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A Target Population for Automatic Emergency Braking in Heavy Vehicles

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15. Supplementary Notes

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Abstract

This report develops a target population for Automatic Emergency Braking systems in vehicles with a gross vehicle weight rating (GVWR) over 10,000 pounds. This technology detects potential frontal crashes and warns the driver and/or engages vehicle braking when it senses a crash to be imminent.

We develop a detailed description of the crashes we think could be addressed by the technology, using a conservative approach that, if anything, underestimates the affected population. Adjusting for recent regulations, our affected population comprises 11,499 crashes annually. These 11,499 crashes involve 7,703 injured people, 173 of whom were killed. Of course, the chief value of this body of work lies not in these figures, which after all provide only upper bounds to the benefits, but rather in the detailed descriptions of affected crashes and subpopulation breakouts that have traditionally fed into benefits estimation.

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Table of Contents

List of Tables

List of Figures

Executive Summary

This report develops a target population for Automatic Emergency Braking (AEB) systems in vehicles with a gross vehicle weight rating (GVWR) over 10,000 pounds. This technology detects potential frontal crashes and warns the driver and/or engages vehicle braking when it senses an imminent crash.

We developed the target population through a multi-step process.

Step 1. First, we reviewed supplier literature in order to learn as much as possible about system activation and performance in various crash conditions.

Step 2. Second, we reviewed a random sample of heavy-vehicle crashes to see whether they shared common features and whether the technology would likely address them.

Step 3. Based on the results of Steps 1 and 2, and using engineering judgment, we then developed a detailed itemization of the crash conditions in which we thought the systems would be beneficial. Consistent with the agency's conservative approach to benefits estimation, we tended to exclude crashes when it was unclear that the technology would affect the outcome. This work comprises the bulk of the report. It produces the "unadjusted target population," which represents the current crashes applicable to AEB.

Step 4. Finally, we adjusted the size of the target population from Step 3 to account for recent and likely future regulations. These adjustments effectively exclude from Step 3's population the crashes, injuries, and fatalities that would be addressed by other mandated technologies that have not yet fully penetrated the heavy-vehicle market.

The end result of this process is a target population of 11,499 crashes annually involving 7,703 injured persons, 173 of whom were killed. We also provide detailed breakouts of the population that could be used to estimate the benefits of the technology.

There are three sources of uncertainty in these estimates:

- First, these estimates were derived from a probability sample of crashes. The 95-percent confidence interval for the crash figure, which reflects the uncertainty due to sampling, is 11,499 +/-4,186 crashes.

- Second, system algorithms are proprietary and so we do not know the exact circumstances in which a given AEB system would engage, what that response would be (warning and/or braking), when the response would occur (how many seconds prior to potential impact), how the driver would react (e.g., whether s/he would brake in response to a warning), and whether and when the system might engage a second-stage response (e.g., supplemental braking).

- Third, the crash data sometimes contain information that is not detailed enough for us to judge whether a given crash would be mitigated by AEB. For instance, a crash report might note that the crash occurred in the rain, but it might not say how heavy the rain is, which might affect system activation and/or response.

The last two sources contribute the greater uncertainty. For instance, had we been more liberal in our assessment of crash circumstances that AEB could address, our target population might have been as large as 40,593 crashes. In the end, however, it is important to keep in mind that the size of a target population provides only an *upper bound* to the benefits. The chief value of this report lies not in its estimated target population size, but rather in the detailed descriptions of affected crashes and subpopulation breakouts that have traditionally fed into benefits estimation.

1. Introduction

Automatic Emergency Braking (AEB) is a technology that combines sensors with computer algorithms to warn drivers of certain types of impending forward collisions. The system automatically engages vehicle braking if the driver doesn't, and supplements a driver's braking if it is deemed insufficient. The goal of this paper is to assess which types of frontal crashes would potentially benefit from the technology if it were installed in all motor vehicles over 10,000 pounds, and estimate how many such crashes occur annually.

a. Heavy Vehicles

This paper concerns AEB in motor vehicles with a gross vehicle weight rating (GVWR) over 10,000 pounds, including single-unit straight trucks, truck tractors, city buses, school buses, motorcoaches, and certain pickup trucks. We refer to these vehicles, excluding the relatively small number that are not regulated by NHTSA, as *heavy vehicles*. Conversely, vehicles that are 10,000 pounds or lighter, excluding the small number not regulated by NHTSA are referred to as *light vehicles*.[1]

b. Introduction to AEB

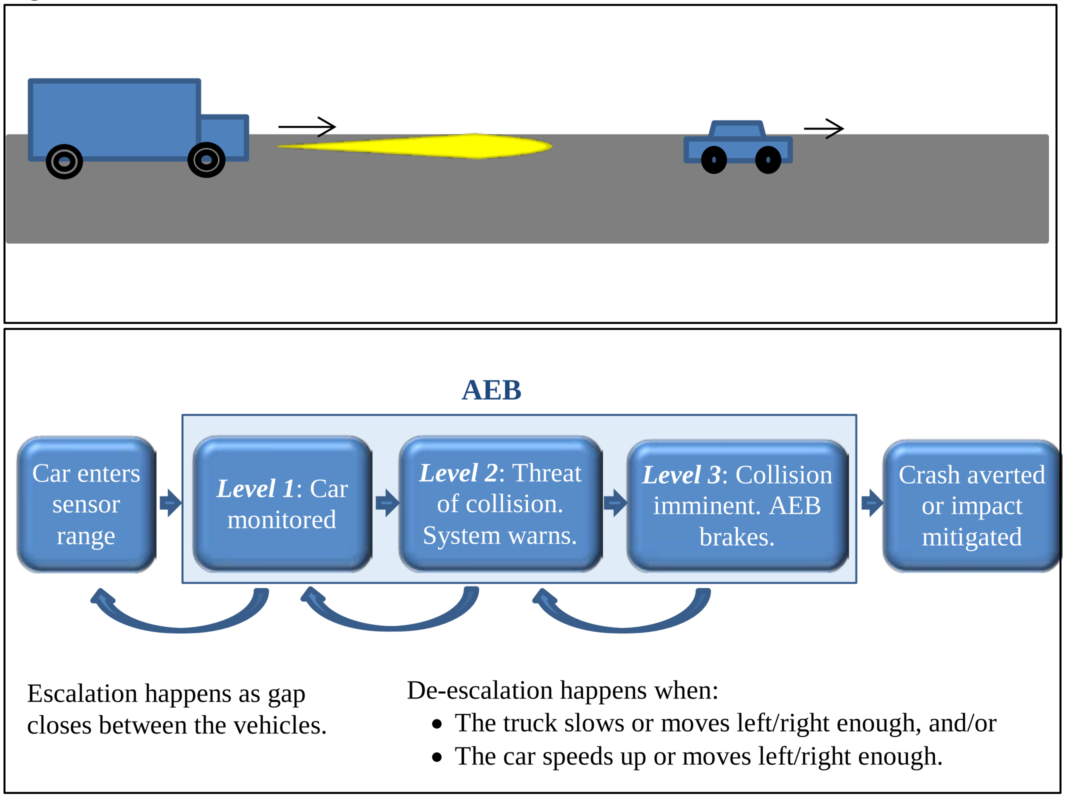
AEB has been around in one form or another since about 2009 in heavy vehicles and earlier in light vehicles. Broadly speaking, the safety problem that motivated the design for heavy-vehicle AEB is frontal impacts, particularly those in which the front of a heavy vehicle collides with the rear of another vehicle (light or heavy). At the time of this study, the technology in heavy vehicles used a single radar sensor,[2] and was produced by two suppliers: Bendix Commercial Vehicle Systems LLC and Meritor WABCO Vehicle Control Systems. Although the two companies designed their systems slightly differently, they each had a cascading system of actions as depicted in Figure 1.[3]

[1] Vehicles not regulated by NHTSA include construction cranes, farming tractors, and other vehicles that are primarily designed for off-road use.

[2] Current systems use both camera and radar input to reduce false positives and improve target recognition. (Bendix Commercial Vehicle Systems LLC, 2015)

[3] We are aware that several heavy-vehicle original equipment manufacturers are developing their own AEB systems. At the time of this study, the performance of all systems in production was similar.

Figure 1: Illustration of AEB's Actions in a Rear-End Collision Threat



Source: (Woodrooffe, et al., 2012)

Two particular components of the system will receive repeated mention in this paper. We refer to the driver alert, which may be audible and/or visual in nature, as *Forward Collision Warning* (FCW) and the engagement of the vehicle brakes absent the driver braking as *Crash Imminent Braking* (CIB).

Not all frontal crashes would be mitigated by the technology. For instance, the current systems do not act in crashes under 10-15 mph, nor do they act in crashes into walls, trees, and other fixed non-vehicular objects.[4] The goal of this paper is to assess which types of frontal crashes would potentially benefit from the technology and estimate how many such crashes occur annually. The types of crashes that would potentially benefit from a technology is called the technology's *target population*.

b. Target Populations in General

Discussing target populations can be confusing, as they can vary widely, even for the same technology. In essence, the role of a target population is to provide a platform for estimating benefits, with

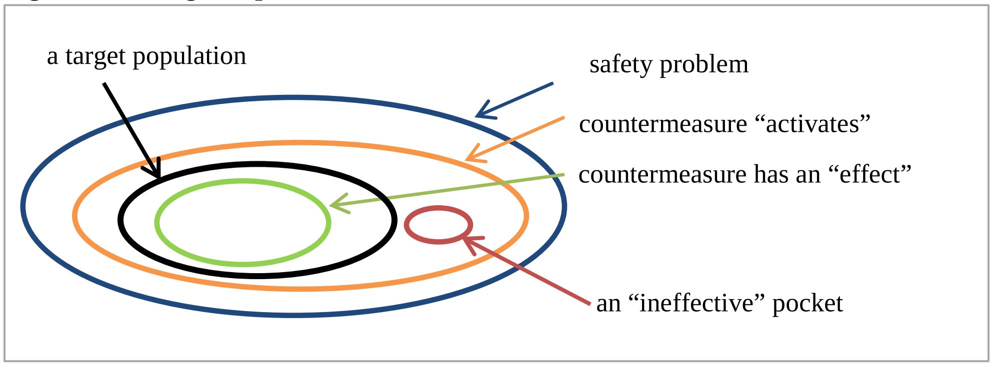
$$\text{Benefits} = \text{Effectiveness} \times (\text{Target population})$$

A technology, like AEB, can have multiple perfectly valid target populations, of various sizes. So long as each is associated with the "right" effectiveness figure, the benefits in the end will be the same. In essence, the size of a target population provides only an *upper bound* to the benefits (since the effectiveness is at most 100%).

[4] The current systems are capable of detecting and activating automatic braking on stopped lead vehicles. In forming a target population, we will assume that systems have the capabilities of next generation systems and so are capable of detecting and activating on moving, decelerating, accelerating, and stopped lead vehicles. See Chapter 3 for additional details about the technologies.

Target populations make the most sense when they lie between the crashes where a technology activates and that where it is beneficial. Ideally, all of these should lie inside the safety problem that motivated the technology's development, as depicted in Figure 2.

Figure 2: A Target Population Schematic



We prefer to define our target populations to be small. In addition to restricting (to the best of our knowledge) to crashes where AEB activates, we also exclude (to the best of our knowledge) as many crashes as possible where AEB would, in our assessment, have little to no impact on the injuries or property damage incurred in the crash (illustrated by the region denoted an "ineffective" pocket in the illustration above). We will also tend to exclude crashes in which the benefit of AEB is unclear. These exclusions put us in a better position to be confident that any benefits calculated from the target population would not be overestimated. (We, however, do *not* estimate benefits in this paper.)

Because of this preference for a small target population, it can be difficult to say what its size means. On the one hand, as noted earlier, the size of any target population provides an upper bound to the benefits (since the effectiveness of any countermeasure is at most 100%). On the other hand, had we set out from the start to derive an upper bound to the benefits, we would not have been inclined to discard crashes in which the benefit of AEB was unclear, and we probably wouldn't have excluded crashes where AEB would have little effect. Consequently it feels odd to describe our target population as an upper limit to benefits, despite the fact that the benefits estimated from our population would not exceed its size.

Fortunately, the size of the target population is not the chief item of value in this report. This report also describes in detail the crashes that we feel would be affected by the technology, and estimates the size of several subpopulations. These are items that are typically heavily used in NHTSA's traditional approach to benefits estimation. A technology like AEB may have several effectiveness estimates. These can come from crash tests and from experiments in which a truck with AEB is fitted with cameras and other equipment to record the circumstances surrounding each crash and near miss. To oversimplify things, suppose a crash test involving truck tractors found AEB to result in a speed reduction that would reduce the number of moderate-to-critical injuries by 30 percent. Say that a field test involving straight trucks found speed reductions that would reduce such injuries by 10 percent. The target population breakouts in Section 7 could be used to apply the 30-percent reduction to the tractors in the target population and the 10-percent reduction to the straight trucks, and combine the resulting benefits (along with those from other heavy-vehicle types).

Of course, new technologies change over time, so it's important to clarify exactly which variant of a technology one is forming a target population for. The "technology" whose target population we assess in this paper is AEB, with both its warning and braking functions, equipped with what we believe to be the technological capabilities available today or within a few years. Based on the technological make-up and capabilities we have seen in current and pre-production systems, this would include systems with "fusion" technologies that combine the inputs of radar and camera systems, and include algorithms that can reliably detect stopped lead vehicles, identify when they pose crash threats, and distinguish them from other fixed objects whose incorporation could otherwise generate large numbers of false positive activations, such as walls, trees, poles, and bridge abutments. Thus, for instance, we will allow all types of lighting conditions in our target crashes, as radar can detect objects at night, whether roads are lit or not (and today's systems have demonstrated this ability).

c. How We Developed the Target Population

We developed the heavy-vehicle AEB target population through the following steps:

Step 1. We reviewed supplier literature on the technology about the two systems – the Meritor WABCO OnGuard™ system and the Bendix® Wingman® Advanced™ system. This work is summarized in Chapter 2.

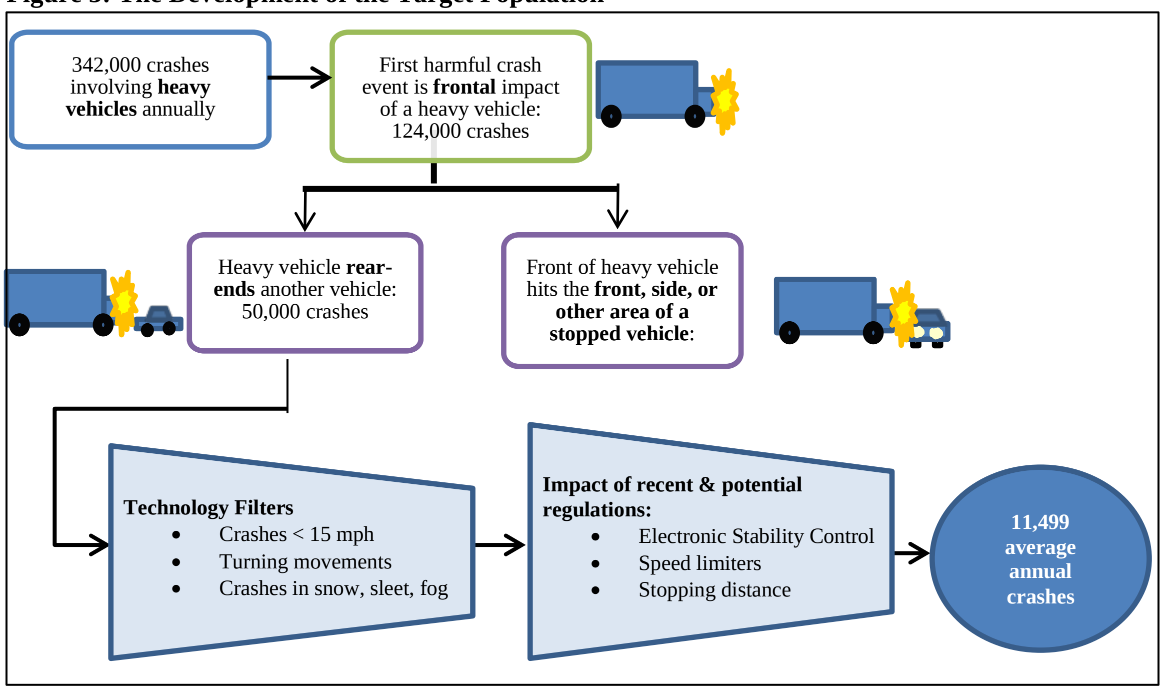
Step 2. We reviewed a random sample of heavy-vehicle crashes from the Large Truck Crash Causation Study (LTCCS), and assessed using engineering judgment whether AEB would have been likely to mitigate or prevent the crash. This work is in Chapter 3.

