /* not use vs. others  */
```

```
        IF (11 <=SEAT_POS <=19) THEN seat_C =1;
        ELSE seat_c =0;    /* front vs. others  */

        IF (sur_COND IN (2,3,4,5,6,7) or VSURCOND in (2,3,4,5,6,7,8,10,11)) THEN surf_C =1;
        ELSE IF (SUR_COND =1 or VsurCOND =1) THEN surf_C=0;    /* DRY VS. WORSE  */
        else surf_c =.;

        if 2001<= year <=2009 then surf_new = sur_COND;
        else if year >=2010 then surf_NEW = VsurCOND;

        if weather in (2,3,4,5,6,7) then weather_c=1;
        else if weather in (0,1)then weather_c=0;

        if (No_Lanes in (3,4,5,6,7) or VNUM_lan in (3,4,5,6,7)) then lane_c=1;
        else if No_Lanes in (1,2) or VNUM_lan in (1,2) then lane_c=0; else lane_c =.;

        if new_under = underide then new_underide = underide;
        else new_underide = new_under;
   if new_UNDEride = 0 then UNDER_c = 0;
        else if  1<= new_UNDERide <=6 then under_c =1;
   else under_c =.;
run;

data sideCT_Fcar_ENH2017;
merge sideCT_Fcar_per17 (in=a) ENH2017(in =b);
by state st_case veh_no;
if a and b;
    if year le 2009 then do;
      if 20<=SP_LIMIT <=30 then spltype=1;
                 else if 31 <=SP_LIMIT <=40 then spltype=2;
                 else if 41 <=SP_LIMIT <=50 then spltype=3;
                 else if SP_LIMIT=55 then spltype=4;
                 else if SP_LIMIT=60 then spltype=5;
                 else if SP_LIMIT=65 then spltype=6;
      else if SP_LIMIT=70 then spltype=7;
                 else if SP_LIMIT=75 then spltype=8;
      else if SP_LIMIT=80 then spltype=9;
                 else splTYPE= .;    /* missing  */
         end;

    else if year ge 2010 then do;
      if 20<= VSPD_LIM <=30 then spltype=1;
                 else if 31 <=VSPD_LIM <=40 then spltype=2;
                 else if 41 <=VSPD_LIM <=50 then spltype=3;
      else if VSPD_LIM=55 then spltype=4;
                 else if VSPD_LIM=60 then spltype=5;
```

```
              else if VSPD_LIM=65 then spltype=6;
      else if VSPD_LIM=70 then spltype=7;
              else if VSPD_LIM=75 then spltype=8;
        else if VSPD_LIM=80 then spltype=9;
              else spltype= .;
         end;

        IF inj_sev  =4 THEN fatal_C =1;
        ELSE fatal_c = 0;    /* death vs. others  */

        IF rest_use in (0,7) then belt_C =1;  /* risky  */
        ELSE belt_c =0;    /* not use vs. others  */

        IF (11 <=SEAT_POS <=19) THEN seat_C =1;
        ELSE seat_c =0;    /* front vs. others  */

        IF (sur_COND IN (2,3,4,5,6,7) or VSURCOND in (2,3,4,5,6,7,8,10,11)) THEN surf_C =1;
        ELSE IF (SUR_COND =1 or VsurCOND =1) THEN surf_C=0;    /* DRY VS. WORSE  */
        else surf_c =.;

        if 2001<= year <=2009 then surf_new = sur_COND;
        else if year >=2010 then surf_NEW = VsurCOND;

        if weather in (2,3,4,5,6,7) then weather_c=1;
        else if weather in (0,1)then weather_c=0;

        if (No_Lanes in (3,4,5,6,7) or VNUM_lan in (3,4,5,6,7)) then lane_c=1;
        else if No_Lanes in (1,2) or VNUM_lan in (1,2) then lane_c=0; else lane_c =.;

        if new_under = underide then new_underide = underide;
        else new_underide = new_under;
   if new_UNDEride = 0 then UNDER_c = 0;
        else if  1<= new_UNDERide <=6 then under_c =1;
   else under_c =.;
run;


/* Updating if CT hits multiple cars  */
data use2017; set  sideCT_Fcar_ENH2017; run;
data use2017; set  enh2017RM; run;

proc freq data = ENH2017;  /* raw data from RuleMaking  */
tables new_under*sex /MISSING norow nocol nopercent;
title "front damaged CT and rear damaged Car with Man_collisons angled and only two veh";
*where (body_c =4 or WT_c=1) and (2008<= year <=2017) and VE_Forms =2;
run;
```

```
proc freq data = use2017;
tables seat_c*fatal_c /cmh MISSING norow nocol nopercent;
title "front damaged CT and rear damaged Car with Man_collisons angled and only two veh";
*where (body_c =4 or WT_c=1) and (2008<= year <=2017) and VE_FORms =2;
run;

proc freq data = use2017;
tables belt_c*fatal_c /MISSING norow nocol nopercent;
title "front damaged CT and rear damaged Car with Man_collisons angled and only two veh";
*where (body_c =4 or WT_c=1) and (2008<= year <=2017) and VE_FORms =2;
run;

proc freq data = use2017;
tables under_c*fatal_c /CMH MISSING norow nocol nopercent;
title "front damaged CT and rear damaged Car with Man_collisons angled and only two veh /underride";
*where (body_c =4 or WT_c=1) and (2008<= year <=2017) and VE_FORms =2;
run;

