Journal of Progress in Safety & Security

Research Article

TU Delft OPEN Publishing

Cost-benefit analysis of side underride guards for new semitrailers in the United States

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Abstract: In the United States, the severe consequences of side underride crashes are well documented, yet no federal regulation requires side underride guards on semitrailers. Side underride guards can prevent vehicle underride and protect cyclists and pedestrians. This paper develops a decision support framework using a cost-benefit analysis to evaluate a potential federal requirement for side underride guards on new semitrailers.

Annually, side underride crashes result in an estimated 300 fatalities and 400 serious injuries, costing society $7.4 billion. To estimate how side guards could reduce these losses, the analysis models paired full-fleet reductions of 50/50, 100/100, and 150/150 (fatalities and serious injuries), then scales impacts to one annual production cohort of 221,000 new semitrailers. Present value is calculated over the 13.2-year service life at a 2 percent discount rate using costs of $1,500, $2,500, and $4,500 per semitrailer, and includes fuel economy adjustments from weight and, where applicable, integration with aerodynamic skirts.

Present value net benefits range from $0.137 billion to $2.8 billion. Scenarios that included fuel-saving skirts yielded additional savings of approximately 500 gallons per semitrailer annually (5.2 metric tons of CO_2), adding $4.9 billion in fuel and $3.3 billion in CO_2 benefits.

Monte Carlo simulations for the $2,500 guard plus skirt configuration estimated mean present value net benefits of $0.58 billion ($0.39 to $0.77 billion) for the 50/50 case, $1.71 billion ($1.35 to $2.11 billion) for the 100/100 case, and $2.84 billion ($2.30 to $3.45 billion) for the 150/150 case. Modeled net benefits were positive in all iterations.

Results indicate that a federal requirement for side underride guards on new semitrailers would produce positive economic and safety effects and meet conditions identified by NHTSA and industry for side underride guard rulemaking. The analysis can be applied in other jurisdictions using local crash, cost, and fleet data.

ISSN: 3050-4570
Vol. 2, 2026
DOI: 10.59490/pss.2.2026.8512

One sentence summary: This cost-benefit analysis evaluates a potential federal requirement for side underride guards on new U.S. semitrailers, estimates positive safety and economic benefits, and presents a framework that can be applied in other jurisdictions.

Keywords: Aerodynamic side skirt, Cost-benefit analysis, Federal safety standard, Regulatory analysis, Semitrailer, Side underride guard

Publishing history: Submitted: 21 November 2025; Revised: 13 February 2026, 5 March 2026; Accepted: 5 March 2026; Published: 15 May 2026

Cite as: Hein, E. (2026). Cost-benefit analysis of side underride guards for new semitrailers in the United States. *Journal of Progress in Safety and Security, 2*. https://doi.org/10.59490/pss.2.2026.8512

1 Introduction

In 1967, actress Jayne Mansfield was killed in a rear underride crash when her car collided with, and slid beneath, the rear of a semitrailer. In response, the Federal Highway Administration proposed a regulation requiring rear underride guards on semitrailers to prevent passenger vehicles from underriding, and indicated that a similar requirement for side underride protection would soon follow (Federal Highway Administration, 1969). The National Highway Traffic Safety Administration (NHTSA) was created in 1970 and assumed rulemaking responsibility for the U.S. Department of Transportation (USDOT). In 1971, under pressure from the trucking industry, NHTSA formally withdrew the proposed rule for rear underride guards (Morris, 1971; National Highway Traffic Safety Administration, 1971; Truck Trailer Manufacturers Association, 1969). A federal safety standard requiring rear underride guards on semitrailers was not finalized until 1996, with a 1998 effective date, yet federal regulators have never proposed side underride guards (Advisory Committee on Underride Protection, 2024; National Highway Traffic Safety Administration, 1996; Thompson et al., 2023a; Thompson et al., 2023b).

Side underride crashes occur when a passenger vehicle collides with the side of a semitrailer and slides beneath it. Due to the height mismatch, the passenger vehicle's crumple zones and airbags often fail to engage, frequently resulting in death or severe injuries to the occupants (Government Accountability Office, 2019; Insurance Institute for Highway Safety, 2023a; Mattos et al., 2021; National Highway Traffic Safety Administration, 2018a; Thompson, et al., 2023a; Thompson et al., 2023b). These crashes bypass the vehicle's primary safety features because the point of impact is often the windshield rather than the front bumper, causing the passenger compartment to be frequently crushed when it contacts the semitrailer (Government Accountability Office, 2019; Mattos et al., 2021; National Highway Traffic Safety Administration, 2018a). Approximately 200 passenger vehicle occupants die each year from side underride crashes with semitrailers (Braver et al., 1997; Brumbelow, 2012; Hein, 2025; Insurance Institute for Highway Safety, 2017c, 2023a; National Transportation Safety Board, 2014; Padmanaban, 2013). In 1977, the Highway Safety Research Institute at the University of Michigan (Minahan & J. O'Day, 1977) estimated that 195 side underride fatalities occurred each year. Simply put, over the last 45 years the annual number of fatalities from passenger vehicle side underride crashes with semitrailers has remained essentially unchanged. Over the last 50 years, this public health burden has resulted in nearly 9,000 fatalities (Hein, 2025).

Vulnerable road users (VRUs), including pedestrians, bicyclists, and motorcyclists, are also at risk of traveling under, and being crushed and killed or seriously injured by semitrailers that lack side guards (Epstein, 2022; Insurance Institute for Highway Safety, 2023a). Between 2019 and 2021, an average of 99 pedestrian fatalities, 22 bicyclist fatalities, and 187 motorcyclist fatalities occurred each year in crashes where the initial point of impact was the side of a large commercial truck (National Highway Traffic Safety Administration, 2025b). Of these, there are an estimated 100 VRU side underride crash fatalities annually (Epstein, 2022; Insurance Institute for Highway Safety, 2023a; National Highway Traffic Safety Administration, 2025b; National Transportation Safety Board, 2013).