Step 3. Based on the results of Steps 1 and 2, we derived filters to identify the types of crashes that AEB would benefit. We applied these filters to NHTSA crash databases to estimate the number of crashes annually that AEB would prevent or mitigate if installed in every heavy vehicle. This detailed and lengthy work is presented in Chapter 4. It produces the "unadjusted target population," which represents the current crashes applicable to AEB.

Step 4. We adjusted the size of the target population from Step 3 to account for recent and likely future regulations. This is summarized in Chapter 5. These adjustments effectively exclude from Step 3's population the crashes that would be prevented by other mandated technologies that have not yet fully penetrated the heavy vehicle market. (Additionally, they reduce the injuries in Step 3's population by the expected effect of such technologies.)

Figure 3 depicts Steps 3 and 4, limiting to the main filters from Step 3.

Figure 3: The Development of the Target Population[5]



With the final target population in hand, we calculate margins of error for its numbers of crashes and injuries (Chapter 6), compare it to a target population developed by the University of Michigan (also in Chapter 6), and examine the prevalence of key characteristics in it (Chapter 7).

[5] The 95% confidence interval for the 11,499 target population figure is 11,499 +/-4,186.

d. Important Caveats Regarding Our Target Population

Developing a target population is not without challenges. Market technologies like AEB generally use proprietary algorithms, making it difficult to ascertain which situations would engage a system response, what that response would be (warning and/or braking), when the response would occur (how many seconds prior to potential impact), how the driver would react (e.g., whether s/he would brake in response to a warning), and whether and when the system might engage a second-stage response (e.g., supplemental braking).

Another important caveat is that AEB is a developing technology. Suppliers are working to improve the sensors and algorithms, and with these improvements, the target population will presumably grow.

A final caveat for any target population is that even with perfect knowledge of proprietary systems and fixing a point in the development timeline, target populations are far from unique. As illustrated in Section 1b above, one can establish perfectly valid target populations that differ wildly in the crashes that they include. What matters in the end are the technology's benefits – the lives saved, injuries mitigated, crashes prevented, and property damaged lessened – which are quantities not estimated in this report.

2. Testing, Literature, and General Knowledge

We reviewed all sources we could find regarding the two production systems, Meritor WABCO's OnGuard™ and Bendix's Wingman® Advanced™, manufactured between 2009-2014. This included:

- Sales brochures (Bendix Commercial Vehicle Systems LLC, 2011b), (Meritor WABCO Vehicle Control Systems, n.d.);
- Questions and answers compiled for potential buyers (Bendix Commercial Vehicle Systems LLC, 2011a);
- Driver tips (Meritor WABCO Vehicle Control Systems, 2013b), (Meritor WABCO Vehicle Control Systems, 2009a);
- Maintenance manuals (Bendix Commercial Vehicle Systems LLC, 2011c), (Meritor WABCO Vehicle Control Systems, 2011), (Meritor WABCO Vehicle Control Systems, 2013a); and
- Technical bulletins (Meritor WABCO Vehicle Control Systems, 2009b), (Meritor WABCO Vehicle Control Systems, 2014b).

These documents were retrieved from the manufacturer's websites, www.meritorwabco.com and www.bendix.com in April 2014.

Each manufacturer uses proprietary algorithms, so the literature is not very specific in describing their systems' technological capabilities. However, we did learn or confirm the following concerning AEB systems, at least as they existed at the time (around the time of April 2014). In some cases, we are aware of subsequent improvements made to the technology and we make note of this in the following:

1. The systems included following-distance alerts. However we do not include in our target population or attempt to estimate the benefits of such alerts, since we lack test data on their performance.

2. The systems were generally active at speeds of 15 mph or faster. That is, system alerts and automated braking were generally suppressed below this speed and generally active at or above this speed. Specifically, the Bendix system had a minimum activation speed of 5 mph for following-distance alerts, 10 mph for stopped-object alerts, and 15 mph for impact alerts, while the Meritor WABCO system had a minimum activation speed of 15 mph for all forward collision alerts.

3. Around the time of April 2014, the systems warned, but did not brake, on stopped lead vehicles. Today's systems brake for stopped lead vehicles, at least in some circumstances (Bendix Commercial Vehicle Systems LLC, 2015). We included such crashes (into stopped lead vehicles) in our target population.

4. The systems did not warn or brake on motorcyclists, pedestrians, and bicyclists. In our estimation, this technological limitation will apply to near future systems as well.

5. The systems required the vehicle "threat" to be traveling in the same direction as the AEB-equipped vehicle, such as in what we typically think of in a rear-end crash. We expect this to be a limitation in the near future as well, with the exception of stopped lead vehicles. (In our estimation, the new lead-vehicle-stopped technology could be applied regardless of whether the rear, front, or side of the stopped lead vehicle faces the AEB-equipped vehicle.)

6. The Bendix and Meritor WABCO systems both employed a single radar sensor (with about a 500-foot range) mounted to the front of the vehicle. Performance could be hampered in weather conditions that could cause ice, snow or dirt to build up and block the sensors. Likewise, front-mounted equipment (like snow plows and deer guards) could block the sensors. Misaligned sensors also reduced system performance. Today's systems use both cameras and radar. (Bendix Commercial Vehicle Systems LLC, 2015)

7. Driver application of the accelerator pedal would override all interventions. However, driver braking would not; rather, the system would supplement the driver's braking with additional automated braking if the driver's braking was assessed to be insufficient.

8. Both systems featured a cascade of alerts and interventions including the sequential use of audible and visible warnings, automatic torque reduction, application of the engine retarder, and finally automatic brake application as needed. The Meritor WABCO system issued a haptic alert (a brake pulse) when a rear-end collision was developing. More information was available about the Bendix system, which used the following cascade of warnings and interventions during a crash-imminent braking activation:
    a. Following Distance Alert(s) may sound (progressive illuminated yellow bars and beeping alerts)
    b. Impact Alert (illuminated red bars and a loud, continuous warning tone)
    c. Automatic Engine Torque Reduction
    d. Automatic Engagement of Engine Retarder
    e. Automatic Application of Foundation Brakes (up to 2/3 of system braking capabilities)

    The impact alert (FCW) was activated when the system algorithmically determined that a collision was very likely or unavoidable without intervention. The algorithm involved consideration of a combination of factors: the velocity of the AEB-equipped vehicle, its headway, and the velocity of the vehicle ahead.

9. During a CIB activation, the Bendix system was designed to intervene with up to two-thirds of the vehicle's braking capacity (about 0.28-0.47g), while the Meritor WABCO system was designed to supply up to one-half of the vehicle's braking capacity (about 0.21-0.35g). Stopping distances from these brake forces are given in the following table.

Table 1: The Stopping Distance for a Given Deceleration

Deceleration	***5 mph***	***20 mph***	***35 mph***	***50 mph***	***65 mph***	***80 mph***
0.23g (1/3 braking)	4 ft	58 ft	178 ft	363 ft	614 ft	930 ft
0.35g (1/2 braking)	2 ft	38 ft	117 ft	239 ft	404 ft	611 ft
0.47g (2/3 braking)	2 ft	28 ft	87 ft	178 ft	301 ft	455 ft
0.70g (full braking)	1 ft	19 ft	59 ft	119 ft	202 ft	306 ft

This information conforms to what we have seen in our test track work and general information we have gleaned from working with the systems and previous conversations with manufacturers. The information in the last two items (8 and 9) do not really impact the target population, but we include them under the heading of general information.

3. Case Reviews

We reviewed a sample of detailed crash investigations in order to better understand three questions that we felt would help us formulate the target population or assess benefits:

- Do heavy-vehicle rear-end crashes (heavy vehicles rear-ending other vehicles) share common features that could be useful in forming a target population?
- Would FCW alone likely avert or mitigate most heavy-vehicle rear-end crashes?
- Among those crashes not likely averted by FCW, would CIB likely avert or mitigate most heavy-vehicle rear-end crashes?

We focused our attention on crashes in which a truck tractor or straight truck rear-ends a light or heavy vehicle, as we expected these to comprise the majority of our target population (and they will). For instance, we excluded buses rear-ending cars,[6] and straight trucks rear-ending motorcycles.

We sampled crashes from NHTSA's Large Truck Crash Causation Study (Federal Motor Carrier Safety Administration, National Highway Traffic Safety Administration, 2006a). The database from this study is the only nationally representative compilation of detailed investigations of heavy vehicle crashes in the United States. Its 967 crashes involve 1,127 large trucks, 959 non-truck motor vehicles, 251 fatalities, and 1,408 injuries. The study focused on crashes that involved an injury or fatality, and was conducted during April 2001 – December 2001 at a probability sample of 24 data collection sites in 17 states. For more information about this study, see http://ai.fmcsa.dot.gov/ltccs/.

We selected three independent random samples of crashes of three types: rear-end crashes in general, rear-end crashes into stopped lead vehicles, and rear-end crashes in which the speed of the following vehicle was at least 50 mph in excess of that of the lead vehicle (using police-reported travel speeds). We stratified each sample by the type of striking vehicle (straight truck vs truck tractor) and the type of lead vehicle (passenger vehicle or heavy vehicle) and sampled cases in proportion to their incidence. Because it was initially unclear how many crashes the engineers would be able to review, we selected the samples as random stream by randomly sorting the cases in each stratum. As engineers became available to review additional cases, we randomly assigned cases to reviewers, taking care to preserve the proportional allocation of the strata.

Two engineers were assigned to review each crash in detail, compiling key information from the crash investigation and coming to independent professional assessments of the likelihood that FCW/CIB would activate and, if so, whether it would have prevented or mitigated the crash. For instance, a reviewer might have assessed a crash via:

Table 2: Sample Assessment of an LTCCS Case

System	***Avoidance*** *likely*	***Mitigation*** *likely, reducing crash severity*	***Activation*** *likely, but no effect on crash severity*	***No activation*** *likely*	***Total***
FCW	20%	40%	40%	0%	100%
CIB	20%	70%	10%	0%	100%

When engineers differed in their assessments, they discussed the case until they came to resolution (which was achieved in all but one case).

Altogether, we reviewed and came to consensus assessment of whether FCW or CIB would be effective in 23 cases. In one case, two engineers reviewed the case and came to a consensus assessment of FCW effectiveness but could not reach agreement on whether CIB would be effective. In five other cases, a single engineer reviewed the case and came to an assessment concerning whether FCW/CIB would be effective.

[6] AEB systems are being designed for buses, and we will include buses in our target population. It was only for the limited purpose of case reviews that we excluded bus crashes.

Regarding the first question (whether rear-end crashes share common features), we were surprised to find no obvious common features.

Regarding the second and third questions (whether FCW and/or CIB would prevent or mitigate most rear-end crashes), we assessed each component (FCW and CIB) to be effective for a broad range of rear-end collisions. In the following table, we counted a component (FCW or CIB) to be "effective" if the consensus review was that there was at least a 50percent chance of mitigating (including avoiding) the collision.

Table 3: Summarized Assessment of the 29 Cases Reviewed by At Least One Engineer

Crash Type	*FCW and CIB each effective*	*FCW effective, CIB not effective*	*CIB effective, FCW not effective*	*FCW effective, no consensus for CIB*	*Neither effective*	*Total*
Rear-end crashes in general	17	4	2	1	5	29
Rear-end crashes into stopped lead vehicles	2	2	2	0	2	8
Rear-end crashes with a relative speed exceeding 50 mph[7]	4	1	1	0	2	8

All reviewed cases involved frontal impacts of straight trucks and truck tractors into passenger vehicle and heavy vehicles.

We weighted the 29 cases by their sampling weights to produce the following estimates.

Table 4: Summarized Assessment of the 29 Cases Reviewed by At Least One Engineer, Weighted Estimates

FCW and CIB effectiveness	*Annualized Crashes*	*Percent*
CIB effective but FCW not effective	583	6%
FCW and CIB effective	4,919	50%
FCW effective but CIB not effective	2,269	23%
FCW effective, no consensus for CIB	45	0.5%
Neither FCW nor CIB effective	2,092	21%
Total	***9,908***	***100%***

An example of a crash where we found that FCW would be likely to mitigate (or avoid) the crash but CIB would not is case number 818003992. In this case, an International truck tractor traveling 55 mph drifted into the next lane of a six-lane interstate with a 6-percent downhill grade, where a slower-moving Kenworth tractor-trailer was traveling ahead at 30 mph. The International braked too late and rear-ended the Kenworth tractor-trailer, then continued into an embankment at the side of the road. In the LTCCS crash investigator's assessment, driver inattention caused the lane drift. Our reviewers felt there was a 75-percent chance that FCW or lane departure warning (LDW) would have at least mitigated the crash, whereas CIB would have had only a negligible impact.

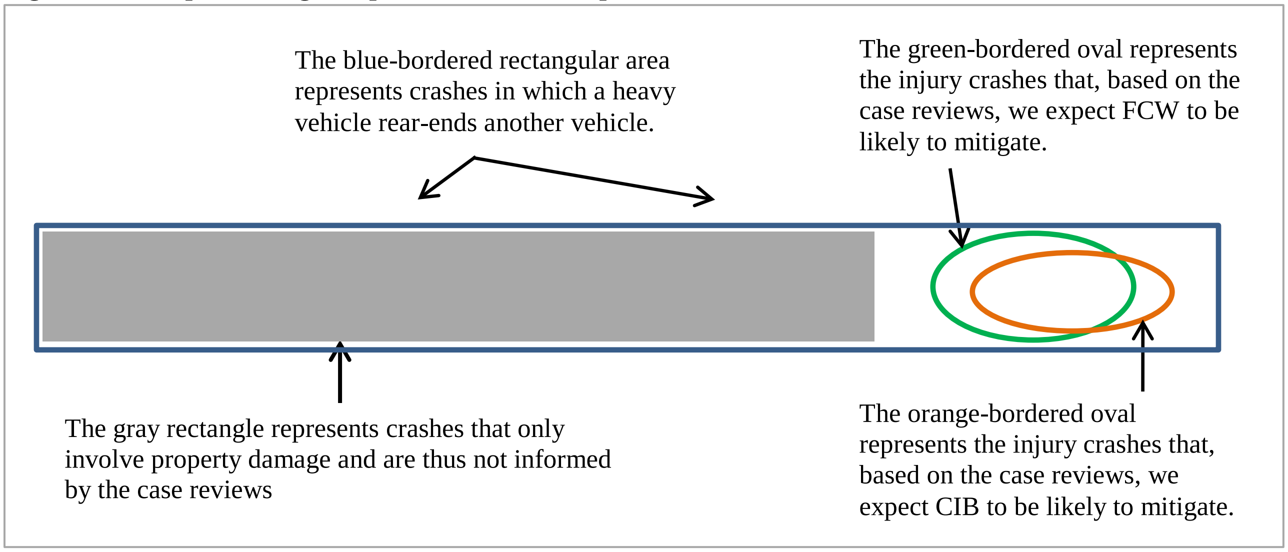
An example of the opposite, where we found CIB would be likely to at least mitigate the crash but FCW would not is case number 818003672. Here, a garbage truck was pulling up behind a parked flatbed truck on the side of a residential street to pick up garbage when a safety pedal guard device suddenly fell on top of the foot pedals, blocking the brake pedal from use by the driver. He rear-ended the stopped flatbed truck ahead, injuring its occupant. We felt that the driver probably would not respond to an additional alert, as a vehicle malfunction prevented him from braking, but if his eyes were off the roadway while attempting to repair the pedal guard, FCW may have helped. CIB could have avoided/mitigated if the garbage truck was traveling above the minimum

[7] Although we reviewed four cases where the relative speed, as indicated by the police reported travel speeds of the two vehicles, was as high as 80 mph, in none of these cases did the reviewers think the relative speed was this high. The reviewers felt that relative speed exceeded 50 mph in 8 cases however (3 of the assigned 4 cases with a police-reported speed differential over 80 mph, and one with no reported speeds).

activation speed. We assigned an 80-percent chance that CIB would at least mitigate the impact, but only a 10-percent that FCW would.