/* check status of underride and body type or thors  */
proc logistic data= use2017; /* descending;  */
  where YEAR =2017;
  model fatal_c (descending) = UNDER_C  seat_c sex_c age_c spltype/outroc=roc;
  title "All Data 2017 multiple risk study of two different conditions";
run;

proc logistic data= use2017; /* descending;  */
  where YEAR =2017;
  model fatal_c (descending) = UNDER_C  seat_c age_c spltype/outroc=roc;
  title "All Data 2017 multiple risk study of two different conditions";
run;

proc freq data = use2017;
tables new_underide*year /MISSING norow nocol nopercent;
title "front damaged CT and rear damaeged Car with Man_collisons angled and only two veh";
where (body_c =4 or WT_c=1) and (2008<= year <=2017); /* and VE_FORms =2; */
run;

proc freq data = use2017;  *fanalysis_per;
tables new_underide*inj_SEV /MISSING norow nocol nopercent;
title "front damaged CT and rear damaeged Car   with Man_collisons angled and only two veh";
*where (body_c =4 or WT_c=1) /* and inj_SEV in (4,6) and per_TYP in (1,2, 9) and (2008<= year
<=2017);
run;
```

```
/* ***** PART 2: GES Data ***** */
/* Step 1: Format and data libraries  */

 /*  ************GES data   ************* */
libname GES_Underride "XXXXX";

/* GES LIBRARIES */
libname ges1998 'XXXXX';
libname ges1999 'XXXXX';
libname ges2000 'XXXXX';
libname ges2001 'XXXXX';
libname ges2002 'XXXXX';
libname ges2003 'XXXXX';
libname ges2004 'XXXXX';
libname ges2005 'XXXXX';
libname ges2006 'XXXXX';
libname ges2007 'XXXXX';
libname ges2008 'XXXXX';
libname ges2009 'XXXXX';
libname ges2010 'XXXXX';
libname ges2011 'XXXXX';
libname ges2012 'XXXXX';
libname ges2013 'XXXXX';
libname ges2014 'XXXXX';
libname ges2015 'XXXXX';
libname CRSS2016 'XXXXX';
libname CRSS2017 'XXXXX';
options nofmterr;

/* Step 2: Format  sources  */

proc format;
value spltypefmt 1="55 mph"
            2="60 mph"
            3="65 mph"
            4="70 mph"
                                    5="75 mph"
                                    6="80 mph"
                                    7="others";
value speedfmt 1="Speeding"
           2="Non-Speeding";
value bodyfmt 1="Combination Trucks"
          2="Single-Unit Trucks"
          4="BUS"
                            5="Others";
run;
```

```
/*  Step 3: Load GES cases */
data Accident_G (keep=year casenum psu psustrat stratum weight ratwgt int_hwy sur_cond
maxsev max_SEV NOINJ spd_lim sp_limit spedLIM_h splTYPE post_V post_V2 drive_V weather
weather_c
num_lan Vnum_lan no_lanes lane_c VE_FORMS VEH_INVL lght_CON lgt_COND light_c
man_CoL man_COLL manCOL_I manCOL_IM);
set
	ges1998.accident(in=yr1998)
	ges1999.accident(in=yr1999)
	ges2000.accident(in=yr2000)
		ges2001.accident(in=yr2001)
	ges2002.accident(in=yr2002)
	ges2003.accident(in=yr2003)
	ges2004.accident(in=yr2004)
	ges2005.accident(in=yr2005)
	ges2006.accident(in=yr2006)
	ges2007.accident(in=yr2007)
	ges2008.accident(in=yr2008)
	ges2009.accident(in=yr2009)
	ges2010.accident(in=yr2010)
	ges2011.accident(in=yr2011)
	ges2012.accident(in=yr2012)
			ges2013.accident(in=yr2013)
	ges2014.accident(in=yr2014)
			ges2015.accident(in=yr2015)
			CRSS2016.accident(in=yr2016)
			CRSS2017.accident(in=yr2017);

			format year best12.;
			/** 1988-2009 GES YEAR variable was length 4. after 2009 length = 8 **/
			length year 8.;

			if yr1998 then year=1998;
	else if yr1999 then year=1999;
	else if yr2000 then year=2000;
	else if yr2001 then year=2001;
	else if yr2002 then year=2002;
	else if yr2003 then year=2003;
	else if yr2004 then year=2004;
	else if yr2005 then year=2005;
	else if yr2006 then year=2006;
	else if yr2007 then year=2007;
	else if yr2008 then year=2008;
	else if yr2009 then year=2009;
	else if yr2010 then year=2010;
```

```
        else if yr2011 then year=2011;
        else if yr2012 then year=2012;
                else if yr2013 then year=2013;
           else if yr2014 then year=2014;
                else if yr2015 then year=2015;
                else if yr2016 then year=2016;
                else if yr2017 then year=2017;

                if year <=2008 then light_c = lght_con;
                else if year>=2009 then light_c = lgt_cond;
run;