While side underride guards are specifically intended to prevent passenger vehicles from sliding beneath a semitrailer, the addition of an aerodynamic side skirt could further mitigate fatalities and serious injuries among VRUs by reducing, and in some configurations blocking, the space beneath the semitrailer (Badgley et al., 2020; Epstein, 2022; Epstein et al., 2014; Insurance Institute for Highway Safety, 2023a; Kiefer, 2023c; Kwan et al., 2019; Mehrotra & Thompson, 2023; Volpe, 2021). For example, in Mexico, semitrailers are required to install pedestrian guards, which can be a slightly modified aerodynamic side skirt (Advisory Committee on Underride Protection, 2024; Hightman, 2024, 38:48). Additionally, in 1996 Strick designed a similar side guard for pedestrians, cyclists, and motorcyclists for use on semitrailers that were exported to Europe (Strick Trailers, LLC, 2022). By integrating side underride guards with aerodynamic skirts (Utility Trailer Manufacturing Company, 2024b; Wilson, 2017), the system can also reduce aerodynamic drag to save fuel, one of the largest operating costs in long-haul trucking (Galipeau-Belair, 2014; Galipeau-Belair et al., 2014; North American Council for Freight Efficiency, 2020).

This study develops a decision support framework and applies it in a cost-benefit analysis of a potential federal safety standard requiring side underride guards on new U.S. semitrailers. By substituting jurisdiction-specific crash, cost, and fleet data, the framework can be replicated and adapted to inform regulatory decision-making.

2 Background

Side underride guards, usually constructed from steel frames or cable/nylon webbing, are affixed to the sides of semitrailers (Airflow Deflector, 2024; Collision Safety Consulting, 2021; Utility Trailer Manufacturing Company, 2024b; Wilson, 2017). Functionally, side guards can help engage passenger-vehicle safety features (Mattos et al., 2021) and can shield passenger vehicles and VRUs from traveling beneath a semitrailer (Badgley et al., 2020; Epstein, 2022; Epstein et al., 2014; Insurance Institute for Highway Safety, 2023a; Kiefer, 2023c; Kwan et al., 2019; Mehrotra & Thompson, 2023; Volpe, 2021). Research, crash tests, and simulations consistently demonstrate that side underride guards can prevent or substantially limit passenger vehicles from underriding semitrailers, a critical factor in reducing fatalities and serious injuries (Brumbelow, 2012; Insurance Institute for Highway Safety, 2017a, 2017b; Kiefer, 2023a, 2023b, 2023d; Kumar et al., 2009; Mattos et al., 2021; Moradi, 2012; Seven Hills Engineering LLC, 2018, 2020; Utility Trailer Manufacturing Company, 2022b, 2023b, 2024b; Wilson, 2017).

Most side underride crashes occur at impact speeds between 30 and 50 mph (Bloch & Schmutzler, 1998; Minahan & J. O'Day, 1977). Crash tests and simulations at impact angles between 90 and 15 degrees indicate that side underride guards can attenuate at 35 to 40 mph crashes, with some simulations demonstrating protection up to 50 mph (Bodapati, 2006; Brumbelow, 2012; Castaneda et al., 2012; Galipeau-Belair, 2014; Galipeau-Belair et al., 2014; Hernando, 2021; Insurance Institute for Highway Safety, 2017a, 2017b; Kiefer, 2023a, 2023d; Kumar et al., 2009; Mattos et al., 2021; Moradi, 2012; Seven Hills Engineering LLC, 2018; Utility Trailer Manufacturing Company, 2022b, 2023b; Wilson, 2017).

Nearly 80 percent of fatalities (966 of 1,415) from side underride crashes recorded in NHTSA's Fatality Analysis Reporting System between 2007 and 2020 occurred on Interstates, U.S. Highways, or State Highways (Hein, 2024). On these roadways, passenger vehicles average 60.1 mph and combination trucks/semitrailers average 57.3 mph, a speed difference of 2.8 mph (National Highway Traffic Safety Administration, 2018b). NHTSA and the National Center for Statistics and Analysis (NCSA) estimated that side underride guards would be 97 percent effective in reducing fatalities and 85 percent effective in reducing serious injuries (National Center for Statistics and Analysis, 2023; National Highway Traffic Safety Administration, 2023). Together, the roadway context and these estimates provide a useful benchmark for the effectiveness assumptions used in the modeled scenarios.

Most major U.S. semitrailer manufacturers hold side underride guard patents (Great Dane LLC, 2021; Jaworski & Montiel Rosales, 2024; Utility Trailer Manufacturing Company, 2023a; Vanguard National Trailer Corporation, 2019; Giromini et al., 2012; Ehrlich et al., 2020; Kunkel et al., 2021). The industry has also drafted guidance addressing design, testing, and performance considerations for side underride guards (Stoughton, 2022b; Strick Trailers, LLC, 2022; Truck Trailer Manufacturers Association, 2021). Several manufacturers have conducted crash tests of side underride guard designs (Insurance Institute for Highway Safety, 2017a, 2017b; Stoughton, 2020, 2022b; Utility Trailer

Manufacturing Company, 2022b, 2023b, 2024b; Wilson, 2017). One manufacturer has factory-installed side underride guards on nearly 70 semitrailers, with sufficient ground clearance to prevent high-centering (Advisory Committee on Underride Protection, 2024; Bennett, 2023, 01:36:25; Utility Trailer Manufacturing Company, 2023a, 2024b). Side underride guards are also available as aftermarket safety options (Airflow Deflector, 2024; Collision Safety Consulting, 2021; Fortier, 2025), including at least one designed to safeguard VRUs (Fortier, 2019, 2025). In addition, one commercially deployed design (Angelwing) has logged more than 1 million road miles without compromising semitrailer integrity or operational performance (Airflow Deflector, 2024).

Prior research documents crash mechanics and side guard effectiveness, yet it does not provide a regulatory cost-benefit framework that integrates safety performance, injury valuation, fuel effects, and annual semitrailer production, nor does it report explicit injury-based break-even thresholds for side underride guard adoption.