Based on the case reviews as summarized in Table 4, we would expect a relationship something like that in Figure 4 between the target population and rear-end crashes. Note that our findings pertain only to injury (including fatal injury) crashes, as the LTCCS focused on such crashes. In contrast, most heavy vehicle crashes damage only property, as illustrated by the fact that 75 percent of large-truck crashes in 2012 did not result in any injuries or fatalities (National Highway Traffic Safety Administration, June 2015). Thus, while our case reviews indicate high effectiveness, we might see an appreciably different situation when we consider crashes of all severity.

Figure 4: Anticipated Target Population Relationships From the Case Reviews



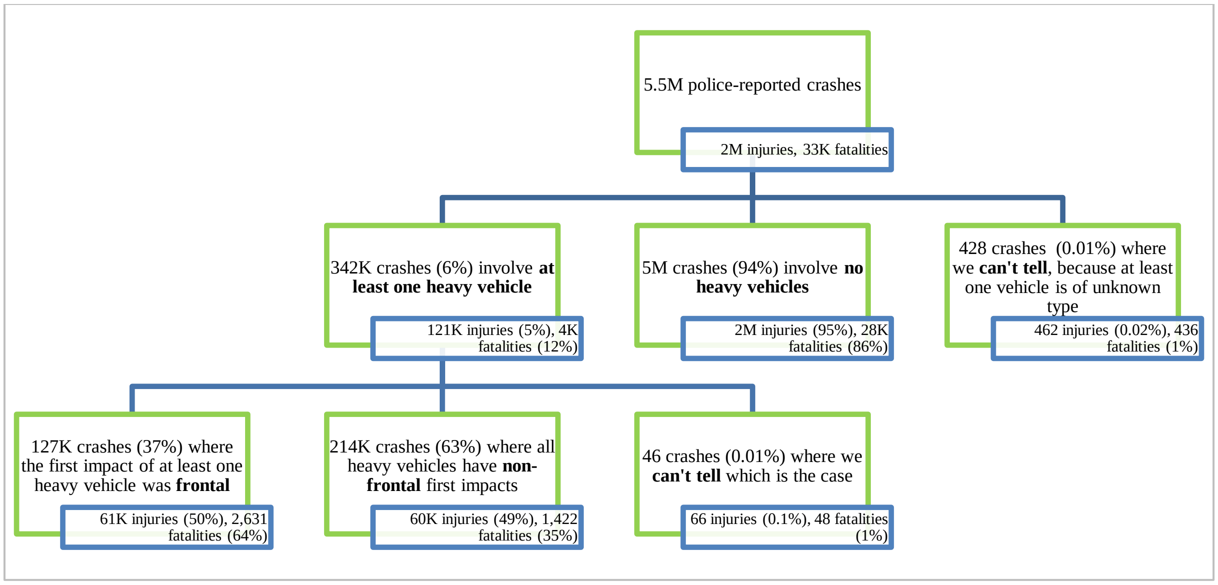
Note that one could conceive of two target populations – one for the "FCW" portion of AEB and one for the "CIB" portion. We take the view instead of a single target population – that for the entire AEB system, with both its FCW and CIB functionalities.

4. Target Population Filters

We formulate our target population by starting with the entire crash population, i.e., the roughly 5.5 million police-reported crashes involving motor vehicles of any type in the United States annually. We then sequentially "trim away" limbs that correspond to irrelevant crashes (such as crashes not involving heavy vehicles), or where the technology would not activate (e.g., crashes under 15 mph) or where technology is not likely to be effective (e.g., on ice).

Along the way, we provide estimates of the size of each "limb," both the trimmed ones as well as those that remain, denominated in the annual numbers of crashes, injuries, and fatalities represented by the limb. (For clarity, our "injuries" include fatal ones, e.g., the 33 thousand fatalities in the top of Figure 5 are among the 2 million injuries.) For instance, the beginnings of our tree would look like:

Figure 5: The First Filters for the Target Population



Source: Annualized figures from 2010-2012 FARS and GES

The percentages in Figure 5 reflect the portion of the analogous total from which it came. For instance, in 37 percent of crashes involving at least one heavy vehicle did a heavy vehicle sustain frontal damage in its first impact (127,000/342,000). The analogous percentage for injuries is 50 percent.

We continue formulating and filtering limbs using information from our crash databases, until we have extracted all information from the data that appears relevant to us. The end result is our target population, prior to adjusting for regulations.

There is no natural choice of order in which to execute the filters. We could first excise crashes involving no heavy vehicles, or first cut those without frontal impacts. So long as we make the same choices along the way, we will end up with the same target population in the end. It is worth noting, however, that the cuts we make first will necessarily be the largest ones, while the last cuts to the tree will be the smallest. Therefore, when examining the size of the limbs we excise at each stage, it is better to consider the *percent* of the total crashes, injuries, or fatalities, rather than the absolute number. Had we cut the non-frontal impacts first rather than the crashes without heavy vehicles, the "non-frontal" limb in Figure 1 would have had many more than 214 thousand crashes, and the "no heavy vehicles" limb many less than 5 million crashes. Their percentages would have differed as well, but not as much. That is, the no-heavy-vehicles limb is a big excision because it is a 94-percent cut (in crashes), and the non-frontal limb is also quite sizable as it cuts 63 percent of the remaining.

We are cognizant that not all people would make the same cuts we did. While some cuts are readily justifiable (such as those involving no heavy vehicles), other are less so, or even downright unclear, whether due to incomplete knowledge of the systems or because a given FARS/GES coded value can reflect a wide range of circumstances. For instance, consider the weather at the time of the crash. FARS/GES has a code of "snow." We do not know exactly how heavy a snowfall the AEB sensors can reliably handle, nor do we know how heavy the snowfall was in the crash, just that it was snowing. In such cases, we note our choice (in this case to cut all crashes in "snowy" conditions) and note that this choice (at least for sizable cuts, say a 5% or greater reduction in crashes, injuries, or fatalities) is debatable. We will mark such instances with the paragraph header "Conservative and Substantial Cut."

In general, when we are uncertain whether to excise or not, we make the conservative choice to excise. The resulting target population is then, if anything, underestimated in size, and the benefits estimate would be conservative.

The reader who is less interested in the detailed derivation of the target population than the final product might wish to skip to Chapter 6.

a. FARS/GES Preliminaries

We formulated our target population using two of NHTSA's crash databases: the Fatality Analysis Reporting System (FARS) is an annual census of *fatal* motor vehicle fatalities in the United States, and the General Estimates System (GES) is an annual probability sample of motor vehicle crashes in the United States (National Highway Traffic Safety Administration, 2013). In combining crashes from two databases, we exclude the fatal crashes from GES, which would otherwise be counted twice.

Alternatively, we could have formulated a target population using the LTCCS (Federal Motor Carrier Safety Administration, National Highway Traffic Safety Administration, 2006a) or the University of Michigan Transportation Research Institute's (UMTRI) Trucks Involved in Fatal Accidents (TIFA) study. We rejected the choice of LTCCS because its crashes date from 2001, and heavy vehicle crashes may have changed substantially in the meantime. (LTCCS was essentially our only choice for case reviews because it has the type of detailed crash investigatory information we needed for the reviews.) While TIFA contains more specific information about the vehicle (such as the cab style) and the driver (such as how long s/he had been driving at the time of the crash), we rejected it because it is limited to fatal crashes (Jarossi, Hershberger, & Woodrooffe, 2012).

We used the 2010-2012 crash years in the target population. At the time we compiled the population, 2012 was the most recent data year. Going back prior to 2010 would predate the FARS/GES data element consolidation, complicating the analysis, while we see from the following table from (National Highway Traffic Safety Administration, June 2015) that heavy-vehicle crashes have been pretty stable in recent years.

Table 5: Large-Truck Involvement in Fatal and Injury Crashes and Involvement Rates, 2004–2013

Year	Number of Large Trucks Involved in Fatal Crashes	Number of Large Trucks Registered	Involvement Rate per 100,000 Registered Large Trucks	Large-Truck Miles Traveled (millions)	Involvement Rate per 100 million Large-Truck Miles Traveled
2004	4,902	8,171,364	59.99	220,811	2.22
2005	4,951	8,481,999	58.37	222,523	2.22
2006	4,766	8,819,007	54.04	222,513	2.14
2007	4,633	10,752,019	43.09	304,178	1.52
2008	4,089	10,873,275	37.61	310,680	1.32
2009	3,211	10,973,214	29.26	288,306	1.11
2010	3,494	10,770,054	32.44	286,527	1.22
2011	3,633	10,270,693	35.37	267,207	1.36
2012	3,825	10,659,380	35.88	269,207	1.42
2013	3,906	10,597,356	36.86	275,018	1.42

Year	Number of Large Trucks Involved in Injury Crashes	Number of Large Trucks Registered	Involvement Rate per 100,000 Registered Large Trucks	Large-Truck Miles Traveled (millions)	Involvement Rate per 100 million Large-Truck Miles Traveled
2004	87,000	8,171,364	1,062	220,811	39
2005	82,000	8,481,999	971	222,523	37
2006	80,000	8,819,007	911	222,513	36
2007	76,000	10,752,019	705	304,178	25
2008	66,000	10,873,275	608	310,680	21
2009	53,000	10,973,214	487	288,306	19
2010	58,000	10,770,054	541	286,527	20
2011	63,000	10,270,693	609	267,207	23
2012	77,000	10,659,380	719	269,207	29
2013	73,000	10,597,356	690	275,018	27

Source: (National Highway Traffic Safety Administration, June 2015)

Among the variables we use from FARS and GES are the databases' pre-crash variables. As the timing of events prior to impact will be important to us, we present the following summary of these variables.

Table 6: Pre-Crash Data Elements

Time ↓	Pre-Event Movement (Prior to Recognition of Critical Event)	This element identifies the attribute that best describes this vehicle's activity prior to the driver's realization of an impending critical event or just prior to impact if the driver took no action or had no time to attempt any evasive maneuvers.
	Critical Event – Pre-Crash (Category)	This element identifies the category of the event that was critical to this vehicle being involved in the crash.
	Critical Event – Pre-Crash (Event)	This element identifies the critical event which made the crash imminent (i.e., something occurred which made the collision possible).
	Attempted Avoidance Maneuver	This element identifies movements and actions taken by the driver within a critical crash envelope, in response to a Critical Pre-crash Event.
	Pre-Impact Stability	This element assesses the stability of the vehicle after the critical event, but before the impact.
	Pre-Impact Location	This element assesses the location of the vehicle after the critical event, but before the impact.
	Crash Type	This element describes the type of crash this in-transport vehicle was involved in based on the First Harmful Event and the pre-crash circumstances.

Source: (National Highway Traffic Safety Administration, 2013)

b. The First Three Levels of Tree Trimming

For ease of understanding, we present the filtration piecemeal, rather than in one large chunk with scattered references to explanations. The following table presents the first "chunk," comprising the first three filters. (We abandon the tree-like depiction from Figure 5 at this point, which would soon become unwieldy, for a more space-efficient table depiction.)

The grayed out "limbs" in the table denote crashes that we are excising from the target population. Subsequent filters are based only on the non-excised limbs. That is, the total number of crashes (127,454 + 214,327 + 46) in the second filter (denoted "2. Frontal?") is equal to total surviving limb(s) from the previous level (341,827), and their percentages likewise correspond (127,454 / 341,827 = 37%).

The first two levels of filter involve pretty easy decisions. We exclude crashes not involving heavy vehicles for obvious reasons, as well as those involving non-frontal first impacts (as the sensors are forward-seeking). We conservatively exclude the relatively small number of crashes in which the vehicle type or initial area of impact was unknown in FARS/GES.

Conservative and Substantial Cut

The hardest choice here comes in the third level, which looks at whether a heavy vehicle's initial frontal impact came about in the crash's first harmful event or a subsequent event. An example of such a case is the 2010 FARS case number 10105. In this crash, a pickup truck collides with a two-door sedan, crosses the median, and collides with a straight truck, which runs off the road and overturns. We do not know how quickly these events followed one another, but it does not seem likely that AEB in such a circumstance would have enough time to sense the pickup truck, classify it as a threat, and sound an alarm or apply the brakes. By the same principle, we excluded all subsequent event frontal impacts to heavy vehicles from the target population, out of a concern that the events preceding the heavy-vehicle impact would generally come in too rapid a succession for AEB to take effective action. This cut accounts for 3 percent of frontal heavy-vehicle crashes, 9 percent of injuries in these crashes, and 8 percent of the fatalities.

We note that this excision does not exclude crashes in which the front of a heavy vehicle hits a vehicle that had previously crashed and was stopped in the road. (FARS and GES count such situations as two distinct crashes.)

Table 7: First Filters of the Target Population Tree

Filter	***Limbs***	***Crashes***	***Injuries***	***Fatali-ties***
0	All crashes (2010-2012 FARS/GES, annualized)	5,457,387	2,314,432	33,033
1. Heavy Vehicle?	Crashes involving **at least one heavy vehicle**	341,827 (6%)	120,857 (5%)	4,101 (12%)
	Crashes with **no heavy vehicles**	5,115,132 (94%)	2,193,113 (95%)	28,496 (86%)
	Crashes with an **unknown vehicle type**.	428 (0.01%)	462 (0.1%)	436 (1%)
2. Frontal?	Crashes where the first impact of at least one heavy vehicle was **frontal**	127,454 (37%)	60,986 (50%)	2,631 (64%)
	All heavy vehicles have **non-frontal** first impacts	214,327 (63%)	59,805 (49%)	1,422 (35%)
	Crashes where we can't tell	46 (0.01%)	66 (0.1%)	48 (1%)
3. First Event?	Crashes whose **first harmful event** involves the frontal impact of a heavy vehicle.	123,840 (97%)	55,677 (91%)	2,419 (92%)
	All heavy-vehicle frontal impacts happen in **subsequent** crash events.	3,615 (3%)	5,309 (9%)	212 (8%)

Source: Annualized figures from 2010-2012 FARS and GES

c. Injuries and Fatalities Among First Event Persons

Going forward, we refer to the vehicle with frontal damage in a rear-end collision (i.e., the vehicle with AEB) as the "subject vehicle" (or "SV") and the vehicle that is rear-ended as the "lead vehicle" (or "LV").

Conservative and Substantial Cut

Even limiting as we did in the previous step to heavy vehicles that sustained their frontal damage in the crash's first harmful event still leaves a number of multi-event crashes in our target population (not that this is in and of itself bad). Indeed, about 6 percent of the 341,827 heavy-vehicle crashes from Table 7 involve three or more vehicles.