data Vehicle_G (keep=year casenum vehno veh_no psu stratum psustrat weight ratwgt gvwr
p_crash1 p_crash2 VSPD_LIM  speed body speed trav_sp drive_V post_V post_V2
body body_C BDYTYP_IM bdytyp_h impact impact1 impact1_IM  impact2 man_col
tow_veh trailer ve_FORMS ve_inVL Harm_EV Rollover GESbody Towed veh_alch V_ALCH_I
V_ALCH_IM);
    set
        ges1998.vehicle(in=yr1998 rename=(vehno=veh_no))
        ges1999.vehicle(in=yr1999 rename=(vehno=veh_no))
        ges2000.vehicle(in=yr2000 rename=(vehno=veh_no))
        ges2001.vehicle(in=yr2001 rename=(vehno=veh_no))
        ges2002.vehicle(in=yr2002 rename=(vehno=veh_no))
        ges2003.vehicle(in=yr2003 rename=(vehno=veh_no))
        ges2004.vehicle(in=yr2004 rename=(vehno=veh_no))
        ges2005.vehicle(in=yr2005 rename=(vehno=veh_no))
        ges2006.vehicle(in=yr2006 rename=(vehno=veh_no))
        ges2007.vehicle(in=yr2007 rename=(vehno=veh_no))
        ges2008.vehicle(in=yr2008 rename=(vehno=veh_no))
        ges2009.vehicle(in=yr2009 rename=(vehno=veh_no))
        ges2010.vehicle(in=yr2010 rename=(vehno=veh_no))
        ges2011.vehicle(in=yr2011)
        ges2012.vehicle(in=yr2012)
        ges2013.vehicle(in=yr2013)
        ges2014.vehicle(in=yr2014)
        ges2015.vehicle(in=yr2015)
        CRSS2016.vehicle(in=yr2016)
        CRSS2017.vehicle(in=yr2017);

if yr1998 then year=1998;
        else if yr1999 then year=1999;
        else if yr2000 then year=2000;
        else if yr2001 then year=2001;
        else if yr2002 then year=2002;
        else if yr2003 then year=2003;
        else if yr2004 then year=2004;
```

```
        else if yr2005 then year=2005;
        else if yr2006 then year=2006;
        else if yr2007 then year=2007;
        else if yr2008 then year=2008;
        else if yr2009 then year=2009;
        else if yr2010 then year=2010;
        else if yr2011 then year=2011;
        else if yr2012 then year=2012;
        else if yr2013 then year=2013;
        else if yr2014 then year=2014;
        else if yr2015 then year=2015;
        else if yr2016 then year=2016;
        else if yr2017 then year=2017;

/*  best 12 numerical format to date format  */
          /*  VEHICLE TYPES  *** CT and SU TRUCKS 1,2 ***;  */
if  year <= 1998 then do;
   if (bdytyp_h in (60 64 78) and (1<=trailer<=4)) or bdytyp_h=66 then body_c =1;
   else if  bdytyp_h in (60 64 78) and trailer in (0 9) then body_C =2;
 end;

else if 1999<=year<=2008 then do;
   if (bdytyp_h in (60 64 78) and (2<=trailer<=5)) or bdytyp_h=66 then body_C =1;
   else if  bdytyp_h in (60 64 78) and trailer in (1 6) then body_C =2;
 end;

else if year=2009 then do;
   if (BDYTYP_H IN (60,64,78) AND 1<=TOW_VEH<=4) OR BDYTYP_H=66 then body_C=1;
   else if  BDYTYP_H IN (60,64,78) AND TOW_VEH IN (0,5,6,9) then body_C=2;
 end;

else if year>=2010 then do;
   if (BDYTYP_IM IN (60,61,62,63,67,68,71,72,78) AND 1<=TOW_VEH<=4) OR BDYTYP_IM=66
then body_C=1;
   else if  BDYTYP_IM IN (60,61,62,63,67,68,71,72,78) AND TOW_VEH IN (0,5,6,9) then body_C=2;
 end;

*** BUS ***;
  if year<=2009 then do;
   IF 50<=BDYTYP_H<=59 THEN BODY_C =3;
  end;

  else if year>=2010 then do;
   IF 50<=BDYTYP_IM<=59 THEN BODY_C=3;
  end;
```

```
*** Passenger Vehicles ***;
/* Passenger Cars
        01-11, 17(1)
Light Trucks & Vans (6)
14,  20-41, 47(8), 48
14, 15, 16, 19, 20, 21, 22(2), 24(3), 25(4), 28, 29, 30, 31, 32, 33, 39, 40, 41, 45, 48
  */
 if year<=2009 then do;
   IF (1<=bdytyp_h<=11) or (bdytyp_h=17) or
    (bdytyp_h in (24,25,45,47,48)) or (14<=bdytyp_h<=22) or (28<=bdytyp_h<=41)
   then body_C =4;
 end;

 else if year>=2010 then do;
   IF (1<=BDYTYP_IM<=11) or (BDYTYP_IM=17) or
    (BDYTYP_IM in (24,25,45,47,48)) or (14<=BDYTYP_IM<=22) or (28<=BDYTYP_IM<=41)
   then body_c =4;
 end;

drive_V =.;
if (year<=2008 and 0<speed<=30) OR (year>=2009 and 0< TRAV_SP<=30) then drive_V= 1;  *'000-
30';
else if (year<=2008 and 31<=speed<=40) OR ( year>=2009 and 31<= TRAV_SP <=40) then drive_V=
2;   *'31-40';
else if (year<=2008 and 41<=speed<=50) OR (year>=2009 and 41<= TRAV_SP <=50) then drive_V=
3;   *'41-50';
else if (year<=2008 and 51<=speed<=55) OR (year >=2009 and 51<= TRAV_SP <=55) then drive_V=
4;   *'51-55';
else if (year<=2008 and 56<=speed<=60) OR (year >=2009 and 56<= TRAV_SP <=60) then drive_V=
5;    *'56-60';
else if (year<=2008 and 61<=speed<=65) OR (year >=2009 and 61<= TRAV_SP <=65) then drive_V=
6;    *'61-65';
else if (year<=2008 and 66<=speed<=70) OR (year >=2009 and 66<= TRAV_SP <=70) then drive_V=
7;    *'66-70';
else if (year<=2008 and 71<=speed<=75) OR (year >=2009 and 71<= TRAV_SP <=75) then drive_V=
8;       *"71-75';
else if (year<=2008 and 76<=speed<=80) OR
(year >=2009 and 76<= TRAV_SP <=149 and TRAV_SP not in (98,99,998,999))then drive_V= 9;
run;