2.1 Institutional resistance and regulatory failure

The NHTSA Administrator has statutory authority under the National Traffic and Motor Vehicle Safety Act of 1966, as amended, to issue and enforce motor vehicle safety standards that reduce crashes, fatalities, and injuries (49 U.S. Code § 30101; 49 CFR 1.95). NHTSA's mission is to save lives, prevent injuries, and reduce economic costs due to road traffic crashes (National Highway Traffic Safety Administration, 2025c). Nevertheless, NHTSA has not advanced any rulemaking on side underride protection (Advisory Committee on Underride Protection, 2024; Mehrotra & Thompson, 2023; Thompson et al., 2023a; Thompson et al., 2023b), which is inconsistent with its statutory authority and safety mission. In addition, NHTSA has not acted on a recent congressional report (Advisory Committee on Underride Protection, 2024), including crash test data (Galipeau-Belair, 2014; Hernando, 2021; Hyundai Translead, 2022; Insurance Institute for Highway Safety, 2017a, 2017b; Kiefer, 2023a, 2023b, 2023c, 2023d; Mattos et al., 2021; Moradi, 2012; National Highway Traffic Safety Administration, 2018a; Seven Hills Engineering LLC, 2018; Stoughton, 2020, 2022b; Thompson et al., 2023a, 2023b; Utility Trailer Manufacturing Company, 2022a, 2022b, 2023b, 2024b; Wilson, 2017), decades of research (Hein, 2023b; Mattos et al., 2021), and recommendations from the National Transportation Safety Board (National Transportation Safety Board, 1971, 2014, 2023), as well as denied or delayed administrative petitions (National Highway Traffic Safety Administration, 1979, 2014, 2022a, 2025a).

Even when Congress mandated that NHTSA assess the feasibility, benefits, and costs of side underride guards on newly-manufactured semitrailers (Infrastructure Investment and Jobs Act, Pub. L. No. 117-58, 135 Stat. 429, 2021), the resulting published Advanced Notice of Proposed Rulemaking (ANPRM) (National Center for Statistics and Analysis, 2023; National Highway Traffic Safety Administration, 2023) was widely criticized for methodological flaws, including the exclusion of safety benefits for VRUs (Braver 2023; Chicago Department of Transportation, 2023; City of Boston Transportation Cabinet, 2023; Consumer Reports, 2023; Hein, 2023a; Institute for Safer Trucking & Road Safe America, 2023; Insurance Institute for Highway Safety, 2023a, 2023b, 2024; National Association of Mutual Insurance Companies, 2023; National Transportation Safety Board, 2023; Seven Hills Engineering LLC, 2023; Truck Safety Coalition et al., 2023). Furthermore, an ANPRM is not a proposed rule or final rule under the Administrative Procedure Act, but a discretionary Federal Register notice used to solicit information for possible future rulemaking (U.S. Department of Transportation, 2022). NHTSA has not prioritized side underride guards, and its review of public comments on the ANPRM remains incomplete more than three years after publication (Office of Management and Budget, 2025).

In the ANPRM, NHTSA did not address the Truck Trailer Manufacturers Association's draft Recommended Practice, submitted to the agency by semitrailer manufacturers (Stoughton, 2022b;

Strick Trailers, LLC, 2022; Truck Trailer Manufacturers Association, 2021). The cost-benefit analysis (National Center for Statistics and Analysis, 2023) also omitted relevant data from Utility Trailer Manufacturing Company, the only major semitrailer manufacturer publicly offering side underride guards (Utility Trailer Manufacturing Company, 2022a, 2022b, 2023b, 2024b). Furthermore, the NCSA analysis (National Center for Statistics and Analysis, 2023) inflated annual semitrailer production by nearly 20 percent (Trailer Body Builders, 2021, 2023, 2025) and utilized the obsolete 2020 Value of a Statistical Life (VSL), rather than the contemporaneous 2023 VSL (U.S. Department of Transportation, 2025). Collectively, these choices in the NCSA cost-benefit analysis distorted the results and substantially underestimated the annual economic benefits of side underride protection.

Perhaps most concerning, neither NHTSA's ANPRM (National Highway Traffic Safety Administration, 2023) nor the NCSA's cost-benefit analysis (National Center for Statistics and Analysis, 2023) underwent peer review as required by the Office of Management and Budget (Office of Management and Budget, 2005, 2023). The analyses also failed to comply with a Presidential Memorandum directing agencies to use the best available science and data for policy decisions (Executive Office of the President, 2021), and disregarded the USDOT's recent scientific integrity policy (U.S. Department of Transportation, 2024a). Peer review serves as a critical check on agency assumptions and helps ensure policy decisions are evidence-based. Failure to follow these published procedures raises serious concerns about the objectivity of the regulatory and cost-benefit analyses.

NHTSA's failure to follow established USDOT directives on scientific integrity (U.S. Department of Transportation, 2024a) is compounded by a persistent pattern of unsupported conclusions that side underride guards would be too costly. For example, in a regulatory analysis concerning rear underride guards, NHTSA stated, without providing evidence, that side underride guards were "not cost effective" (National Highway Traffic Safety Administration, 1991). A 2021 Freedom of Information Act request confirmed that the agency held no data, analysis, or records to support this assertion (National Highway Traffic Safety Administration, 2022b). Despite this, NCSA's cost-benefit analysis for the ANPRM claimed that "a similar regulation (for side underride guards) 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" (National Center for Statistics and Analysis, 2023). This claim is not supported by the agency's record. NHTSA has never proposed a regulation for side underride guards (Advisory Committee on Underride Protection, 2024), nor has it produced any records or documentation supporting the 1991 assertion that side guards were "not cost effective" (National Highway Traffic Safety Administration, 1991, 2022b).