Chain reaction crashes complicate our task, in that we must decide which of their injuries and fatalities to include in our figures. On the one hand, if a truck rear-ends a car, which sets off a multi-car pileup, avoiding the truck collision avoids the whole chain-reaction pileup. Thus, AEB can certainly prevent injuries and fatalities in subsequent event vehicles. And arguably, mitigating the truck crash could (or might not) mitigate subsequent impacts. Clearly all crash-involved persons potentially stand to benefit from putting AEB in the truck.

On the other hand, the benefit methodology we used for light-vehicle AEB, which applied estimated SV speed reductions and injury risk curves, arguably only applies to (at most) the vehicles in SV-LV impacts (National Highway Traffic Safety Administration, August 2014). The delta-V[8] reduction for vehicles in subsequent events might (or maybe is likely to) be less, and the injury risk curves might not be applicable to the crash configurations of subsequent event vehicles (e.g., fires, rollovers). Arguably, applying this method would overstate the benefits.

In the end, we decided to report both sets of figures (i.e., all injuries in the targeted crashes and those for people involved in the first harmful crash event), which effectively pushes the decision down the road to benefits estimation. For now, we limit the injury and fatality figures in the filtering from this point on to those among people involved in the crash's first event (which was a frontal heavy-vehicle impact).
For vehicle-to-vehicle first harmful events, these people are the occupants of the two vehicles. For vehicle-to-non-motorist first harmful events, they are the occupants of the (heavy) vehicle and the non-motorist.

The effect of replacing the injuries and fatalities with those occurring among first-event people is to reduce the injury figure by 7 percent and the fatality figure by 5 percent (the number of crashes was, of course, unchanged).

Table 8: Limiting the Injury and Fatality Figures to First-Event People

Filter	*Limbs*	*Crashes*	*Injuries to First-Event People*	*Fatalities Among First-Event People*
3a. Limit to First-Event Injuries	Crashes in which the **first harmful event** involves the frontal impact of a heavy vehicle.	123,840	51,566	2,300

Source: Annualized figures from 2010-2012 FARS and GES

Note that we are not claiming that, for example, the 51,566 injuries from Table 8 all happened in the first crash event. FARS and GES lack the detail to discern the particular event that gave rise to a given injury. Rather, there were (on average, during 2010-2012) 51,566 injuries to people involved in first events. Some of these injuries were sustained in the second crash event, for example, because the vehicle was struck twice.

d. Filter #4: Object and Area Struck

As noted earlier, the primary crash mode that motivated AEB's development was heavy vehicles rear-ending other vehicles. In this step, we keep in the target population all rear-end crashes (that remain thus far in our filtering), regardless of whether the lead vehicle was moving or stopped for any amount of time pre-impact. Although the current systems may warn but do not brake on stopped lead vehicles, we expect that the next generation of production systems will both warn and brake on them. (Table 8 does not break out the rear-end collisions by whether the lead vehicle was stopped, a calculation that we will delay until arriving at our target population.)

We also retain in the target population all crashes in which the (front of a) heavy vehicle impacts a stopped vehicle (in the first harmful crash event), regardless of the lead vehicle's orientation. To us, such cases are little different

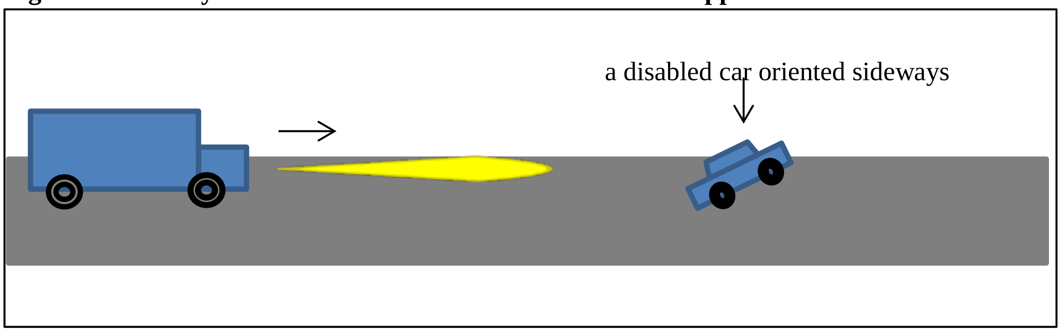
[8] Delta-V is the change that a vehicle's velocity vector undergoes during a crash.

from a Lead Vehicle Stopped (LVS) rear-end scenario. We presume that AEB will identify a stopped front-end vehicle profile as a threat, just as it would a stopped rear-end vehicle profile.

FARS and GES present us with two variables that concern pre-event motion, which could be used to discern whether our lead vehicle was stopped for a long enough period for AEB to take effective action: Pre-Event Movement, which describes motion prior to the circumstance that made a vehicle's crash involvement imminent, and Travel Speed, which presents the police reported speed prior to impact. Neither presents us with the sort of timing information that would be helpful in assessing whether the lead vehicle was stopped long enough to enable effective system action. It would seem that the best we can do to discern which lead vehicles stopped long enough would be to require both variables to indicate the vehicle was stationary. Such crashes are among those counted in the second data row of Table 9.

The other type of crash counted in the second data row is one involving a driverless lead vehicle. For the FARS/GES pre-event movement variable, the "no driver" category takes precedence over the "stopped in travel lane" and "parked/disabled" categories. That is, a disabled vehicle is coded as "parked/disabled" when the driver is in the vehicle prior to the critical event, and as "no driver" if the driver has left the vehicle, for example, on the side of the road. Thus, in theory, the "no driver" cases include both moving and stopped vehicles. However, all "no driver" cases that have a coded pre-crash speed (travel speed) are coded with a speed of 0 mph, which suggests that all or most "no driver" cases involve stopped vehicles. Consequently, we include all driverless lead vehicles in the target population.

Figure 6: A Heavy Vehicle With a Frontal Collision into a Stopped Vehicle



Recall that, consistent with the filter illustration in Figure 5, each subsequent collection of "limbs" is limited to those that survived the previous filters. Starting with Table 9, we emphasize this by including a Total line, on which the figures agree with the total of the previous filter's surviving limbs, and a reminder in the header for the limb column that the rows of the table are limited to those crashes that survived the previous filter. It is important to note this when considering a particular row. For instance, the 20 crashes in Table 9 for which we do not know what happened in the first event are not all such crashes for which this information is unknown, but only among those crashes whose first harmful event involves the frontal impact of a heavy vehicle (the surviving limb from Filter #3).

Table 9: Filter #4, Object and Area Struck

Filter	*Limbs, Limited to Those Surviving From Filter #3*	*Crashes*	*Injuries to First-Event People*	*Fatalities Among First-Event People*
4. Object and Area Struck	A heavy vehicle hits the rear of a vehicle. No restriction on the lead vehicle's pre-event movement or pre-impact speed.	49,717 (40%)	19,352 (38%)	305 (13%)
	A heavy vehicle hits the front, side, top, bottom, or other area of a vehicle, or hits an unknown area of a vehicle. The lead vehicle was stopped, both pre-event and pre-crash, or had no driver.	1,815 (1%)	214 (0.4%)	12 (1%)
	All other impacts into another vehicle.	57,034 (46%)	26,863 (52%)	1,510 (66%)

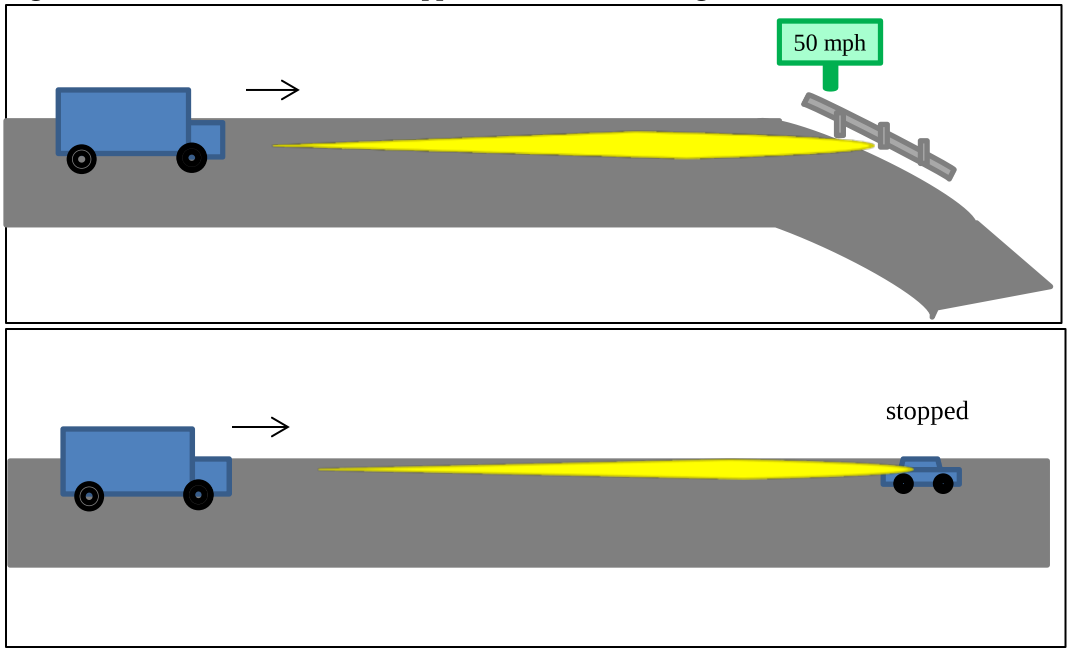
A heavy vehicle hits a fixed object, such as a wall, tree, utility pole, jersey wall, bridge, or guardrail.	9,618 (8%)	3,375 (7%)	196 (9%)
A heavy vehicle hits a pedestrian, bicyclist, horse rider, skateboarder, train, deer, animal-drawn conveyance, or other moving object.	5,634 (5%)	1,745 (3%)	276 (12%)
We do not know what happened in first event.	20 (0.02%)	20 (0.04%)	- (0%)
Total (equals surviving limbs from Filter #3)	123,840	51,566	2,300

Source: Annualized figures from 2010-2012 FARS and GES

While this filter cuts a large chunk out of our target population, we don't mark any excised limbs as "Conservative and Substantial Cuts." While some are certainly substantial, we see no evidence that AEB would appreciably affect head-on collisions, side impacts at intersections (except for stopped lead vehicles), or crashes into pedestrians and bicyclists.

Regarding fixed object impacts, like crashes of trucks into guard rails and trees, one might naturally wonder why we think that future algorithms will be able to "handle" crashes into stopped vehicles – sorting out the "threats" from the non-threats – and not handle crashes into a guardrail, for instance. The essential difference between the two is that trucks regularly approach guard rails at high speed in controlled driving. Consider a truck approaching a guard rail on a curve 80 feet ahead at 55 mph, as illustrated in the figure below. Maintaining the same trajectory and speed, the truck would be one second away from impact, which might not be an unreasonable time to apply automated braking in a truck-to-stopped car circumstance like in the second half of the figure. However, the truck driver approaching the curve could simply apply 0.2g of braking to get down to about 50 mph and take the curve at a safe speed. It is our understanding that even the latest detection algorithms cannot reliably distinguish controlled driving from dangerous driving when approaching objects like the guardrail on a curve, and so the algorithms intentionally try *not* to act on such objects.

Figure 7: A Guard Rail Versus a Stopped Car in Sensor Range



e. Filter #5: Lead Vehicle Type

Having restricted now to crashes in which the first harmful event involves the front of a heavy vehicle colliding with either the rear of a vehicle or some part of a stopped vehicle, we introduce some convenient terminology: We'll call the former vehicle the *subject vehicle* or the *following vehicle*. We call the other vehicle the *lead vehicle*. Note that the lead vehicle itself could be over 10,000 pounds, and if it is stopped, could even be facing the subject vehicle, in which case our target crash could involve two heavy vehicles with frontal damage.

The choice of which types of lead vehicles to allow was an easy one. We believe the systems act on vehicle types that are the size of a passenger car or larger, and system literature indicates they will not act on smaller vehicles, like motorcycles.

Although one might be inclined to include street sweepers and dune buggies among the targeted crashes, they receive the same FARS/GES code as go-carts and various miscellaneous types, which one might be less inclined to include. In any case, there are only about two such crashes per year of the types that have survived the filter thus far.

Table 10: Filter #5, Lead Vehicle Type

Filter	***Limbs, Limited to Those Surviving From Filter #4***	***Crashes***	***Injuries to First-Event People***	***Fatalities Among First-Event People***
5. LV Type	Crashes where the front of a heavy vehicle hits the rear of a **passenger vehicle, large limo, or light-truck-based motorhome** in the first harmful crash event.	45,305 (88%)	16,861 (86%)	219 (69%)
	The front of a heavy vehicle hits the rear of a **heavy vehicle** (in the first harmful crash event).	5,231 (10%)	2,290 (12%)	73 (23%)
	The lead vehicle is **construction or farm equipment other than a truck**	7 (0.01%)	11 (0.1%)	5 (2%)
	The lead vehicle is a **motorcycle, snowmobile, golf cart, low speed vehicle or 3-wheeled auto**	130 (0.3%)	28 (0.1%)	7 (2%)
	The lead vehicle is **some other type of vehicle, possibly a go-cart, fork lift, street sweeper or dune buggy (can't differentiate)**	2 (0.004%)	2 (0.01%)	0 (0%)
	The lead vehicle type is unknown.	859 (2%)	373 (2%)	13 (4%)
Total		51,534	19,565	317

Source: Annualized figures from 2010-2012 FARS and GES

f. Filter #6: Pre-Impact Location

The FARS/GES variable Pre-Impact Location describes where a vehicle is situated between the time that a crash became imminent (the occurrence of the critical event) and impact. Possible values of the variable are that a vehicle stayed in its travel lane during this time, stayed on the roadway but left its lane, or left the roadway, among other values. In order to ensure that AEB has sufficient time to detect threats and act on them, we require that both vehicles remain in their travel lane during this time.

As with the Pre-Event Movement variable, the code "no driver" takes precedence over other applicable codes for Pre-Impact Location. As we found with Pre-Event Movement, all lead vehicles coded with "no driver" have a Travel Speed of either 0 mph or unknown, suggesting that all (or most) are stopped. It stands to reason that such vehicles would have stayed in their travel lane between the time the crash was imminent and impact, so we include these cases as well. However if the following vehicle was coded as driverless, we exclude it. Such a vehicle has no driver to hear an FCW alert, and one that is stopped will not benefit from automated braking.