/* Add PERSON file  */
data person_G (keep = year casenum vehno veh_no psu stratum psustrat
weight ratwgt rest_sys rest_use age age_C age_im sex sex_c inj_SEV
seat_pos seat_c per_typ per_type max_SEV drinking per_alch);
     set
          ges1998.person(in=yr1998 rename=(vehno=veh_no))
```

```
          ges1999.person(in=yr1999 rename=(vehno=veh_no))
          ges2000.person(in=yr2000 rename=(vehno=veh_no))
          ges2001.person(in=yr2001 rename=(vehno=veh_no))
          ges2002.person(in=yr2002 rename=(vehno=veh_no))
          ges2003.person(in=yr2003 rename=(vehno=veh_no))
          ges2004.person(in=yr2004 rename=(vehno=veh_no))
          ges2005.person(in=yr2005 rename=(vehno=veh_no))
          ges2006.person(in=yr2006 rename=(vehno=veh_no))
          ges2007.person(in=yr2007 rename=(vehno=veh_no))
          ges2008.person(in=yr2008 rename=(vehno=veh_no))
          ges2009.person(in=yr2009 rename=(vehno=veh_no))
          ges2010.person(in=yr2010 rename=(vehno=veh_no))
    ges2011.person(in=yr2011)          /* 'veh_no' is used since 2011 in manual  */
    ges2012.person(in=yr2012)
    ges2013.person(in=yr2013)
    ges2014.person(in=yr2014)
    ges2015.person(in=yr2015)
    CRSS2016.person(in=yr2016)
    CRSS2017.person(in=yr2017);

if yr1998 then year=1998;
       else if yr1999 then year=1999;
       else if yr2000 then year=2000;
       else if yr2001 then year=2001;
       else if yr2002 then year=2002;
       else if yr2003 then year=2003;
       else if yr2004 then year=2004;
       else if yr2005 then year=2005;
       else if yr2006 then year=2006;
       else if yr2007 then year=2007;
       else if yr2008 then year=2008;
       else if yr2009 then year=2009;
       else if yr2010 then year=2010;
       else if yr2011 then year=2011;
       else if yr2012 then year=2012;
       else if yr2013 then year=2013;
       else if yr2014 then year=2014;
       else if yr2015 then year=2015;
       else if yr2016 then year=2016;
       else if yr2017 then year=2017;

if 11<=seat_pos <=19 then seat_c =1;
          else if 20<=seat_pos <=54 then seat_c =0;
          else seat_c =.;

if sex =2 then sex_c =1;  /*female  */
```

```
          else sex_c =0;

if 0<=age <=3 then age_c=1;
          else if 4<=age<=12 then age_c=2;
          else if 13<=age<=20 then age_c=3;
          else if 21<=age<=40 then age_c=4;
          else if 41<=age<=60 then age_c=5;
          else if 61<=age<=75 then age_c=6;
          else if 76<=age<=97 then age_c=7;
          else age_c = .;   /* missing or unknown  */

ratwgt=weight;       /* to agree with FARS later  */
run;

proc sort data=person_G;
by year psu casenum veh_no;
run;

proc sort data=accident_G;
by year psu casenum;
run;

proc sort data=vehicle_G;
by year psu casenum veh_no;
run;

data ganalysis; *(drop=int_hwy);
merge vehicle_G(in=veh) accident_G(in=acc);         /* two vehicle files to choose from  */
by year psu casenum;
if VEH and ACC;                            /* keep all vehicles  */
  ratwgt=weight;              /* to agree with FARS later  */

if year le 2008 then do;
        if 20<=SPD_LIM <=30 OR 20<=spedLIM_h <=30 then spltype=1;
                    else if 31<=SPD_LIM<=40 OR 31<=spedLIM_h <=40 then spltype=2;
                    else if 41<=SPD_LIM<=50 OR 41 <=spedLIM_h<=50 then spltype=3;
        else if SPD_LIM=55 OR spedLIM_h =55 then spltype=4;
                    else if SPD_LIM=60 OR spedLIM_h =60 then spltype=5;
                    else if SPD_LIM=65 OR spedLIM_h =65 then spltype=6;
        else if SPD_LIM=70 OR spedLIM_h =70 then spltype=7;
                    else if SPD_LIM=75 OR spedLIM_h =75 then spltype=8;
        else if SPD_LIM=80 OR spedLIM_h =80 then spltype=9;
                    else spltype= .;              /* missing  */
          end;

          else if year ge 2009 then do;                   /* sp_limit for 2009 only  */
```