In the absence of federal regulations, the trucking industry has long demonstrated reluctance to adopt side underride guards for widespread deployment, typically citing costs and raising speculative claims of "unintended consequences" (Advisory Committee on Underride Protection, 2024; American Trucking Associations, 2019; Government Accountability Office, 2019; Mehrotra & Thompson, 2023; Owner-Operator Independent Drivers Association, 2025a, 2025b; Sievers, 2020; Thompson et al., 2023a, 2023b; Truck Trailer Manufacturers Association, 1969; Utility Trailer Manufacturing Company, 2022a). In fact, resistance can be traced back to a 1969 comment that was filed opposing possible side underride protection requirements (Truck Trailer Manufacturers Association, 1969). In the decades since, organized industry opposition to side underride guards has continued, with lobbying groups reiterating these objections in regulatory comments and Congressional testimony (Owner-Operator Independent Drivers Association, 2025a, 2025b). Investigative reporting has shown that such lobbying directly shaped USDOT's regulatory decisions, including a rejection of side guard requirements after meetings with industry representatives (Mehrotra & Thompson, 2023; Thompson et al., 2023b). Without a federal mandate, semitrailer manufacturers are uncertain about future regulatory standards and, as a result, are reluctant to move forward with these safety devices (Government Accountability Office, 2019).

Information from industry sources on side guard effectiveness has not been consistent. For example, Utility Trailer Manufacturing Company characterized the results of the same crash test differently across venues. In 2022, Utility Trailer Manufacturing Company reported to NHTSA that in a crash test of its side impact guard in which only 30 percent of the passenger vehicle's width overlapped the end of the guard, the "instrumented dummy survived the impact" (Utility Trailer Manufacturing Company, 2022a). In correspondence with a safety advocate, Utility Trailer Manufacturing Company described the results from the same crash test as "Utility Trailer's SIG (side impact guard) prevented passenger-compartment intrusion without significant injury to the instrumented crash dummy" (Utility Trailer Manufacturing Company, 2022c). By contrast, Utility Trailer Manufacturing Company stated in the recent congressional report that the side impact guard from the same crash test "dramatically failed to prevent passenger-compartment intrusion" (Advisory Committee on Underride Protection, 2024). These outwardly contradictory descriptions of the same crash test illustrate how industry representatives can selectively frame performance depending on regulatory or political context, or by emphasizing different criteria (occupant survival versus compartment intrusion).

NHTSA's own Advisory Committee on Underride Protection, a federally chartered body established by Congress under the Infrastructure Investment and Jobs Act (Infrastructure Investment and Jobs Act, Pub. L. No. 117-58, 135 Stat. 429, 2021), concluded in its congressional report that "very little has changed regarding side underride guard advancements in the last 50 years, and no substantial progress has been made by USDOT to prevent these horrific crash fatalities and injuries" (Advisory Committee on Underride Protection, 2024). This finding underscores decades of federal regulatory inaction despite clear evidence of preventable harm.

Accordingly, this study presents a comprehensive cost-benefit analysis of a prospective federal rulemaking to require side underride guards on newly manufactured enclosed freight semitrailers, including dry vans and refrigerated models, in the United States.

3 Data and methodology

3.1 Vehicle population, cohort scaling, and service life assumptions

In 2021, NHTSA's Office of Defects Investigation surveyed eight major U.S. semitrailer manufacturers. NHTSA concluded that these manufacturers represent nearly 100 percent of semitrailers that could be equipped with side underride guards, and it reported an in-service population of 2.45 million van (box) type semitrailers (National Highway Traffic Safety Administration, 2022a). This estimate is consistent with industry segment statistics indicating more than 2 million dry van trailers in operation (ACT Research, 2026).

The analysis scales full-fleet annual safety benefits to one annual production cohort of new semitrailers using the average annual U.S. production estimate of 221,000 units (Trailer Body Builders, 2021, 2023, 2025). Safety effectiveness is defined as paired annual reductions of 50 (low), 100 (medium), or 150 (high) fatalities and serious injuries per year under full-fleet adoption. The annual new-trailer cohort share is calculated as annual new production divided by the estimated in-service van-type semitrailer population, 221,000 / 2,450,000 = 0.090204, or approximately 9.02 percent. Annual fatalities and serious injuries prevented for one year of new semitrailers are calculated as the cohort share multiplied by the assumed full-fleet annual safety benefits.

This single cohort and scaling approach mirrors the method used in NHTSA's NCSA cost-benefit analysis of side impact guards (National Center for Statistics and Analysis, 2023). That analysis estimates mitigated fatalities and serious injuries under full-fleet adoption and scales the results to one year of new semitrailers using the new-production share of the fleet.

For lifetime impacts, the average semitrailer service life is estimated at 13.2 years (American Transportation Research Institute, 2025). Semitrailers are assumed to be used at a constant rate until retirement, and side underride guards are assumed to maintain safety benefits over the full service life.

The analysis converts annual benefits and annual operating cost effects using a lifetime present value adjustment factor (PVAF), defined as the sum of the annual discount factors over the 13.2-year service life with 2 percent discounting (PVAF = 11.5) (Office of Management and Budget, 2023). This present value approach does not model fleet turnover as older equipment is retired and replaced. It aligns with methodology that applies discounted lifetime impacts to calculate safety benefits and costs, including installation and any fuel adjustment effects, across the service life of semitrailers (National Center for Statistics and Analysis, 2023).

The analysis systematically varies key parameters and reports results in a consistent format. This structured sensitivity framework evaluates defined combinations of assumptions, including paired impacts in fatalities and serious injuries prevented, alternative unit guard costs, and modeled fuel adjustment cases, and reports present value net benefits for each scenario. Parameter values are drawn from peer-reviewed literature, federal regulatory documents, and industry information. The analysis supports replication and updates as new data become available.

3.2 Baseline fatalities and serious injuries

In the United States, side underride crashes are estimated to cause approximately 300 fatalities per year, including both vehicle occupants and VRUs (Braver et al., 1997, 1998; Brumbelow, 2012; Hein, 2025; Insurance Institute for Highway Safety, 2023a, 2023b, 2025; National Transportation Safety Board, 2013, 2014; Padmanaban, 2013). Serious injuries are estimated at approximately 400 per year (Braver et al., 1997; National Center for Statistics and Analysis, 2023; National Highway Traffic Safety Administration, 2023; National Transportation Safety Board, 2013). The baseline for this analysis represents the current state of practice, in which there is no federal regulatory standard requiring side underride guards on new semitrailers. Industry resistance to voluntary adoption of side underride guards (Government Accountability Office, 2019; Mehrotra & Thompson, 2023; Thompson et al., 2023a, 2023b) reinforces the assumption that crash rates are expected to remain largely unchanged in the absence of federal regulation. The annual societal cost of these crashes is calculated using USDOT's $13.7 million VSL for fatalities (U.S. Department of Transportation, 2025) and FMCSA's $8.12 million valuation of Maximum Abbreviated Injury Scale Level 5 ($MAIS_5$) for serious nonfatal injuries (Federal Motor Carrier Safety Administration, 2024).