Table 11: Filter #6, Pre-Impact Location

Limbs, Limited to Those Surviving From Filter #5		*Crashes*	*Injuries to First-Event People*	*Fatalities Among First-Event People*
Subject Vehicle (SV) Pre-Impact Location	*Lead Vehicle (LV) Pre-Impact Location*			
SV stayed in original lane pre-crash	LV stayed in original lane pre-crash or had no driver	37,244 (74%)	14,403 (75%)	226 (76%)
SV left travel lane or roadway, or entered roadway pre-crash	LV stayed in original lane pre-crash or had no driver	5,610 (11%)	1,480 (8%)	19 (6%)
SV stayed in original lane pre-crash	LV left travel lane or roadway, or entered roadway pre-crash	4,730 (9%)	2,505 (13%)	35 (12%)
SV stayed on road pre-crash but don't know if left lane, or pre-crash location unknown	LV stayed in original lane pre-crash	725 (1%)	210 (1%)	2 (1%)
SV left travel lane or roadway, or entered roadway pre-crash	LV left travel lane or roadway, or entered roadway pre-crash	723 (1%)	180 (1%)	11 (4%)
SV stayed on road pre-crash but don't know if left lane, or pre-crash location unknown	LV stayed on road pre-crash but don't know if left lane, or pre-crash location unknown	442 (1%)	56 (0%)	1 (0%)
SV stayed in original lane pre-crash	LV stayed on road pre-crash but don't know if left lane, or pre-crash location unknown	343 (1%)	226 (1%)	1 (0%)
SV had no driver pre-crash		263 1%)	1 (0%)	0 (0%)
SV stayed on road pre-crash but don't know if left lane, or pre-crash location unknown	LV left travel lane or roadway, remained off roadway, or entered roadway pre-crash	149 (0%)	60 (0%)	1 (0%)
SV left travel lane or roadway, or entered roadway pre-crash	LV stayed on road pre-crash but don't know if left lane, or pre-crash location unknown	139 (0%)	34 (0%)	0 (0%)
SV and LV remained off roadway pre-crash		103 (0%)	1 (0%)	0 (0%)
SV stayed on road pre-crash but don't know if left lane, or pre-crash location unknown	LV had no driver pre-crash	70 (0%)	0 (0%)	0 (0%)
SV left travel lane or roadway, or entered roadway pre-crash	LV remained off roadway pre-crash	3 (0%)	5 (0%)	1 (0%)

Source: Annualized figures from 2010-2012 FARS and GES

Many of the cuts we make in this filter are either small or establish that one of the two vehicles left the travel lane at some point between crash imminence and impact, suggesting that the lead vehicle left the forward sensor range or the detection algorithm would no longer classify it as a threat. However the first two cuts are worth addressing as they are sizable in number.

Conservative and Substantial Cut

Cases where the subject vehicle left its travel lane and the lead vehicle stayed in its lane can come about because:

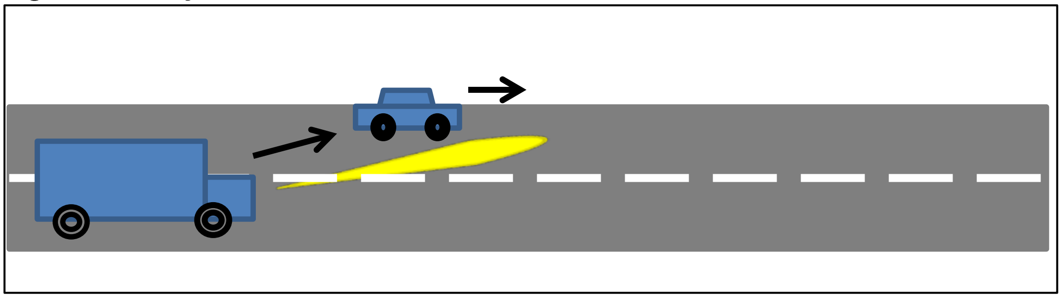
- the subject vehicle steers to avoid one vehicle (which, if it occurs soon enough, will suppress AEB) and hits another in the new lane; or
- the subject vehicle executes an improper lane change, striking a vehicle in the new lane, a circumstance that will often happen quickly.

However, throwing this category out will also toss crashes that the FCW and CIB portions of AEB may well legitimately help, like:

- an inattentive SV driver (perhaps drowsy, distracted, or drunk) veers into another lane, colliding with a vehicle there.

Arguably, Lane Departure Warning might prove a more cost-effective, and possibly a more reliable, countermeasure to this last type of crash. To be conservative, we decided to exclude the entire category of crashes where the subject vehicle left its travel lane and the lead vehicle stayed in its lane.

Figure 8: A Subject Vehicle Leaves Its Travel Lane and a Lead Vehicle Does Not



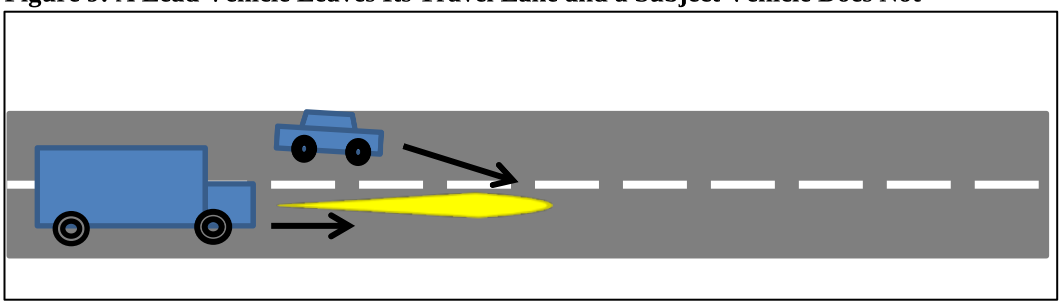
Conservative and Substantial Cut

The other substantial cut occurs for the opposite scenario - where the lead vehicle left its travel lane and the subject vehicle stayed in its lane. Such cases can arise because:

- the lead vehicle, whether intentionally, or through inattention or recklessness, cuts in front of the subject vehicle; or
- a vehicle loses control, perhaps from the other side of the road and perhaps spinning, and ends up in front of the subject vehicle (and happens to be positioned with its rear to the subject vehicle at impact).

These types of circumstances frequently present little time to avert a collision. However, it is possible, in theory at least, that AEB would have enough time to act in particular circumstances, so perhaps this cut also excludes some "legitimate" cases.

Figure 9: A Lead Vehicle Leaves Its Travel Lane and a Subject Vehicle Does Not



g. Filter #7: Pre-Event Movement

The Pre-Event Movement element describes a vehicle's activity before the crash became imminent (i.e., before the occurrence of the critical event) if the driver attempted to avoid the collision. For drivers who took no evasive maneuver, the variable describes the vehicle's movement just prior to impact.

Here we seek to keep cases that indicate the lead vehicle was in the sensor's lateral range sometime before the crash became imminent. That is, we do not want to wait until imminence for the vehicles to be "lined up," as we presume that AEB needs some time to be sure that a perceived threat is real before issuing automated braking.

Thus, we keep cases that indicate each vehicle was proceeding forward ("going straight," "accelerating," "decelerating," etc.), while excluding those that indicate lateral movement by either vehicle ("turning," "curving," etc.). The exception to this rule is that we allow one of the two vehicles to be going straight ahead while the other is changing lanes, as we feel this circumstance generally presents AEB with a threat – at first a portion of the lead vehicle, followed by the entire lead vehicle – long enough for it to warn and/or brake.

Figure 10: A Subject Vehicle Changes Lanes and a Lead Vehicle Goes Straight

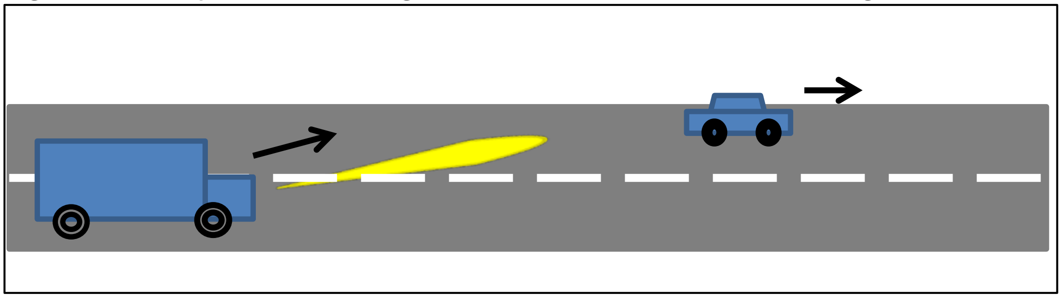


Table 12: Filter #7, Pre- Event Movement

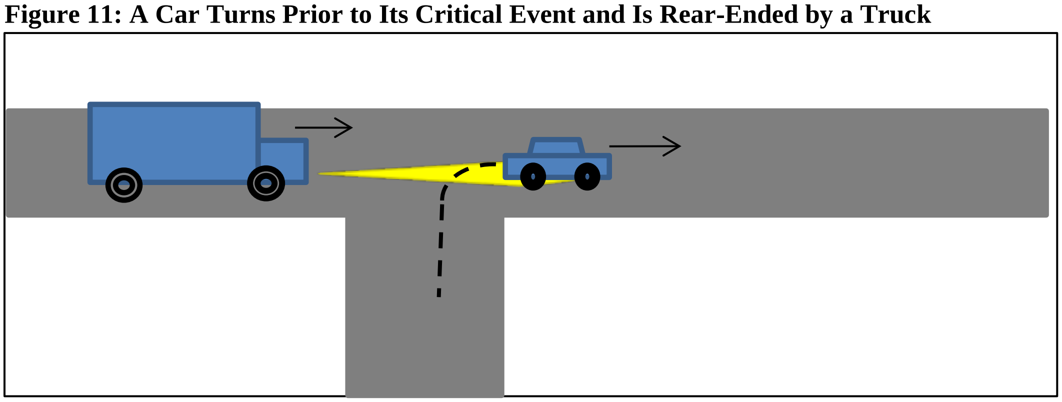
Limbs, Limited to Those Surviving From Filter #6		*Crashes*	*Injuries to First-Event People*	*Fatalities Among First-Event People*
Subject Vehicle (SV) Pre-Event Movement	*Lead Vehicle (LV) Pre-Event Movement*			
SV was going straight, accelerating, decelerating, passing, starting, or stopped before the critical event	LV was going straight, accelerating, decelerating, passing, stopped, parked, starting, or had no driver before the critical event	30,240 (81%)	12,803 (89%)	198 (88%)
SV was going straight, accelerating, decelerating, passing, starting, or stopped before the critical event	LV was backing up pre-event or its movement is described as other or unknown	849 (2%)	23 (0%)	2 (1%)
SV was going straight, accelerating, decelerating, passing, starting, or stopped before the critical event	LV was changing lanes or merging before the critical event	967 (3%)	175 (1%)	4 (2%)
SV was changing lanes or merging before the critical event	LV was going straight, accelerating, decelerating, passing, stopped, parked, starting, or had no driver before the critical event	361 (1%)	65 (0%)	2 (1%)
SV pre-event movement is described as other or unknown	LV was going straight, accelerating, decelerating, passing, stopped, parked, starting, or had no driver before the critical event	4 (0%)	5 (0%)	0 (0%)
SV was changing lanes or merging before the critical event	LV was backing up pre-event or its movement is described as other or unknown	0 (0%)	0 (0%)	0 (0%)
SV was leaving/entering parking spot, turning, curving, or avoiding something before the critical event	LV was going straight, accelerating, decelerating, passing, stopped, parked, starting, or had no driver before the critical event	2,758 (7%)	521 (4%)	9 (4%)
SV was going straight, accelerating, decelerating, passing, starting, or stopped before the critical event	LV was leaving/entering parking spot, turning, curving, or avoiding something before the critical event	1,333 (4%)	603 (4%)	6 (3%)
SV was leaving/entering parking spot, turning, curving, or avoiding something before the critical event	LV was leaving/entering parking spot, turning, curving, or avoiding something before the critical event	436 (1%)	200 (1%)	4 (2%)

Limbs, Limited to Those Surviving From Filter #6		Crashes	Injuries to First-Event People	Fatalities Among First-Event People
Subject Vehicle (SV) Pre-Event Movement	***Lead Vehicle (LV) Pre-Event Movement***			
SV was leaving/entering parking spot, turning, curving, or avoiding something before the critical event	LV was backing up pre-event or its movement is described as other or unknown	100 (0%)	1 (0%)	0 (0%)
SV was leaving/entering parking spot, turning, curving, or avoiding something before the critical event	LV was changing lanes or merging before the critical event	107 (0%)	0 (0%)	0 (0%)
SV was changing lanes or merging before the critical event	LV was changing lanes or merging before the critical event	88 (0%)	7 (0%)	1 (0%)
SV was changing lanes or merging before the critical event	LV was leaving/entering parking spot, turning, curving, or avoiding something before the critical event	0 (0%)	0 (0%)	0 (0%)

Source: Annualized figures from 2010-2012 FARS and GES

An example of a crash that is excluded in this cut would be a car that turns from a cross street directly in front of a truck. The crash became imminent when the car, having completed its turn, is in front of the truck. Just prior to that (i.e., its pre-event movement) was that it was turning (see Figure 11). This presents AEB with little time to confirm that the perceived threat is real before applying the brakes.

Figure 11: A Car Turns Prior to Its Critical Event and Is Rear-Ended by a Truck



h. Filter #8: Road Conditions

We exclude crashes that occurred on icy roads or in standing water because it is difficult to mitigate, much less avoid, a crash in these conditions. We conservatively exclude crashes on snowy roads because there might be ice underneath. In contrast to other filters, we retain crashes in which the road conditions are not reported, as they are likely to be "dry" or "wet", both of which are favorable to AEB's performance.

Table 13: Filter #8, Road Conditions

Filter	*Limbs, Limited to Those Surviving from Filter #7*	*Crashes*	*Injuries to First Event Persons*	*Fatalities Among First Event Persons*
8. Road conditions	Dry	27,830 (86%)	10,981 (84%)	186 (91%)
	Wet	3,096 (10%)	1,497 (11%)	14 (7%)
	Slush	44 (0%)	69 (1%)	0 (0%)

	Non-Trafficway Area	2 (0%)	2 (0%)	0 (0%)
	Other	76 (0%)	0 (0%)	0 (0%)
	Unknown	3 (0%)	3 (0%)	0 (0%)
	Not Reported	431 (1%)	195 (1%)	0 (0%)
	Ice/Frost	440 (1%)	192 (1%)	3 (1%)
	Snow	493 (2%)	127 (1%)	2 (1%)
	Water (Standing or Moving)	7 (0%)	6 (0%)	0 (0%)

Source: Annualized figures from 2010-2012 FARS and GES

i. Filter #9: Atmospheric Conditions

Heavy precipitation may hamper AEB's sensor's ability to detect the lead vehicle. The FARS/GES data element Atmospheric Conditions does not differentiate between heavy and light precipitation, so we conservatively exclude all crashes coded as occurring in precipitation. These crashes are in the minority.

A Conservative and Substantial Cut

Crashes in the rain occur at a rate above our 5-percent threshold, and we exclude them for the reasons cited above.

Table 14: Filter #9, Atmospheric Conditions

Filter	*Limbs, Limited to Those Surviving From Filter #8*	*Crashes*	*Injuries to First-Event People*	*Fatalities Among First-Event People*
9. Atmospheric conditions	Clear	25,053 (80%)	10,151 (80%)	164 (82%)
	Cloudy	3,902 (12%)	1,457 (11%)	25 (13%)
	Severe Crosswinds	21 (0%)	41 (0%)	1 (1%)
	Rain	2,132 (7%)	969 (8%)	7 (4%)
	Snow	191 (1%)	67 (1%)	1 (1%)
	Fog, Smog, Smoke	56 (0%)	53 (0%)	2 (1%)
	Blowing Sand, Soil, Dirt	34 (0%)	1 (0%)	0 (0%)
	Sleet, Hail (Freezing Rain or Drizzle)	6 (0%)	3 (0%)	0 (0%)
	Blowing Snow	2 (0%)	0 (0%)	0 (0%)
	Other	83 (0%)	5 (0%)	0 (0%)

Source: Annualized figures from 2010-2012 FARS and GES

j. Filter #10: Visual Obstructions

The FARS/GES code "Driver's Vision Obscured by" presents visual obstructions that may have contributed to the cause of the crash. The next table presents those from our crashes that have thus far survived the cuts. A crash may have more than one visual obstruction, although there was only one such case among those that have survived thus far – a case where the heavy vehicle's vision was obscured by both light (glare, sunlight, or headlights) and a physical obstruction (a curve, hill, or road feature).