```
    if 20<= VSPD_LIM <=30 OR 20<= sp_limit <=30 then spltype=1;
            else if 31 <=VSPD_LIM <=40 or 31 <=sp_limit <=40 then spltype=2;
            else if 41 <=VSPD_LIM <=50 or 41 <=sp_limit <=50then spltype=3;
    else if VSPD_LIM=55 OR sp_limit =55  then spltype=4;
            else if VSPD_LIM=60 OR sp_limit =60 then spltype=5;
            else if VSPD_LIM=65 OR sp_limit = 65 then spltype=6;
      else if VSPD_LIM=70 OR sp_limit =70 then spltype=7;
            else if VSPD_LIM=75 OR sp_limit = 75 then spltype=8;
      else if VSPD_LIM=80 OR sp_limit =80 then spltype=9;
            else spltype= .;          /* missing  */
      end;

      if weather in (2,3,4,5,6,7,8,10,11,12) then weather_c=1;
            else if weather in (0,1) then weather_c=0;
  if sur_cond in (2,3,4,5) then road_c=1;
            else if sur_cond =1 then road_c =0;
      if (num_Lan in (3,4,5,6,7) or Vnum_lan in (3,4,5,6) OR No_Lanes in (3,4,5,6,7)) then lane_c=1;
      else if (num_Lan in (1,2) OR Vnum_lan in (1,2) OR No_Lanes in (1,2)) then lane_c=0;

if spltype=4 then speed2=rannor(123) * 4 + 64.2;        /* mean and standard error  */
else if spltype=5 then speed2=rannor(1234) * 4 + 65.5;
else if spltype=6 then speed2=rannor(12345) * 3.69 + 66.7;
else if spltype=7 then speed2=rannor(123456) * 4.55 + 68.6;
else if spltype=8 then speed2=rannor(1234567) * 5.63 + 72.3;

/*  means ONLY  ****************  */
if spltype =4 then speed3=64.2;
else if spltype=5 then speed3=65.5;      /* mean value only  */
else if spltype=6 then speed3=66.7;
else if spltype=7 then speed3=68.6;
else if spltype=8 then speed3=72.3;

if spltype=4 then speed4=rannor(123) * 3.52 + 62.07;        /* mean and standard error  */
else if spltype=5 then speed4=rannor(1234) * 3.05 + 63.46;
else if spltype=6 then speed4=rannor(12345) * 3.77 + 66.63;
else if spltype=7 then speed4=rannor(123456) * 4.00 + 68.90;
else if spltype=8 then speed4=rannor(1234567) * 4.48 + 68.34;

if (2000 <= year <=2017);
*annualAverage = ratWGT/3;
run;

/* Step 4: Merge 15 years of data, GES 1998 to 2012  */
proc sort data=Ganalysis;
by year psu casenum veh_no;
run;
```

```
/* Analysis for side-hit CT and frontal-damaged LPV  */
/*   Identify frontal damaged cars first */
data light_veh_G2 (rename = (trav_sp = speed_T));             /* light VEH is frontally damaged  */
set Ganalysis;
if ( (impact1 in (1,11,12,13) or impact1_im in (1,11,12, 13)) and year>=2010)
or ( (impact in (1,5) or impact_H in (1,5)) and year<=2009);
if  body_c in (4);              /* light vehicles  */
run;

/* Side-damaged trucks  */
data CT_G2 (rename = (trav_sp = speed_c));           /* focusing on light rear-hit only  */
set Ganalysis;
if ( (impact1 in (2,3,4,8,9,10,14,34,61,62,63,81,82,83)
   OR IMPACT1_IM in (2,3,4,8,9,10,14,34,61,62,63,81,82,83 )) AND year>=2010)
OR ( (impact in (2,3,6) or IMPACT_H in (2,3,6)) and year<2010 );
if body_c =1;                 /* side-CT  */
run;

/* Merge trucks and LPVs  */
data pair_veh_G2;                    /* focusing on light rear-hit only  */
merge CT_G2 (in=a) light_veh_G2(in=b);
by year psu casenum;       *veh_no;
if a and b;
 diff_v = speed_T - speed_C;           /* light vehicles  */
    if (diff_V >500) or (diff_V <-500) or (diff_v =.) then diff_c = .;
      else if  0<= diff_V <=10 then diff_c =1;
                 else if 11 <=diff_V <=20 then diff_c =2;
                 else if 21 <=diff_V <=30 then diff_c =3;
      else if 31 <=diff_V <=40 then diff_c =4;
                 else if 41 <=diff_V <=50 then diff_c =5;
      else if 51 <=diff_V <=60 then diff_c =6;
                 else if 61 <=diff_V <=70 then diff_c =7;
      else if 71 <=diff_v <=500 then diff_c=8;
                 else diff_c = .;
if (man_COLL in (6,7,8,9) and year>=2011) OR (man_COL in (4,5,6,7) and year<=2010);
run;

/* Injured occupants in light VEH  */
data ganalysis_per2; *(drop=int_hwy);   /* from striking Veh and Body_C  */
merge pair_veh_G2 (in=a) person_G(in=b);
by year psu casenum;                          *veh_no;
if a and b;
          if inj_sev in (4,6) then fatal_c=1;
          else fatal_C=0;
if rest_sys in (0,7,30) OR rest_use in (0,7,30)then belt_c=1;  /* risky and not used */
```