3.3 Safety effectiveness of side underride guards

Crash test evidence and published evaluations indicate that side underride guards are effective in preventing passenger vehicles and VRUs from traveling beneath semitrailers (Galipeau-Belair, 2014; Hernando, 2021; Hyundai Translead, 2022; Insurance Institute for Highway Safety, 2017a, 2017b; Kiefer, 2023a, 2023b, 2023c, 2023d; Mattos et al., 2021; Moradi, 2012; National Highway Traffic Safety Administration, 2018a; Rechnitzer, 1993; Seven Hills Engineering LLC, 2018; Stoughton, 2020, 2022b; Mehrotra & Thompson, 2023; Utility Trailer Manufacturing Company, 2022a, 2022b, 2023b, 2024b; Wilson, 2017). Side underride guards are expected to reduce fatalities and serious injuries, but the magnitude of these effects remains uncertain without widescale implementation.

Safety effectiveness is defined as the annual number of fatalities and serious injuries prevented under full-fleet adoption, meaning the entire in-service van-type semitrailer fleet is equipped with side underride guards. To model a range of plausible outcomes, three safety-effectiveness scenarios were evaluated, reflecting paired annual reductions of 50 (low), 100 (moderate), or 150 (high) fatalities and serious injuries (Brumbelow, 2012; Insurance Institute for Highway Safety, 2023a; National Center for Statistics and Analysis, 2023; National Highway Traffic Safety Administration, 2023). These full-fleet annual benefits are scaled to one annual production cohort of new semitrailers using the cohort share method described in Section 3.1.

3.4 Unit cost

The analysis uses three unit-cost estimates for side underride guards, reflecting variation in manufacturing origin and aerodynamic skirt integration. The aerodynamic side skirt is included only in the integrated cost cases and is modeled strictly as a fuel-savings effect, not as a change in the safety-effectiveness scenarios. Because aerodynamic skirts are already used on some new semitrailers, the integrated configurations are modeled to avoid an added fuel penalty rather than attribute incremental net fuel savings attributable to a side underride guard requirement. Each unit cost represents installation of a full side guard system on a trailer, including guards on both sides. The unit-cost cases are: a $1,500 installation representing mass-produced OEM side underride guards without aerodynamic skirts; a $2,500 installation representing OEM integrated side guards with aerodynamic skirts; and a $4,500 installation representing aftermarket integrated side guards with aerodynamic skirts (Airflow Deflector, 2024; Epstein, 2022; Government Accountability Office, 2019; National Center for Statistics and Analysis, 2023; Seven Hills Engineering LLC, 2023; Strick Corporation, 2000).

3.5 Fuel economy

Fuel consumption impacts associated with the additional weight of side underride guards were modeled using two configurations, a 500-pound guard-only and a 1,000-pound integrated guard with an aerodynamic skirt (Airflow Deflector, 2024; National Center for Statistics and Analysis, 2023). The added weight was represented as a reduction in fuel economy of 0.25 percent and 0.5 percent, respectively, applied as a proportional increase in gallons of diesel used relative to baseline (North American Council for Freight Efficiency, 2019, 2020). For configurations that included aerodynamic skirts, a conservative 5 percent improvement in fuel economy (North American Council for Freight Efficiency, 2020; Utility Trailer Manufacturing Company, 2024a) was applied as a proportional decrease in gallons of diesel used relative to baseline. In those integrated cases, the skirt effect is modeled to fully offset the weight-related increase in fuel consumption, resulting in no net fuel penalty. Because aerodynamic devices are already used on some new semitrailers, the skirt effect is treated as a configuration assumption in the integrated cases and is not intended to be attributed as incremental fuel savings caused by a federal side underride guard requirement.

The analysis used a baseline fuel economy of 7.4 mpg, an average combined truck and semitrailer weight of 63,000 pounds, an average annual mileage of 82,677 miles per semitrailer, and a diesel cost of $3.78 per gallon (American Transportation Research Institute, 2025; North American Council for Freight Efficiency, 2019, 2020; U.S. Energy Information Administration, 2025; Williams & D. Murray, 2020). Associated changes in CO_2 emissions were calculated from the modeled change in annual diesel consumption, using 10.21 kg CO_2 per gallon of diesel fuel (U.S. Environmental Protection Agency, 2025) and reported as metric tons of CO_2 per year. The estimated reductions in CO_2 emissions were valued using $250 per metric ton (U.S. Department of Transportation, 2024b).

Results are reported as annual per-semitrailer impacts, then scaled and discounted using the cohort share and present value methods described in Section 3.1. The model assumes the same baseline miles driven and no change in how semitrailers are used or purchased, and does not model changes in trailer demand, freight demand, pricing, or consumer or producer surplus. The modeled fuel economy effects reflect side guard weight and, where applicable, the aerodynamic skirt, and are reported as changes in annual fuel costs and associated CO_2 emissions increases or reductions.

3.6 Analytical approach

This analytical approach follows federal regulatory impact guidance (Office of Management and Budget, 2023), aligns with methodological standards established by the USDOT (U.S. Department of Transportation, 2024b), and mirrors the cost-benefit approach used in NHTSA's side underride ANPRM and NCSA cost-benefit analysis (National Center for Statistics and Analysis, 2023; National Highway Traffic Safety Administration, 2023). Benefits are monetized using USDOT's current VSL (U.S. Department of Transportation, 2025) and FMCSA's MAIS5 valuation for serious nonfatal injuries (Federal Motor Carrier Safety Administration, 2024). Benefits and costs were estimated and reported in U.S. dollars (National Center for Statistics and Analysis, 2023; U.S. Department of Transportation, 2024b). Present value net benefits were calculated as monetized safety benefits minus installation and operating costs (Table 1).