We chose to keep crashes in which the heavy-vehicle driver's vision was obscured by reflected glare, bright sunlight, or headlight. We expect that these types of visual obstructions would also obscure a vision-based AEB system. However, a radar-based AEB system should not be affected. At this time, all AEB systems for heavy vehicles utilize radar sensors. Therefore, we believe it is appropriate to include these crashes in the target population.

Table 15: Visual Obstructions

Filter	*Limbs, Limited to Those Surviving From Filter #9*	*Crashes*	*Injuries to First-Event People*	*Fatalities Among First-Event People*
9. Visual Obstructions	No Obstruction Noted	27,237 (94%)	11,105 (95%)	180 (94%)
	Reflected Glare, Bright Sunlight, Headlights	220 (1%)	121 (1%)	2 (1%)
	In-Transport Motor Vehicle (including load)	53 (0%)	71 (1%)	1 (1%)
	Not-in-Transport Motor Vehicle (parked, working)	1 (0%)	0 (0%)	0 (0%)
	Obstructing Angles on Vehicle	3 (0%)	5 (0%)	0 (0%)
	Obstruction Interior to the Vehicle	11 (0%)	5 (0%)	0 (0%)
	Other Visual Obstruction	80 (0%)	3 (0%)	1 (1%)
	Rain, Snow, Fog, Smoke, Sand, Dust	1 (0%)	2 (0%)	1 (1%)
	Unknown	1,344 (5%)	324 (3%)	2 (1%)
	Vision Obscured - No Details	21 (0%)	6 (0%)	1 (1%)
	Curve, Hill or Other Roadway Design Feature	7 (0%)	7 (0%)	4 (2%)

Source: Annualized figures from 2010-2012 FARS and GES

Among the types of visual obstructions, the only one that gave us concern was "Curve, Hill or Other Roadway Design Feature" since AEB cannot "see" the lead vehicle through such visual obstructions. As the next table indicates, there were seven crashes that met this description and we exclude them.

Table 16: Crashes With and Without Visual Obstructions

Filter	*Limbs, Limited to Those Surviving From Filter #9*	*Crashes*	*Injuries to First-Event People*	*Fatalities Among First-Event People*
9. Visual Obstructions	No obstruction to the subject vehicle driver's vision noted	27,237 (94%)	11,105 (95%)	180 (95%)
	The subject vehicle driver's vision was obstructed by something other than a curve, hill, or roadway design feature	390 (1%)	212 (2%)	4 (2%)
	Unknown whether the subject vehicle driver's vision was obstructed	1,344 (5%)	324 (3%)	2 (1%)
	The subject vehicle's vision was obscured by curve, hill, or roadway design feature(s)	7 (0%)	7 (0%)	4 (2%)

Source: Annualized figures from 2010-2012 FARS and GES

k. Filter #11: Speed and Avoidance Maneuver

Our last filter concerns two variables:

- the estimated speed at which the subject vehicle was traveling pre-crash (the FARS/GES Travel Speed variable)[9]

[9] It is important to note that the FARS/GES Travel Speed Variable reports the estimated speed as reported by the police officer filling out the crash report. We do not know in any given crash *how* the officer arrived at the speed s/he reports. S/he might have based the estimate on the extent of vehicle damage, skid marks, other scene evidence, driver/witness interviews, or a combination of these. Rarely are Event Data Recorders or crash reconstructions used for this speed estimate. Consequently, the speed reported by the Travel Speed variable may differ a great deal from the actual speed a vehicle was traveling. However, this variable provides the best information we have concerning speed, and so we use it in this report.

- any (not completely successful) maneuvers the subject vehicle made to avoid the crash (the FARS/GES P_Crash3 variable)

We address these data elements in the same filter because each has a large number of unknowns – large enough that we won't feel comfortable simply including or excluding all cases with unknown values. By distributing the unknown values for both variables at the same time, we will account for relationships between the two variables.

Let's first address the easier of the two variables – travel speed – as far as its relevance to the target population. Supplier literature indicates that AEB will not take action when the vehicle on which it is installed is traveling below about 15 mph (presumably out of a concern for false positive alarms and braking).[10] Thus we exclude from the target population crashes where the hypothetically AEB-equipped vehicle was traveling below 15 mph (including stopped subject vehicles), and keep those with speeds in the 15-97 mph range.[11]

Next, we tackle avoidance maneuvers. The literature also indicates, and talks with light- and heavy-vehicle manufacturers and suppliers suggest, that the systems are designed to give primacy to the driver's actions (except in the sense that systems may supplement driver braking). If the driver applies the throttle in a situation that the system feels to be crash imminent, the system is designed to accept the acceleration as an adequate response and suppress the alert and possible braking it would otherwise engage. Consequently we exclude from the target population crashes where the hypothetically AEB-equipped vehicle accelerated in an attempt to avoid the crash.

If, however, the driver steers to try to avoid colliding with the lead vehicle, we shall *retain* this case in the target population. The reason for such is this: In filter #6, we limited to crashes where the subject vehicle stayed in its travel lane between the time that a crash became imminent (the occurrence of the critical event) and impact. As steering to avoid a collision would, if effected early enough, typically involve exiting the travel lane, it stands to reason that the steering maneuvers in our crashes must have happened quite late in the pre-crash timeline, and probably late enough that AEB would have already acted. Indeed, by this time, AEB would probably both have warned the driver of the impending collision and, if the driver still hadn't acted or braked enough, applied automated braking. Thus we retain the steering cases.

If the driver brakes to try to avoid the collision and AEB "thinks" the amount of braking is insufficient, AEB will supplement the driver's braking by an amount it feels sufficient to avoid the crash, up to a pre-specified amount. (The current Bendix system uses a threshold of about 0.47g, while Meritor WABCO uses about 0.35g.) Thus we retain braking cases in the target population.

A small fraction of our cases (about 1%) are coded with a subject vehicle avoidance maneuver of "other." Such cases presumably involve multiple avoidance maneuvers (although not just braking and steering, whose combined activity has its own FARS/GES codes). We chose to retain such cases (although one could arguably delete them if one thought them likely to involve throttle activity).

The next table gives the number of cases that we would retain and exclude based on the above discussion. Note that our logic will exclude some cases from the target population where one of the variables (travel speed or avoidance maneuver) is unknown: For instance crashes with a subject vehicle traveling under 15 mph are excluded, regardless

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[10] The situation is not quite as clear cut as this. As described in the section on supplier literature, the Meritor WABCO system uses a 15 mph threshold for both alerts and braking, but the Bendix system permits alerts above 10 mph and braking above 15 mph. Thus, we could have used 10 mph for crashes that alerts could mitigate and 15 mph that require an automated braking countermeasure. However this would not change our targeted crashes by terribly much: About 11% of crashes that survived Filters 1-10 and that have a reported travel speed occurred at subject vehicle speeds in the 10-14 mph range. Low-speed crashes, though, tend not to result in many injuries, and injuries contribute to most of the potential benefit. Consequently we use the 15 mph threshold for both countermeasures for simplicity.

[11] Beginning with the 2009 data year, FARS and GES allow travel speeds up to 151 mph to be coded as individual values. E.g., a truck that police estimated to be traveling 100 mph can be coded with a value of "100 mph" for its Travel Speed in FARS and GES.As recently as the 2008 data year, the values of "98" and "99" were reserved for indicating that the travel speed was indicated to be unknown on the police report, or there was no indication of travel speed on the police report form. At the time of this writing, there have been indications of some erroneous codes of "98" or "99" in recent data years. Combined with the fact that heavy vehicles rarely travel above 100 mph, we decided to treat all values of 98-151 as unknown travel speeds. Only 0.2% of crashes that survived filters 1-10 and had reported speeds had such values.

of whether we know anything about avoidance actions it may have taken. Likewise we exclude all subject vehicles that accelerated to try to avoid impact, even those with unknown travel speed.

Left unaddressed at this point is the large number of cases with unknown values, which cannot be categorized by our logic. These necessarily involve unknown values for at least one of the variables, but as explained, not all of them. Their number is also given in the following table.

Table 17: Filter #11, Subject Vehicle Speed and Avoidance Maneuver, Before Distributing Unknowns

Filter	*Limbs, Limited to Those Surviving from Filter #10*	*Crashes*	*Injuries to First Event Persons*	*Fatalities Among First Event Persons*
9. Speed and Maneuver	The subject vehicle was traveling 15-97 mph; AND this vehicle either takes no avoidance maneuver or takes one described as steering, braking, both steering and braking, or "other".	3,786 (13%)	2,478 (21%)	74 (40%)
	The subject vehicle was traveling 0-14 mph; OR this vehicle accelerates to avoid the crash.	4,897 (17%)	910 (8%)	2 (1%)
	All other cases. For these cases the subject vehicle travel speed, and/or whether it tried to avoid the lead vehicle is unknown, but any known values do not put it in the 'No' category. For instance a stopped subject vehicle with unknown avoidance maneuver will be counted in the previous row, not this one.	20,287 (70%)	8,253 (71%)	110 (59%)

Source: Annualized figures from 2010-2012 FARS and GES

At this point we could work to develop and apply an imputation model to generate educated guesses for unknown travel speeds and avoidance maneuvers, in order to categorize the individual FARS and GES cases in the last row of the preceding table as either belonging to our target population or not. We take instead the simpler route (which although simpler, is still common statistical practice) of distributing the unknown values in proportion to the knowns. For instance, the 8,683 crashes (3,786 + 4,897) that we can categorize at this point as being targeted or not break out as follows: 44 percent are in the target population (3,786/8,683), with the remaining 56 percent falling outside it. In distributing the unknowns, we increase the number of targeted crashes by 44 percent, to 12,630 and the number not targeted by 56 percent, to 16,340. The full set of figures is presented in the next table.

Table 18: Filter #11, Subject Vehicle Speed and Avoidance Maneuver, After Distributing Unknowns

Filter	*Limbs, Limited to Those Surviving From Filter #10*	*Crashes*	*Injuries to First Event Persons*	*Fatalities Among First Event Persons*
9. Speed and Maneuver	The subject vehicle was traveling 15-97 mph; AND this vehicle either takes no avoidance maneuver or takes one described as steering, braking, both steering and braking, or "other".	12,630 (44%)	8,513 (73%)	182 (98%)
	The subject vehicle was traveling 0-14 mph; OR this vehicle accelerates to avoid the crash.	16,340 (56%)	3,127 (27%)	

Source: Annualized figures from 2010-2012 FARS and GES

l. The Target Population, Before Regulatory Adjustments

With Filter #11, we have concluded the filtration process. Through this process, we have whittled away crashes in which we think AEB would not have activated or would have not had an appreciable effect on the resulting injuries.

What results is the set of crashes that, based on the most recent crash data (FARS/GES 2010-2012), we believe to be reasonably targeted by the technology. We refer to this as the *target population before regulatory adjustments* or the *unadjusted target population*. The size of this population is given in the first data row of Table 19 and repeated in the following table.

Table 19: The Size of the Target Population, Before Regulatory Adjustments

Crashes	*Injuries to First-Event People*	*Fatalities Among First-Event People*
12,630	8,513	182

Source: Annualized figures from 2010-2012 FARS and GES

The Appendix compiles the entire filtration process in a single, long table. For clarity, our unadjusted target population consists of crashes that meet all of the following criteria:

Figure 12: Our Target Population Filters

To be in the target population, a crash must satisfy all of the following criteria:

- The crash's first harmful event must be that the front of a heavy vehicle (the subject vehicle) collides at 15 mph or greater with either the rear of another vehicle or with any portion of a stationary vehicle (the lead vehicle).
- The lead vehicle must be a light vehicle (passenger car, Sport Utility Vehicle, van, or pickup truck), a medium- or heavy-duty vehicle, or a trailer.
- Before the crash became imminent, either both vehicles were going straight (no lateral movement), or one was going straight and one was changing lanes.
- Between the time that the crash became imminent and impact, both vehicles must remain in their travel lanes. (The lead vehicle may be stopped.) The subject vehicle may try to avoid the crash through braking or steering, but not simply by accelerating. (Subject vehicles with no avoidance maneuver are allowed.)
- The crash occurred on a paved[12] roadway that was generally clear of ice, snow, and standing water.
- The weather is clear or cloudy (severe crosswinds are allowed). The subject vehicle driver's view of the lead vehicle is not blocked by a hill, curve, or road feature.

[12] FARS identifies paved roads (in the VPAVETYP variable), and the relatively few heavy vehicle crashes that occurred on roads identified as non-paved in 2010-2012 were excluded by one or more of our filtration criteria. GES does not specifically identify paved roads but its closest surrogate (the surface condition variable VSURCOND) indicates that none of our targeted crashes occurred on roads whose surface was primarily covered by dirt, gravel, mud or sand.

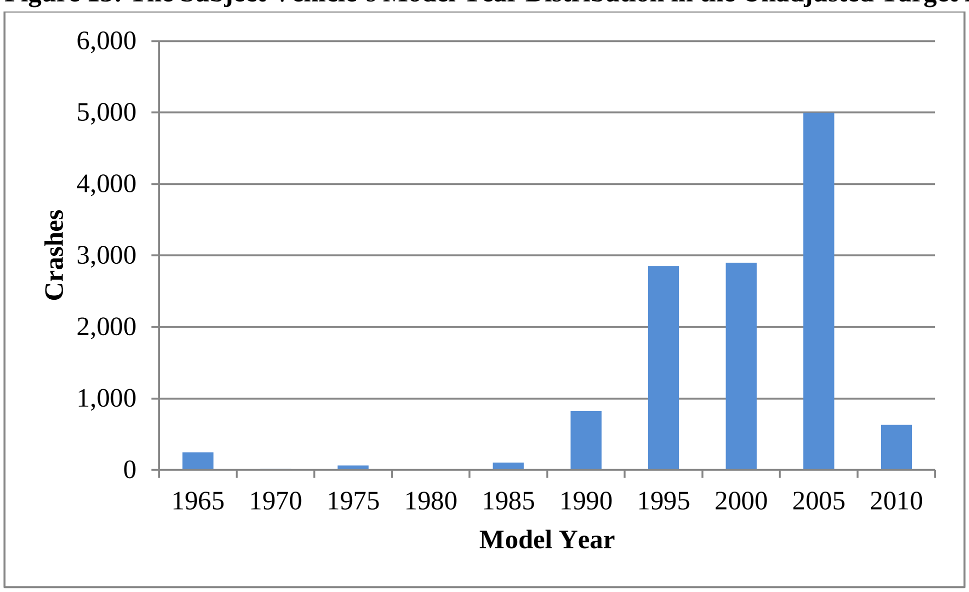
5. Regulatory Adjustments

The last table indicated that based on 2010-2012 crash data, we estimate 12,630 crashes per year could be impacted by requiring new heavy vehicles to have AEB. This is fine as far as an estimate of the number of crashes that the technology would target *today*, but it does not suffice as an estimate number of targeted crashes in the *future*. The cars and trucks on the road ten or fifteen years from now will be safer because an increasing share of them will comply with recently promulgated safety standards. They will get in fewer crashes and their occupants will sustain fewer injuries. As a result, even if we took *no* regulatory action regarding AEB, we would expect the number of AEB-targeted crashes ten or fifteen years from now to fall below the 12,630 figure.

For instance, starting with about model year 2012, new air-braked tractors must be able to stop in 235-310 feet from 60 mph depending on load and tractor type. The crashes we looked at from the 2010-2012 data years primarily involved pre-2012 model year tractors, some of which did not meet this requirement. Indeed 24% (3,052 on average) of the 12,630 crashes that survived Filter 11 involved pre-2012 model year tractors that braked pre-impact. In the future, we expect increasingly many tractors on the road to be able to stop faster as a result of the mandate. It stands to reason that at least some of the 3,052 crashes we saw on average in 2010-2012 won't happen in the future. While the figures in Table 19 present a reasonable assessment of the current state of affairs, they overestimate the future.