```
else if rest_sys in (1,2,3,4,5,6,8,10,11,12,21,22,23,28)
OR rest_use in (1,2,3,4,5,6,8,10,11,12,21,22,23,28) then belt_c=0;  /* used belt */
else belt_c=. ;   /* missing unknown */
run;

proc freq data = Ganalysis_PER2;
tables year*inj_SEV /MISSING norow nocol nopercent;
weight weight;
title 'GES 2008-17 occupants of LPVs
involved CT side crashes and injured inj_SEV (0 to 9) by LIGHT VEH';
where 2008<=year <=2017 and body_c=4
and (per_TYP in (1,2,9) or per_TYPE in (1,2,9));
run;

proc freq data = Ganalysis_PER2;
tables diff_c*inj_SEV /MISSING norow nocol nopercent;
weight weight;
title 'Speed difference and GES 2008-17 occupants of LPV occupants
involved in CT side crashes and injured inj_SEV NE 0 by light VEH';
where (2008<=year <=2017) and (inj_SEV NE 0 and body_c=4)
and (per_TYP in (1,2,9) or per_TYPE in (1,2,9));
run;

/*  CDS data patterns  */
 libname CDS15 "XXXXX";

data Crashmode10 (keep = TowPAR VIN VINmake vinWGT make model year modelYR rollover
PSU ratWGT bodyTYPE bodyclt areaDamage areaDamageOCC vehFORMS vehSIZE vehage drink
body crashMode age DV DVtotal belt injsou bdy_reg sex ais mais profile surType
spLimit fOveride Roveride Overide TRKUride);
set CDS15.CrashModeOCC;
if 2006 <= year <=2015;            /* 10 years of data  */
run;

data GV_OA10 (keep = TowPAR VIN VINmake vinWGT make model year modelYR rollover
PSU ratWGT bodyTYPE bodyclt areaDamage areaDamageOCC vehFORMS vehSIZE vehage drink
body crashMode age DV DVtotal belt injsou bdy_reg sex ais mais profile surType
spLimit fOveride Roveride Overide TRKUride);
set CDS15.GV_OA;
if 2006 <= year <=2015;            /* 10 years of data  */
run;

/* Rollovers and ejections  */
PROC FREQ DATA= GV_OA10;
WHERE 2006 <=YEAR <=2015 =
and TOWPAR=1 and 1 LE BODYTYPE LE 49;
```

```
/* bodyTYPE 1-13 cars, and=14 to 49 truck  */
TABLES Foveride*MAIS/NOCOL NOrow nopercent MISSING FORMAT=COMMA10.0;
WEIGHT ratWGT;  *annualAverage;                  /* original ratWGT /3 =annual weight  */
*format bdy_reg bdy_reg. injsou injsou.;
format MAIS mais.;
TITLE1 "weighted injured vs. FRONTAL Underride";
TITLE2 "NASS-CDS 2006-2015 annual average of Light Veh.";
RUN;

PROC FREQ DATA= CrashMode10;
WHERE 2006 <=YEAR <=2015 and (0<= vehAGE<=10)  /* AND 11 LE SEATPOS LE 59 and 0<=
age <=98  */
and TOWPAR=1 and 1 LE BODYTYPE LE 49 and (areaDamage =1 or areaDamageOCC =1); /* and
areaDamage in (13,14 )  */
                /* bodyTYPE 1-13 cars, and=14 to 49 truck  */
TABLES FOveride*MAIS/NOCOL NOrow nopercent MISSING FORMAT=COMMA10.0;
WEIGHT ratWGT;  *annualAverage;                  /* original ratWGT /3 =annual weight  */
*format bdy_reg bdy_reg. injsou injsou.;
format MAIS mais.;
TITLE1 "Weighted injured vs. Underride and frontal damage";
TITLE2 "NASS-CDS 2006-2015 annual average of Light Veh.";
RUN;

/* Interactions: Two vehicles ONLY = SIDE-truck and frontal-damaged light VEH, considering
man_collison
********** 2016 examples  *****************  */

data sideCT_Fcar2016_merge1c (keep = underide year state st_case veh_no body_typ make vin
man_coll ve_forms impact1 m_harm VSPD_LIM body_c vspd_lim p_crash1 veh_man UNDERIDE
trav_sp M_HARM RollOVER wt_c body_c month day hour);
merge side_CT_F (in=a) vehicle_light_frontaL(in=b);
by year state st_case;
if a and b;
if year =2016 and man_COLL in (3,4,5,6,7,8,99) and (body_c =4 or WT_c=1) and ve_forms =2;
/* one year example CT and side-interactions only  */
title "smaller size: side damaged CT and frontal damaged car with Man_collisons angled";
run;

/* Check status of underride and body type */
proc freq data = sideCT_Fcar2016_merge1c;
tables underide * BODY_typ /MISSING norow nocol nopercent;
title "Smaller size: side damaged CT and frontal damaged car with Man_collisons angled and only two
veh";
where (body_c =4 or WT_c=1) and VE_FORms =2;
run;
```

```
data sideCT_Fcar2016_merge1a (keep = underide state st_case veh_no body_typ make vin
man_coll ve_forms impact1 m_harm VSPD_LIM body_c wt_c);
    /* side/undecarriage damaged CT and fontal dameged car  */
merge side_CT_F (in=a) vehicle_light_frontaL(in=b);
by year state st_case;                  *veh_no;
if a and b;
  if year =2016 and (body_c =4 or WT_c=1);        /* one year example CT and side-interactions only  */
title "interaction between side damaged CT and frontal damaged car in 2016 only";
run;

/* check status of underride and body type or others*/
proc freq data = sideCT_Fcar2016_merge1a;
tables underide * BODY_typ /MISSING norow nocol nopercent;
title 'GES frontal-damaged light VEH and CT Side interactions by year, Table 3';
where (body_c =4 or WT_c=1) and VE_FORms >=2;
run;