Table 1. Formulas for present value benefits and costs, fuel economy adjustments, and break-even thresholds for a potential side underride guard standard.*

Equation	Formula
Annual Baseline Societal Cost (Current State, No Standard)	(Annual Number of Fatalities × VSL) + (Annual Number of Serious Injuries × $MAIS_5$)
Cohort Share	Annual Number of New Semitrailers Manufactured / In-Service Semitrailer Population
Annual Cohort Fatalities Prevented (Scaled)	Full-Fleet Fatalities Prevented × Cohort Share
Annual Cohort Serious Injuries Prevented (Scaled)	Full-Fleet Serious Injuries Prevented × Cohort Share
Lifetime Present Value Adjustment Factor (PVAF)	(1 – (1 + Discount Rate)^(-service life in years)) / Discount Rate
Annual Cohort Safety Benefits	(Annual Cohort Fatalities Prevented × VSL) + (Annual Cohort Serious Injuries Prevented × $MAIS_5$)
Present Value Safety Benefits	Annual Cohort Safety Benefits × PVAF
Cohort Installation Cost	Annual Number of New Semitrailers Manufactured × Unit Cost of Side Underride Guard (per Semitrailer)
Adjusted Fuel Economy (mpg), Guard Weight Only (500 lb or 1,000 lb)	Baseline mpg of a Loaded Combination Truck and Semitrailer × (1 – Fuel Penalty Rate)
Additional Gallons per Semitrailer per Year	(Baseline miles / Adjusted mpg) – (Baseline miles / Baseline mpg)
Annual Cohort Fuel Penalty Cost	Annual Number of New Semitrailers Manufactured × Additional Gallons per Semitrailer per Year × Diesel Price

Present Value Fuel Penalty Cost	Annual Cohort Fuel Penalty Cost × PVAF
Present Value Total Costs (Installation + Fuel Penalty Cost)	Cohort Installation Cost + Present Value Fuel Penalty Cost
Adjusted Fuel Economy (mpg), Guard Weight Plus Aerodynamic Skirt Benefit (Integrated Case)	(Baseline mpg × (1 – Fuel Penalty Rate)) / (1 − Aerodynamic Fuel Savings Rate)
Break-Even Analysis (Net Benefits = 0, Paired Fatalities and Serious Injuries)	Present Value of Total Costs / ((VSL + $MAIS_5$) × Cohort Share × PVAF)

* A supplementary Excel workbook contains the calculations for Table 1.

3.7 Uncertainty analysis

Uncertainty in present value net benefit estimates was quantified using Monte Carlo simulation, focusing on two sources: crash applicability and guard effectiveness. The probabilistic analysis is applied only to the $2,500 guard plus skirt configuration, which is treated as the implementation baseline, while the $1,500 and $4,500 configurations are evaluated as deterministic alternative scenarios. Effectiveness is represented as paired annual lives saved and serious injuries prevented under three full-fleet cases (50/50, 100/100, and 150/150).

In this framework, overall safety effectiveness is represented as the product of crash applicability and guard effectiveness. Crash applicability represents uncertainty in the number of side underride crashes that a side guard could realistically affect, given the inclusion decisions for higher speed crashes, multi-vehicle collisions, and VRUs. For example, the impact speed data NHTSA used to determine which crashes to include in the side underride estimates are subject to substantial uncertainty (Government Accountability Office, 2019; National Highway Traffic Safety Administration, 2013, 2026). Despite research by NHTSA and others showing side underride guard effectiveness up to 50 mph (Bodapati, 2006; Galipeau-Belair, 2014; Mattos et al., 2021; Moradi, 2012; National Highway Traffic Safety Administration, 2018a), the ANPRM excluded side underride crashes above 40 mph, those involving more than one passenger vehicle, and all VRU crashes (National Center for Statistics and Analysis, 2023; National Highway Traffic Safety Administration, 2023). Guard effectiveness represents uncertainty in guard performance.

Both components are modeled using triangular distributions with a mode of 1.0 and bounds of ±15 percent. The side underride guard market remains immature, with only one manufacturer currently offering an OEM-installed system and only a small number of aftermarket offerings. As a result, real-world deployment and performance data remain limited, and triangular distributions were selected to provide a bounded, transparent representation of that uncertainty. The ±15 percent bounds were chosen because a ±10 percent range would likely understate the plausible variation, while a ±25 percent range would extend beyond what the current evidence base can support. The multipliers are used only to improve interpretability and are not intended to imply that crash applicability and guard effectiveness are separately estimated from data or that separating these components adds robustness relative to using a single overall effectiveness factor. In each simulation iteration, the same combined multiplier is applied to both lives saved and serious injuries prevented, so the two outcomes rise and fall together.

Each iteration converts simulated full-fleet annual safety outcomes to cohort impacts using the cohort share method described in Section 3.1. Monetized annual safety benefits are calculated by applying USDOT's VSL to fatalities prevented and FMCSA's $MAIS_5$ valuation to serious injuries prevented. Annual benefits are converted to lifetime present value using the same discount rate, service life, and

PVAF applied in the base model. Present value net benefits in the Monte Carlo analysis are calculated as present value safety benefits minus the present value cost of the $2,500 guard plus skirt configuration. This configuration is used as the implementation baseline because it reflects an OEM guard and skirt package, avoids a fuel penalty, and provides a practical baseline for testing uncertainty. The analysis does not attribute incremental fuel savings to a federal side underride guard requirement, because aerodynamic devices may already be present on new semitrailers or adopted independently of side guards. Simulation results are summarized using the simulated mean and the 2.5th and 97.5th percentiles (95% uncertainty interval). Retrofit and maintenance requirements are not modeled because the analysis focuses on OEM installation on new semitrailers, and empirical data on side guard maintenance and repair are sparse.