About 74 percent of the subject vehicles in our unadjusted target population have model years since 1995 (see Figure 13).

Figure 13: The Subject Vehicle's Model Year Distribution in the Unadjusted Target Population



Source: Annualized figures from 2010-2012 FARS and GES

NHTSA has proposed or promulgated four rules that applied, or are expected to apply, to at least a portion of this model year range (the post-1995 model year heavy vehicles):

- Electronic Stability Control (ESC)
- Anti-lock Braking Systems (ABS)
- Stopping distance
- Speed limiters

a. Electronic Stability Control

NHTSA has mandated this technology in new truck tractors and motorcoaches over 26,000 pounds (National Highway Traffic Safety Administration, 2015). ESC targets first-event untripped rollovers and loss-of-control crashes. Our unadjusted target population contains no rollover crashes and only three crashes in which a tractor, cross country bus, or a bus coded by FARS/GES as being of type "other" lost control (see Table 20). As such, reducing the unadjusted target population to account for ESC would make little difference (and we won't).

Table 20: Unadjusted Target Population Crashes involving Tractors, Cross Country Buses, and "Other" Buses

The Subject Vehicle's Critical Event	*Crashes*	*Injuries to First-Event People*	*Fatalities Among First-Event People*
From adjacent lane (same direction) over left lane line	23	35	2
From adjacent lane (same direction) over right lane line	23	22	1
From crossing street, across path	59	156	1
From parking lane, median, shoulder, roadside	1	2	0
Other vehicle stopped	1,827	1,144	57
Over the lane line on left side of travel lane	2	1	1
Over the lane line on right side of travel lane	10	10	1
This vehicle decelerating	3	6	2
Traveling in same direction while decelerating	2,256	2,114	25
Traveling in same direction with lower or steady speed	717	752	37
Traveling too fast for conditions	3	11	4

Source: Annualized figures from 2010-2012 FARS and GES, using body types 51, 58, 59, 66, 72.

b. Anti-Lock Braking Systems

FMVSS No. 121 mandates ABS in air-braked vehicles over 10,000 lbs, phasing in this requirement over the March 1, 1997 – March 1, 1999 production period (Federal Highway Administration, 1998). This technology targets a variety of crash modes, including rollovers, jackknife crashes and various types of frontal impacts.

The most common crash mode in our target population is rear-end crashes, and NHTSA's evaluation of this rule after it took effect found that ABS had no discernable effect in this crash mode. (Allen, 2010)

This leaves us with non-rear-end crashes, and wondering by how much ABS might reduce the non-rear-end crashes in our target population. Obviously the addition of ABS would not affect any of the crashes involving post-1999 model year subject vehicles, as the air-braked ones already have ABS and the non-air-braked ones are not required to have it.

Consequently, we focus on the target crashes population crashes involving pre-2000 model year subject vehicles that were *not* coded with the value "front-to-rear" for the FARS/GES Manner of Collision variable. Table 21 shows that there were 89 such crashes on average during the 2010-2012 crash years. The regulatory evaluation estimates that ABS would reduce these crashes (at least those involving air-braked subject vehicles) by about 14%.[13] That is, ABS would reduce our current target population by at most 12 crashes (89 × 0.14) annually, a difference that matters little. Consequently we don't make this adjustment either.

[13] In Table 13 of (Allen, 2010), Allen estimates a median reduction in "at-fault in other multi-vehicle collisions" of 14%.

Table 21: Target Population Crashes Involving Pre-2000 Model Year Subject Vehicles

Manner of Collision	*Crashes*	*Injuries to First-Event People*	*Fatalities Among First-Event People*
Angle	70	161	2
Front-to-Front	1	0	0
Front-to-Rear	4,020	2,368	24
Other	1	1	1
Sideswipe - Same Direction	11	11	0

Source: Annualized figures from 2010-2012 FARS and GES

c. Stopping Distance

This rule requires air-braked tractors to be able to stop in 235-310 feet from 60 mph depending on load and tractor type (National Highway Traffic Safety Administration, 2011). The rule took effect with roughly the 2012 model year fleet.[14]

Although it applies only to tractors, and only those truck tractors that braked pre-impact, the stopping distance requirement will clearly reduce our AEB target population. Indeed the rule identifies among its applicable crashes, those in which a tractor that, despite braking, rear-ends another vehicle or hits a vehicle that turned across its path.

To estimate how much the rule will reduce our population, we use the only effectiveness figures presented in the stopping distance rule, presented in Table 22.

Table 22: The Effectiveness of the Stopping Distance Rule

AIS[15]	*0*	*1*	*2*	*3*	*4*	*5*	*Fatality*
Occupants in applicable crashes without the rule	45,678	12,896	1,854	708	101	53	785
Occupants in applicable crashes with the rule	28,527	7,674	1,178	452	66	37	553
% reduction (effectiveness)	38%	41%	37%	37%	35%	30%	30%

We derive estimates of crashes avoided and injuries mitigated by stopping distance from this table as follows. We estimate the crashes avoided as the reduction in involved persons, i.e., the weighted average of the seven effectiveness estimates in Table 22 (weighted by the occupants without the rule), which comes to 38 percent. We estimate the injuries mitigated by the weighted average of the AIS 1-6 effectiveness figures, which is 39 percent. We now have three effectiveness figures: 38 percent for crash reduction, 39 percent for injury reduction, and 30 percent for fatality reduction.

The rule estimated that the 3 percent of the model year 2008 tractor fleet already met the stopping distance requirement. As manufacturers typically phase-in a mandate rather than improve their entire fleet all at once, we estimate the following compliance fractions, which culminate in the rule’s mandate that the entire 2012 fleet meet the requirement.

[14] Under the rule, two-axle tractors and tractors above 59,600 pounds GVWR do not need to comply until model year 2014. However most tractors must meet the rule by model year 2012.
[15] The Abbreviated Injury Scale (AIS) is a numerical assessment of injury severity, with values ranging from 0 (no injury) to 6 (fatal injury). The AIS values 1-5 represent increasing degrees of non-fatal injury severity.

Table 23: Estimated Percent of the Tractor Fleet Meeting the Stopping Distance Rule

Fleet year	*2008*	*2009*	*2010*	*2011*	*2012*
% of air-braked tractors meeting the stopping distance rule	3%	25%	50%	75%	100%

Putting all of this together, we estimate the effect of the rule on our target population by applying our effectiveness figures (38% for crashes, 39% for injury reduction, and 30% for fatalities) to the current targeted crashes involving a pre-model year 2012 tractor that braked before impact, and using Table 20 to account for early compliance. For instance, 75 crashes in our current target population involved a model year 2009 tractor that braked before impact. We think that 25% of these tractors voluntarily met the stopping distance rule, leaving 56 tractors (0.75×75) that didn't. Applying our 38-percent effectiveness, we think that 22 of these crashes would have been averted by the stopping distance rule.

Performing the same calculation on the rest of the target population, a calculation that only applies to pre-2012 model year tractors that braked prior to impact), results in the following figures.

Table 24: The Size of the Target Population, Adjusted for the Stopping Distance Rule

Crashes	***Injuries to First Event Persons***	***Fatalities Among First Event Persons***
11,499	7,703	173

Source: Annualized figures from 2010-2012 FARS and GES

This completes our adjustments to the target population. Specifically, we have now adjusted the targeted crashes as they occur in the recent past (2010-2012) in order to reflect the numbers of targeted crashes we expect to occur in the eventual future, once all heavy vehicles on the road are equipped with all of the mandatory safety technologies.

d. Speed Limiters

At the time of this writing, NHTSA has proposed to mandate speed limiters on certain heavy vehicles. The rule would apply to tractors, single-unit straight trucks over 26,000 pounds GVWR, city buses, and intercity buses, and would require the installation of technology to prevent them from traveling in excess of a certain speed, which is yet to be specified (National Highway Traffic Safety Administration, Federal Motor Carrier Safety Administration, 2016). Such a mandate (if promulgated) would certainly reduce the instance and severity of these vehicles rear-ending other vehicles, and thus our target population. In this section, we estimate the reduction to our target population. This section is for informationally purposes only, and its results will not be incorporated in our final target population figures, since the rule is only in the proposal stage.

NHTSA has not proposed a particular maximum speed that the speed limiters should use, but rather presents information on the costs and benefits if speeds were limited to 60, 65, and 68 mph. Not knowing what the maximum speed would be if the final rule is adopted, we illustrate the effect using 65 mph.

The Preliminary Regulatory Impact Analysis (PRIA) for the proposed rule does not estimate number of crashes avoided by speed limiters, only the number of injuries mitigated. Consequently, we cannot estimate the impact of a speed limiter rule on our target population. However we can estimate the reductions to injuries and fatalities.

Using figures from the PRIA, we estimate in Table 25 and Table 26 that the average effectiveness of a 65-mph speed limiter is 0%-2% for saving lives and 0%-48% for mitigating injury, depending on the truck type and whether we use the PRIA's "high" or "low" estimate.

Table 25: Average Effectiveness of 65-mph Speed Limiters for Saving Lives

Truck type	Fatalities in the Speed Limiter Target Population	Estimated Lives Saved		Average Effectiveness	
		Low	High	Low	High
Tractor	10,412	62	204	1%	2%

Straight truck	958	1	5	0%	1%
Bus	303	0	5	0%	2%

Source: The target population and lives saved figures are from (National Highway Traffic Safety Administration, Office of Regulatory Analysis and Evaluation, August 2016). The average effectiveness is their ratio.

Table 26: Average Effectiveness of 65-mph Speed Limiters for Mitigating Injuries

Truck type	Number of Injured Persons in the Speed Limiter Target Population	Estimated Injuries Mitigated		Average Effectiveness	
		Low	High	Low	High
Tractor	9,295	1,351	4,440	15%	48%
Straight truck	982	19	102	2%	10%
Bus	1,841	0	112	0%	6%

Source: The target population and injury figures are from (National Highway Traffic Safety Administration, Office of Regulatory Analysis and Evaluation, August 2016). The average effectiveness is their ratio.

Applying these to our target population, we find in Table 27 and Table 28 that if all trucks had a 65-mph speed limiter, our target population would be reduced by 2-7 fatalities and 54-180 injuries. For instance, at that point in the future when all tractors on the road meet the stopping distance rule, we estimate that there will be 362 injuries annually in AEB-targeted crashes in which the tractor is traveling over 65 mph. NHTSA's proposal estimates that 15%-48% of these injuries (i.e., 53-173 injuries) could be mitigated by limiting the tractor's speed to 65 mph. Totaling the figures for the other types of trucks and performing the same calculation for fatalities, we estimate that the rule, were it to take effect, would reduce our target population by 54-180 injuries to first event persons) and 2-7 fatalities.

Table 27: Lives Saved by 65-mph Speed Limiters in the AEB Target Population

Truck type	***Estimated Annual Fatalities Among First Event Persons in Crashes over 65 mph, When All Tractors Meet The Stopping Distance Rule***	***Avg Effectiveness of 65-mph Speed Limiters for Saving Lives***		***Lives Saved***	
		Low	***High***	***Low***	***High***
Tractor	42	1%	2%	2	7
Single-unit straight truck	2	0%	1%	0	0
City or intercity bus	0	0%	2%	0	0
Total	***44***			***2***	***7***

Table 28: Injuries Mitigated by 65-mph Speed Limiters in the AEB Target Population

Truck type	***Estimated Annual Injuries to First Event Persons in Crashes Over 65 mph, When All Tractors Meet the Stopping Distance Rule***	***Avg Effectiveness of 65-mph Speed Limiters for Mitigating Injuries***		***Injuries Mitigated***	
		Low	***High***	***Low***	***High***
Tractor	362	15%	48%	53	173
Single-unit straight truck	72	2%	10%	1	7
City or intercity bus	0	0%	6%	0	0
Total	***434***			***54***	***180***

Source: Annualized figures from 2010-2012 FARS and GES, with effectiveness figures applied from (National Highway Traffic Safety Administration, Office of Regulatory Analysis and Evaluation, August 2016)

6. Our Final Target Population

Having completed our adjustments we have arrived at our final target population, which we refer to as such or simply as the target population. To review, the numbers of crashes, and the numbers of injuries and fatalities among first-event-involved persons, are as in the following table. (These figures are from Table 24 as we are not adjusting the target population for the speed limiter proposal.)

Table 29: The Final Target Population

Crashes	*Injuries to First-Event People*	*Fatalities Among First-Event People*
11,499	7,703	173

Source: Annualized figures from 2010-2012 FARS and GES

The number of injuries to all involved people – including those from subsequent as well as the first harmful event – is 9,698 and the number of fatally injured among them is 198.

The following table summarizes how we got here, giving brief descriptions of the filters we applied, quantifying their effects, and showing the effect of the regulatory adjustment. The percentages in this table reflect the portion surviving from the previous row (i.e., percent = current cell divided by the corresponding cell from the previous row).

Table 30: Summarized Derivation of the Target Population

Filters 1-3	*Crashes*	*Injuries*	*Fatalities*
0. All crashes (2010-2012 FARS/GES, annualized)	5,457,387	2,314,432	33,033
1. Limit to crashes involving **heavy vehicles**	341,827 (6%)	120,857 (5%)	4,101 (12%)
2. Limit to **frontal** crashes of heavy vehicles	127,454 (37%)	60,986 (50%)	2,631 (64%)
3. Limit to crashes whose **first harmful event** is the frontal impact of a heavy vehicle.	123,840 (97%)	55,677 (91%)	2,419 (92%)

Filters 3a and following	*Crashes*	*Injuries to First-Event People*	*Fatalities to First-Event People*
3a. Limit injuries and fatalities to those **people involved in the crash's first harmful crash event**.	123,840 (100%)	51,566 (93%)	2,300 (95%)
4. Limit to crashes whose first harmful event is the frontal impact of a heavy vehicle (the subject vehicle, or SV) to the **rear of another vehicle or to any part of a stationary vehicle** (the lead vehicle, or LV).	51,532 (42%)	19,566 (38%)	317 (14%)
5. Exclude crashes into **motorcycles**, golf carts, and assorted small vehicles.	50,543 (98%)	19,162 (98%)	297 (94%)
6. Require both vehicles to **remain in the travel lane** after the crash became imminent.	37,244 (74%)	14,403 (75%)	226 (76%)
7. Limit the lateral movement of the vehicles before the crash was imminent to **going straight ahead or at most one vehicle changing lanes.**	32,421 (87%)	13,071 (91%)	206 (91%)
8. Exclude roads with **ice, snow, or standing water.**	31,482 (97%)	12,747 (98%)	200 (98%)
9. Exclude crashes in the **rain, snow, sleet, and fog**.	28,976 (92%)	11,649 (91%)	190 (95%)

10. Exclude crashes where the subject vehicle's **view of the lead vehicle was obstructed** by a curve, hill, or road feature.	28,971 (100%)	11,641 (100%)	186 (98%)
11. Require the subject vehicle to be traveling at least **15 mph**, and exclude cases where this vehicle tried to avoid the crash merely by accelerating	12,630 (44%)	8,513 (73%)	182 (98%)

The current (unadjusted) target population	12,630	8,513	182
The future (adjusted) target population when all vehicles meet current and proposed safety standards.	11,499 (91%)	7,703 (90%)	173 (5%)

Source: Annualized figures from 2010-2012 FARS and GES

a. Addressing Uncertainty

Two sources of uncertainty lie behind our estimate that 11,499 crashes per year are targeted by heavy vehicle AEB (and behind our injury and fatality metrics): sampling error from GES and the handful of choices we had to make in filtering that were based on limited information and hence not clear cut.

Sampling error is the error incurred from having sampled, rather than having taken information from an entire population, and is commonly expressed as a confidence interval. FARS is a census of fatalities and thus has no sampling error. GES however, samples about one in every hundred crashes and thus has sampling error. Estimating this error requires the use of variance estimation techniques, such as Taylor series decompositions (which is the technique we will use), in order to account for GES's multi-stage probability design.