/* Interaction: SIDE-truck and frontal-damaged light VEH, considering man_collison
********** 2016 examples  *****************  */
data sideCT_Fcar2016_merge1b (keep = underide state st_case veh_no body_typ make vin man_coll
ve_forms impact1 m_harm VSPD_LIM body_c wt_c);
    /* side/undecarriage damaged CT and fontal dameged car  */
merge side_CT_F (in=a) vehicle_light_frontal(in=b);
by year state st_case;
if a and b;
if year =2016 and man_COLL in (3,4,5,6,7,8,99) and (body_c =4 or WT_c=1);
/* one year example CT and side-interactions only  */
title "side damaged CT and frontal damaged car with Man_collisons angled";
run;

/* Check status of underride and body type */
proc freq data = sideCT_Fcar2016_merge1b;
tables underide * BODY_typ /MISSING norow nocol nopercent;
title ‘GES frontal-damaged light VEH and CT Side interactions by year, Table 1';
where (body_c =4 or WT_c=1) and VE_FORms >=2;
run;

/* 2017  */
data sideCT_Fcar2017_merge1a  (keep = underide state st_case veh_no body_typ make vin man_coll
ve_forms impact1 m_harm VSPD_LIM body_c vspd_lim p_crash1 veh_man UNDERIDE trav_sp
M_HARM RollOVER wt_c body_c);
    /* side/undecarriage damaged CT and fontal dameged car  */
merge side_CT_F (in=a) vehicle_light_frontaL(in=b);
by year state st_case;                  *veh_no;
if a and b;
```

```
  if year =2017 and (body_c =4 or WT_c=1);        /* one year example CT and side-interactions only  */
title "interaction between side damaged CT and frontal damaged car in 2016 only";
run;

proc freq data = sideCT_Fcar2017_merge1a;
tables underide * BODY_typ /MISSING norow nocol nopercent;
title ‘GES frontal-damaged light VEH and CT Side interactions by year, Table 3';
where (body_c =4 or WT_c=1) and VE_FORms >=2;
run;

/* ********* 2017 examples  *****************  */
data sideCT_Fcar2017_merge1b (keep = underide state st_case veh_no body_typ make vin man_coll
ve_forms impact1 m_harm VSPD_LIM body_c wt_c);
    /* side/undecarriage damaged CT and fontal damaged car  */
merge side_CT_F (in=a) vehicle_light_frontal(in=b);
by year state st_case;
if a and b;
if year =2017 and man_COLL in (3,4,5,6,7,8,99) and (body_c =4 or WT_c=1);        /* one year example
CT and side-interactions only  */
title "side damaged CT and frontal damaged car with Man_collisons angled";
run;

/* Check status of underride and body type */
proc freq data = sideCT_Fcar2017_merge1b;
tables underide * BODY_typ /MISSING norow nocol nopercent;
title 'FARS frontal-damaeged light VEH and CT Side interactions by year, Table 1';
where (body_c =4 or WT_c=1) and VE_FORms >=2;
run;

/*  **************  ROLLOVER  Check  ***************  */

proc freq data = Fanalysis_PER;
tables year*ej_PATH/MISSING norow nocol nopercent;
*weight ratwgt;
title 'Rollover occupant fatalities and ejection PATH
and LIGHT vehicle <=10,000 lbs FARS 2004-17';
where 2004<=year <=2017 and (rollover in (1,2,9) or M_harm=1)
and per_typ in (1,2,9) and (body_c =4 or WT_c =1) and inj_SEV=4;
run;

proc freq data = F_VEH_PER;
tables year*ej_PATH/MISSING norow nocol nopercent;
*weight ratwgt;
title 'Rollover occupant fatalities and ejection PATH
and LIGHT vehicle <=10,000 lbs FARS 2004-17';
where 2004<=year <=2017 and (rollover NE 0 or M_harm=1)
```

```
and per_typ in (1,2,9) and (body_c =4 or WT_c =1) and inj_SEV=4;
run;

proc freq data = F_VEH_PER;
tables year*ej_PATH/MISSING norow nocol;
*weight ratwgt;
title 'Rollover and not-roll occupant fatalities and ejection PATH
and LIGHT vehicle <=10,000 lbs FARS 2004-17';
where 2004<=year <=2017 /* AND (rollover NE 0 or M_harm=1)  */
and per_typ in (1,2,9) and (body_c =4 or WT_c =1) and inj_SEV=4;
run;

/* Additional details  */
data rear_CT;
input grp resp $ cnt @;
datalines;
1 no 2430
1 yes 1786        /*  1=NO Underride group  */
2 no 702
2 yes 535          /* 2= Underride group  */
;
proc freq data=rear_CT;
tables grp*resp/cmh nopercent nocol;
weight cnt;
title '2x2 table for all speed maneuvers during 2000-2011';
run;

data front_CT;
input grp resp $ cnt @;
datalines;
1 no 3777
1 yes 3358        /*  1=NO Underride group  */
2 no 337
2 yes 168          /* 2= Underride group  */
;
proc freq data=front_CT;
tables grp*resp/cmh nopercent nocol;
weight cnt;
title '2x2 table for all speed maneuvers during 2000-2011';
run;

data side_CT;
input grp resp $ cnt @;
datalines;
1 no 2290
1 yes 1604        /*  1=NO Underride group  */
```