3.8 Break-even analysis

A break-even benchmark was calculated to estimate the annual full-fleet equivalent safety benefit required for monetized safety benefits to equal total costs in the lifetime present value model. The primary benchmark assumes paired impacts, the same number of fatalities prevented and serious injuries prevented. Total costs include side underride guard installation and, where applicable, the fuel consumption adjustment attributable to the added guard weight. Annual safety impacts are scaled and discounted using the cohort share and present value methods described in Section 3.1. This benchmark identifies the annual full-fleet equivalent safety impact that marks the threshold where net benefits equal zero (break-even). In addition, a fatalities-only break-even threshold was calculated by solving for the number of fatalities required for benefits to equal costs excluding serious injury benefits. Different combinations of fatalities and serious injuries prevented can produce the same break-even outcome (net benefits equal to zero) because the Value of a Statistical Life is about 1.7 times the $MAIS_5$ valuation (Federal Motor Carrier Safety Administration, 2024; U.S. Department of Transportation, 2025).

All calculations and the Monte Carlo implementation, including cell level formulas, are provided in supplementary Excel workbooks to support replication.

4 Results and Discussion

4.1 Economic analysis

Annually, side underride crashes of passenger vehicles and VRUs into semitrailers that lack side underride guards result in an estimated 300 fatalities and 400 serious injuries, imposing an estimated baseline societal cost of $7.4 billion. This baseline reflects the status quo in the absence of federal regulation and underscores the economic burden of regulatory inaction. Without quantifying these ongoing losses, the public and policymakers may misinterpret the “No Action” alternative as cost-neutral, distorting an accurate comparison of regulatory options.

In all modeled cases, the present value net safety benefits of equipping new semitrailers[1] with side underride guards exceed the associated costs (Table 2). Under the scenario of preventing 50 fatalities and preventing 50 serious injuries annually, with a $1,500 unit cost and a 500-pound fuel adjustment, the estimated present value net economic benefit is $0.531 billion (Table 2). Even under conservative assumptions, net benefits remain positive. For example, under the same safety scenario with a $4,500 integrated guard plus skirts unit cost, the estimated present value net economic benefit is $0.137

[1] For context, using representative purchase prices (e.g., Commercial Truck Trader, 2025) for a 53-foot dry-van semitrailer ($45,000) and a 53-foot refrigerated semitrailer ($90,000), the modeled unit costs correspond to an incremental purchase cost of approximately 3.3%, 5.6%, and 10.0% for a dry van and 1.7%, 2.8%, and 5.0% for a refrigerated semitrailer.

billion (Table 2). In the higher-effectiveness scenario of preventing 150 fatalities and preventing 150 serious injuries annually, with a $2,500 integrated guard plus skirts unit cost, the analysis yields an estimated present value net economic benefit of $2.8 billion (Table 2). Overall, these results indicate that a federal regulatory standard requiring side underride guards is cost-effective under a broad range of modeled assumptions.

Table 2. Present value results for side underride guard scenarios by safety effectiveness and unit cost, including fuel and CO_2 effects where applicable.[2]

Scenario	PV Safety Benefits ($B)	PV Installation Costs ($B)	PV Fuel Cost Adjustment ($B) ($CO_2$, $B)	PV Net Economic Benefit ($B)	PV Skirt Fuel Savings ($B) ($CO_2$, $B)
Prevent 50 Deaths + 50 Serious Injuries, $1,500 SUG only + 500 lb Fuel Penalty	$1.132	$0.332	$0.269 ($0.182)	$0.531	N/A
Prevent 50 Deaths + 50 Serious Injuries, $2,500 Integrated SUG + Skirts (No Net Fuel Penalty)	$1.132	$0.553	N/A	$0.579	$4.855 ($3.278)
Prevent 50 Deaths + 50 Serious Injuries, $4,500 Integrated SUG + Skirts (No Net Fuel Penalty)	$1.132	$0.995	N/A	$0.137	$4.855 ($3.278)
Prevent 100 Deaths + 100 Serious Injuries, $1,500 SUG only + 500 lb Fuel Penalty	$2.264	$0.332	$0.269 ($0.182)	$1.663	N/A

[2] Note. PV = present value. Dollar values are reported in $ billions (B). Values in parentheses report the monetized CO_2 change associated with the fuel change for transparency only and are not included in Present Value Net Economic Benefit. “N/A” indicates no fuel penalty is applied in the integrated guard plus skirts configurations. Fuel savings and CO_2 values depend on skirt inclusion and are identical across safety-effectiveness scenarios.

Prevent 100 Deaths + 100 Serious Injuries, $2,500 Integrated SUG + Skirts (No Net Fuel Penalty)	$2.264	$0.553	N/A	$1.711	$4.855 ($3.278)
Prevent 100 Deaths + 100 Serious Injuries, $4,500 Integrated SUG + Skirts (No Net Fuel Penalty)	$2.264	$0.995	N/A	$1.269	$4.855 ($3.278)
Prevent 150 Deaths + 150 Serious Injuries, $1,500 SUG only + 500 lb Fuel Penalty	$3.396	$0.332	$0.269 ($0.182)	$2.795	N/A
Prevent 150 Deaths + 150 Serious Injuries, $2,500 Integrated SUG + Skirts (No Net Fuel Penalty)	$3.396	$0.553	N/A	$2.843	$4.855 ($3.278)
Prevent 150 Deaths + 150 Serious Injuries, $4,500 Integrated SUG + Skirts (No Net Fuel Penalty)	$3.396	$0.995	N/A	$2.401	$4.855 ($3.278)

4.2 Uncertainty analysis

For the $2,500 guard plus skirts configuration, Monte Carlo simulations show that present value net benefits were positive in all iterations. Based on 10,000 simulations per case, mean present value net benefits were $0.58 billion (95% uncertainty interval, 2.5th to 97.5th percentiles: $0.39 billion to $0.77 billion), $1.71 billion ($1.35 billion to $2.11 billion), and $2.84 billion ($2.30 billion to $3.45 billion) for the 50/50, 100/100, and 150/150 effectiveness cases, respectively.

4.3 Break-even threshold

Break-even thresholds were modest relative to the modeled effectiveness cases. Under the paired benchmark, with equal annual reductions in fatalities and serious injuries, the break-even annual fleetwide equivalent threshold is approximately 27 for the $1,500 guard-only case (including the 500 lb fuel adjustment), 24 for the $2,500 guard plus skirts case, and 44 for the $4,500 guard plus skirts case.[3] Under the fatalities-only benchmark, which excludes serious injury benefits, the break-even annual fleetwide equivalent thresholds are approximately 42, 39, and 70 fatalities prevented for the $1,500, $2,500, and $4,500 cases, respectively.

4.4 Fuel efficiency and operational cost

Integrating aerodynamic skirts with side underride guards can yield substantial diesel fuel savings. Even with an added 1,000 lb configuration, a modest 5 percent improvement in fuel efficiency would raise average fuel economy to 7.75 miles per gallon and reduce diesel use by 505 gallons (5.2 metric tons of CO_2) per semitrailer per year. Scaled to the average annual number of new semitrailers manufactured, this equals 111.7 million gallons (1.1 million metric tons of CO_2) saved per year. At a diesel price of $3.78 per gallon, this corresponds to about $1,910 in annual fuel savings per semitrailer. Over the service life in the present value model, the associated fuel savings are about $4.9 billion, with about $3.3 billion in monetized CO_2 benefits (Table 2).

In contrast, the fuel adjustment associated with the added weight of side underride guards is comparatively minor. A 500 lb guard is estimated to increase fuel consumption by 28 gallons (0.29 metric tons of CO_2) per semitrailer per year, or about $105 in added annual fuel cost, while a 1,000 lb configuration results in an additional 56 gallons (0.57 metric tons of CO_2), or about $212 in added annual fuel cost. These penalties are far smaller than the potential aerodynamic benefits when side underride guards are combined with fuel-saving skirts.

4.5 Limitations

Costs are borne primarily by fleet operators, since manufacturers would likely pass these expenses through to trailer pricing, while benefits accrue more broadly to society through reduced mortality and severe injury burden. Although the results support the economic feasibility of a federal mandate for side underride guards on new semitrailers, regulatory rulemaking would still need to develop a performance standard, a compliance test method, an implementation timeline, and enforceable requirements that can be applied consistently across manufacturers and equipment configurations.

Similar to the engineering improvements of rear underride guards (Stoughton, 2022a), a federal regulatory standard requiring side underride guards would undoubtedly prompt the development of alternative designs and innovations in reducing the weight of side guards while maintaining or improving safety effectiveness. The weight of side underride guards was modeled using 500 lb and 1,000 lb; however, other braided cable, nylon webbing, or aluminum side guard designs are available (Fontaine Commercial Trailer Inc., 2021; Fortier, 2019; Kiefer, 2018; Vanguard National Trailer Corporation, 2019; Giromini et al., 2012). In fact, NHTSA estimated that an effective side underride guard constructed of aluminum would weigh approximately 215 pounds (National Highway Traffic Safety Administration, 2018a).

Annual economic benefits should be considered minimum estimates because they do not incorporate additional benefits to the trucking industry including reduced legal liability (Manins, 2024; Sievers, 2020), reductions in insurance premiums (Kwan et al., 2019), and less risk exposure for drivers

[3] Calculations are available in the supplementary Excel workbook.

including potential criminal consequences in severe crashes (Nespral, 2025; Walsh, 2021). These issues are all outside the scope of the present research.

5 Conclusion and recommendations

This study applies the USDOT valuation framework and NCSA cohort-scaling methods under transparent, testable assumptions to monetize the safety benefits of side underride guards and compare those benefits with compliance costs, informing the regulatory assessment of a potential federal standard for new semitrailers.

This approach is transferable to other contexts and countries for regulatory appraisal of side underride guards. Analysts can estimate benefits, costs, and break-even thresholds by substituting jurisdiction-specific inputs, including injury valuations, fleet production volumes, unit costs, and safety effectiveness. The structure also supports sensitivity testing to compare alternative parameter sets and to document the robustness of results for policy review.

In every modeled scenario, preventing 50 to 150 fatalities and comparable numbers of serious injuries produces positive present value net economic benefits. Estimated net benefits range from $0.137 billion to $2.8 billion and consistently exceed the combined costs of side underride guard installation and the fuel penalty attributable to added weight. Successful crash tests, research, evaluations, and initial deployments, including Utility Trailer Manufacturing Company's integration of nearly 70 semitrailers and AngelWing's demonstrated durability, show that the technology is viable in practice. These data, together with NHTSA's statement that "If the evidence gathered by the agency indicates that side underride rulemaking could contribute significantly to safety, the agency will commence rulemaking" (National Highway Traffic Safety Administration, 1979) support moving forward with a federal side underride guard standard. The Truck Trailer Manufacturers Association and Utility Trailer Manufacturing Company have stated that they would support side underride guards "if they ever become economically justified and technologically feasible" (Truck Trailer Manufacturers Association, 2023; Utility Trailer Manufacturing Company, 2022a). Collectively, the conditions identified by NHTSA, the Truck Trailer Manufacturers Association, and Utility Trailer Manufacturing Company have been met in the modeled cases presented in this study. These findings can also inform current legislative proposals in the United States concerning side underride protection requirements for new semitrailers (S. 3775, 119th Cong., 2026; H.R. 7354, 119th Cong., 2026).

CRediT authorship contribution statement

Eric Hein: Conceptualization, methodology, investigation, data curation, formal analysis, validation, writing of the original draft, review, and editing. The author has read and approved the final version of the manuscript.

Data availability

The calculations supporting this article are provided in supplementary Excel workbooks available on the article landing page at the same DOI link as this paper. The workbooks include the calculations underlying Table 1, present value benefit and cost estimates, fuel economy adjustments, break-even thresholds, and the Monte Carlo simulation used to quantify uncertainty in present value net benefit estimates.

Use of AI

The entire manuscript was developed by the author through original thinking, research, and writing. After drafting the manuscript, the author used ChatGPT only to help refine wording and improve clarity, and to cross-check calculations. The author takes full responsibility for the content of the published article.

Declaration of competing interests

There are no conflicts of interest.

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