```
2 no 610
2 yes 499          /* 2= Underride group  */
;
proc freq data=side_CT;
tables grp*resp/cmh nopercent nocol;
weight cnt;
title '2x2 table for all speed maneuvers during 2000-2011';
run;

data hybrid123;
input grp resp $ cnt @;
datalines;
1 no 65
1 yes 49        /*  1= Underride and NO intrusion group  */
2 no 315
2 yes 260          /* 2= Underride and INTRUsion group  */
;
proc freq data=hybrid123;
tables grp*resp/cmh nopercent nocol;
weight cnt;
title '2x2 table for all speed maneuvers during 2000-2011';
run;
```

# Appendix B: Review of the Process of Coding Underrides and Overrides Among FARS Cases

The FARS, which became operational in 1975, contains data on a census of fatal traffic crashes within the 50 States, the District of Columbia, and Puerto Rico. To be included in FARS, a crash must involve a motor vehicle traveling on a trafficway customarily open to the public, and must result in the death of an occupant of a vehicle or a nonoccupant within 30 days (720 hours) of the crash.

FARS is directed by the National Center for Statistics and Analysis, a component of NHTSA. NHTSA has a cooperative agreement with an agency in each State's government to provide information on all qualifying fatal crashes in the State. These agreements are managed by NCSA's FARS Program staff. Trained State employees, called FARS analysts, are responsible for gathering, translating, and transmitting their State's data to NCSA in a standard format. The number of analysts varies by State.

FARS data are obtained from various States' documents, such as the following.

- Police Crash Reports
- Death Certificates
- State Vehicle Registration Files
- Coroner/Medical Examiner Reports
- State Driver Licensing Files
- State Highway Department Data
- Emergency Medical Service Reports
- Vital Statistics and other State Records

From these documents, the analysts code more than 140 FARS data elements. The specific data elements may be modified slightly each year to conform to changing user needs, vehicle characteristics, and highway safety emphasis areas. The data collected within FARS do not include any personal identifying information, such as names, addresses, or social security numbers. Thus, any data kept in FARS data files and made available to the public fully conform to the Privacy Act.

Each analyst interprets and codes data directly onto an electronic data file. The data are automatically checked when entered for acceptable range values and for consistency, enabling the analyst to make corrections immediately. Several programs continually monitor and improve the completeness and accuracy of the data.

Each analyst uses a coding manual which provides a set of written instructions on how to transfer the information from a police accident/crash report (PCR) to the FARS data. To augment the coding manual, classes are held each year to train the coders, and a systemwide FARS meeting is held to reinforce uniform coding practices.

After the data file is created, quality checks are performed on the data. When these are completed, the electronic data are made available to the public. The FARS data are also used to respond to requests from the international and national highway safety communities, State and local governments, Congress, Federal agencies, research organizations, industry, the media, and private citizens.

In February 2020 NHTSA's State Data Reporting System Division conducted a special review of FARS cases that were identified as possible underride/Ooerride cases as part of an Evaluation of Vehicle Underride and Associated Fatalities in Light Vehicle Crashes into the Side of Truck Trailers Report. In addition, the Special Crash Investigations Division conducted a more in-depth review of the same cases and the findings were compared. This review intended to identify how often underride/override cases may have been miscoded in FARS, understand why miscoding may exist, and address the findings appropriately.

The current data element, ***UNDERRIDE/OVERRIDE*** identifies this vehicle's involvement in an underride or override during the crash. Note that the striking vehicle, not the vehicle struck, determines the ***UNDERRIDE/OVERRIDE*** condition. From 1975 to 1993 both the initial and principal impacts were counted. In the event and only in the event, that the initial or principal impact point was an ***UNDERRIDE/OVERRIDE*** were the data element IMPACT1 or IMPACT2 flagged/counted as such. However, all other ***UNDERRIDES/OVERRIDES*** were not counted, nor should they have been counted. Impacts were counted, not underrides. Therefore, the data element ***UNDERIDE*** was added to the FARS in 1994. The data element ***UNDERIDE*** is dependent on the data contained in the PCR.

0 No Underride or Override (1994-2011)
0 No Underride or Override Noted (2012-Later)

*WITH MOTOR VEHICLE IN TRANSPORT*
1 Underride (Compartment Intrusion)
2 Underride (No Compartment Intrusion)
3 Underride (Compartment Intrusion Unknown)

WITH MOTOR VEHICLE NOT IN TRANSPORT
4 Underride (Compartment Intrusion)
5 Underride (No Compartment Intrusion)
6 Underride (Compartment Intrusion Unknown)
7 Override, Motor Vehicle in Transport
8 Override, Motor Vehicle Not in Transport
9 Unknown if Underride or Override

The review uncovered the following specific issues:

- Coding variations did exist between the various case coders and reviewers.
- Coding override is challenging and likely completely missed or improperly coded.
- The element definition of underride/override could benefit from additional key words and visual scenarios to help determine underride/override (e.g., lodged, pinned, drove completely under).
- Refresher training of the underride and override variables is necessary.

Based on the feedback received from the review of the 2017 FARS ***UNDERRIDE/OVERRIDE*** cases, NHTSA has made the following improvements:

- The internal review served as the final guidance for a 2017 FARS file correction.
- FARS developed a new data element for the 2021 data file year to streamline and simplify data collection and reporting of ***UNDERRIDE/OVERRIDE***.

- This new data element, titled, "***Vehicle Underride/Override,***" remains on the vehicle level of coding, however it will capture the element for all vehicles involved and will not attempt to assess compartment intrusion.
- The new data element is being included in all planned training and refresher courses for the FARS field personnel to ensure consistent and quality data coding and analysis.

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