The next table presents 90-percent and 95-percent confidence intervals for the numbers of targeted crashes, injuries, and fatalities, as computed using the variance techniques alluded to above. Specifically, these figures were computed from the variance between the first sampling stage sampling units, which, since the pool from which these units were chosen is large (in each first stage stratum), provides an approximately unbiased estimate of the true variance.

Table 31: Confidence Intervals for the Numbers of Targeted Crashes, Injuries, and Fatalities

Confidence Level	***Crashes***	***Injuries to First-Event People***	***Fatalities Among First-Event People***
90%	11,499 +/-3,447	7,703 +/-2,455	173 +/-0
95%	11,499 +/-4,186	7,703 +/- 2,980	173 +/-0

Source: Annualized figures from 2010-2012 FARS and GES

For instance, we can be 95-percent certain that the number of targeted crashes lies in the range of 7,313–15,686, and slightly less certain (90% confidence) that the figure lies in the narrower range of 8,052–14,947. Notice that the fatalities figure has no sampling error since it comes from the FARS census.

We next address our second source of uncertainty. Its nature will not permit pinning down with confidence ranges, but we can give crude upper bounds to its effect.

This second source derives from the multiple conservative choices that we have noted through the paper as "Conservative and Substantial Cuts." The greatest of these were:

- (Filter #6) We required both vehicles to **remain in the travel lane** after the crash became imminent. This cut the number of crashes by 26 percent, injuries by 25 percent, and fatalities by 24 percent.

- (Filter #7) We limited the lateral movement of the vehicles before the crash was imminent to **going straight ahead or at most one vehicle changing lanes**. This cut the crashes by 13 percent, injuries by 9 percent, and fatalities by 9 percent.

- (Filter #11) We required the subject vehicle to be traveling at least **15 mph**, and exclude cases where this vehicle tried to avoid the crash merely by accelerating. This cut the crashes by 56 percent, injuries by 27 percent, and fatalities by 2 percent.

Our either filters were, in our view, fairly solidly rooted in the limitations of the systems (e.g., that the impact to the subject vehicle be frontal), or had little effect. The three filters bulleted above (from Filters 6, 7, and 11) are each somewhat debatable. For instance, technology may soon remove the low speed limitation, as we are already see some low speed passenger vehicle systems, like Volvo's City Safety technology. Had we not implemented any of these three filters, our estimated number of targeted crashes would have been larger by a factor of 1/(1-0.26)(1-0.13)(1-0.56) = 3.53. That is, we would have estimated the targeted crashes to be 11,499 × 3.53 = 40,593 crashes annually. (For simplicity, we are assuming that the regulatory adjustment would have had the same 9% effect.) The figures for injuries and fatalities are given in the next table.

Table 32: The Numbers of Targeted Crashes, Injuries, and Fatalities Had We Not Applied the Travel Lane, Lateral Movement, and Speed Filters

Crashes	***Injuries to First-Event People***	***Fatalities Among First-Event People***
40,593	15,461	255

Source: Annualized figures from 2010-2012 FARS and GES

b. Comparison to Other Target Populations

NHTSA contracted the University of Michigan's Transportation Research Institute (UMTRI) to, among other things, develop a target population for heavy vehicle AEB. UMTRI's population comprises 32,360 crashes annually, much larger than our 11,499-crash population. (Woodrooffe, et al., 2012) As discussed in Chapter 1, there is no particular problem with independently developed target populations for the same technology having different sizes. Really what matters in the end are the benefits, and one can obtain the same benefits using a large population or a small one. However for curiosity's sake, we examine UMTRI's choices in developing their population and compare them to ours.

Data Sources

UMTRI used 2003-2008 GES and TIFA (Trucks in Fatal Accidents). (Jarossi, Hershberger, & Woodrooffe, 2012) We used 2010-2012 GES and FARS. The choice of TIFA vs FARS should not matter much in that UMTRI seems to pretty much confine themselves to data elements available in FARS.

The choice of data years does matter, in that prior to 2010, FARS and TIFA lacked information on the individual events that make up a crash, including identifying which vehicle a heavy vehicle struck. We used the event information to compute the numbers of injuries and fatalities among persons involved in the first harmful event, which is arguably all that AEB could reasonably target, and which UMTRI wouldn't have been able to do. Limiting to first event persons would reduce our targeted injuries by 21% and fatalities by 13%.

We also used the event information to exclude crashes into motorcycles and assorted small vehicle types, but this did not have much effect (less than 1%), and even without the event info, UMTRI could still identify the lead vehicle type in the two-vehicle crashes, which as noted earlier comprise about 94 percent of heavy vehicle crashes.

State of Technology

Both UMTRI and we developed populations of crashes that each felt would be targeted by a near-term future AEB system (about a few years hence). In particular, each allowed a Lead Vehicle Stopped capability.

Heavy Vehicle Scope

We included all types of heavy vehicles in our target population. UMTRI limited theirs (per NHTSA's instruction) to tractor-semitrailers and straight trucks. About 12 percent of our target population consists of crashes of subject vehicles other than these two types.

Target Population Filters

UMTRI chose its filters based on a review of cases from the LTCCS and TIFA databases and state crash files from North Carolina and California. We chose our filters based on supplier information, a review of LTCCS cases, and general knowledge. We list the filters for each below.

Figure 14: UMTRI's Target Population Criteria

To be in the target population, a crash must satisfy all of the following criteria:

- The crash involves a tractor or straight truck whose accident type is coded as 20, 24, or 28.
- This truck driver is not coded as driving aggressively, driving in an erratic, reckless, or negligent manner, or racing.
- No tire, brake, steering, or suspension defects on this truck are noted as contributing to the crash.
- This truck does not lose control as a result of a flat tire or tire blowout.
- The road is generally free of snow, slush, ice, frost, sand, dirt, mud, gravel, oil, standing water, and the road surface has not been washed out.

Comparing this list to our criteria in Figure 12, the key differences between our filters and UMTRI's would seem to be the following.

- We require both vehicles to remain in their travel lane after the crash became imminent, so that we can be sure that the lead vehicle didn't only enter the sensor range too late for AEB to have an effect the crash. (This filter cut 26% of cases.)
- We require the subject vehicle to be traveling at least 15 mph. (This filter cut about 12% of cases.)
- We exclude most cases of lateral movement by either vehicle before the crash became imminent, to be sure that the lead vehicle was in sensor range before the crash is imminent. (This filter cut about 13% of cases.)
- We exclude all crashes in the rain.[16] (This filter cut about 7% of cases.)
- We require the subject vehicle collision to occur in the crash's first harmful event. (This cut 3% of cases.)
- We require the subject vehicle's collision to occur in the crash's first harmful event (effectively excluding collisions that were result of a chain reaction; this cut 3% of cases.)
- We made various other choices that had lesser impacts.

Some differences contributed the other way, where UMTRI was more restrictive than we were. The effects of these choices, listed below, were obviously dwarfed by those listed above (since UMTRI's population is larger).

- UMTRI requires the truck to be a tractor or straight truck, whereas we permit any type heavy vehicle.
- We permit crashes into the front or side of a stopped lead vehicle, and UMTRI doesn't.
- We permit crashes of with any coded accident type, so long as they met our other criteria.

Ultimately, our filters reduced the population of heavy vehicle crashes by 96 percent. That is, our unadjusted target population of 12,630 annual crashes comprises 4 percent of the current annual 341,827 heavy-vehicle crashes. We haven't computed the analogous figure for UMTRI's filters, but it must exceed 4 percent appreciably.

Regulatory Adjustments

We adjusted our population for promulgated and proposed regulations, while UMTRI did not. This reduced our targeted crashes by 9 percent.

[16] As we noted in Section 4i, this is a conservative exclusion. Current systems might be able to handle some amount of rain, and the FARS/GES Atmospheric Conditions variable does not differentiate between light and heavy precipitation.

Target Population Size

The net impact of UMTRI's and our choices in developing the target population have a substantial impact on the size. Table 33 presents the comparison. We note that the comparison of the injury and fatality figures are even more pronounced if we think of our first-event injuries as our notion of targeted injuries and UMTRI's all-event injuries as their notion of targeted injuries.

Table 33: Percentage Differences Between UMTRI's and Our Target Population

Entity	*Crashes*	*Injuries*	*Fatalities*	*Injuries to People Involved in the First Harmful Crash Event*	*Fatalities Among People Involved in the First Harmful Crash Event*
			All heavy vehicles		
UMTRI	32,360	15,430	303	NA	NA
NHTSA	11,499	9,698	198	7,703	173
% difference	64%	37%	35%	NA	NA
			Truck tractors		
UMTRI	15,987	7,934	231	NA	NA
NHTSA	3,791	4,533	136	3,384	118
% difference	76%	43%	41%	NA	NA
			Straight trucks		
UMTRI	16,373	7,496	72	NA	NA
NHTSA	6,284	3,923	49	3,339	43
% difference	62%	48%	32%	NA	NA

Source: Annualized figures from 2010-2012 FARS and GES, and (Woodrooffe, et al., 2012)

One might ask whether UMTRI's figures are within our uncertainty band. The question is not really meaningful for the portion of uncertainty that is due to sampling error: Both UMTRI and we used GES (albeit from different crash years), and thus used the same data collection sites (Primary Sampling Units), which are the greatest source of sampling variation. A direct comparison between UMTRI's figures in the above table to the figures in Table 32 (what we would have obtained without Filters 6, 7, and 11) is also not so meaningful, since UMTRI limits to tractors and straight trucks and Table 32 does not. We expect that if we recomputed Table 32 limiting to UMTRI's vehicle types, we would find UMTRI's figures to be close to the results, since Filters 6, 7, and 11 account for most of our difference with UMTRI.

Breakout of Stopped Lead Vehicles

UMTRI used data from the LTCCS, and crash files from California and North Carolina to estimate the percent of stopped lead vehicles that were moving when AEB could have detected them. We did not. UMTRI estimates this percent to be 17-65 percent, depending on truck type and crash severity.

Table 34: The Percent of Lead Vehicles Coded as "Stopped" That Were Moving When AEB Could Have Detected Them

Crash severity	*Tractor semitrailer*	*Straight truck*
Fatal	16.7%	28.1%
Nonfatal	58.5%	64.7%

Source: Table 13 of (Woodrooffe, et al., 2012)

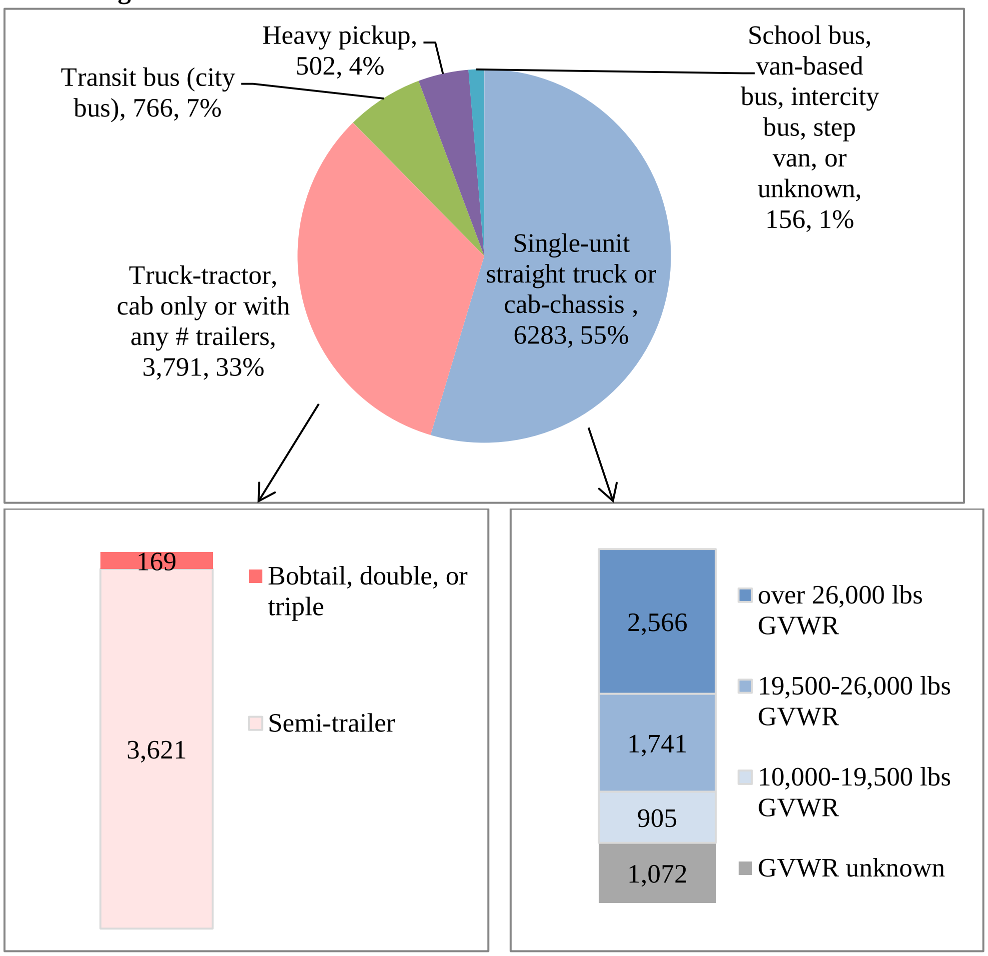
All in all, there are substantial differences in the size and make-up of our target population, compared to that in (Woodrooffe, et al., 2012).

7. Characteristics of Targeted Crashes

The next several tables and figures present predominantly univariate distributions of the (final) target population for several characteristics that would seem of interest.

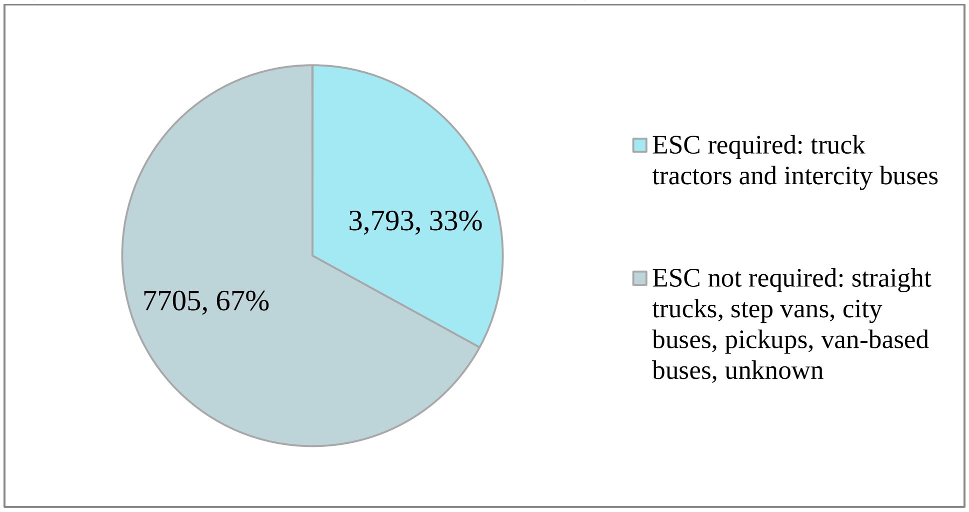
a. Characteristic: Heavy Vehicle Type

Figure 15: The Types of Heavy Vehicles in the Target Population: Body Type, GVWR, and Configuration



Source: Annualized figures from 2010-2012 FARS and GES

Figure 16: The Types of Heavy Vehicles in the Target Population: Whether ESC is Required



Source: Annualized figures from 2010-2012 FARS and GES

Table 35: The Numbers of Targeted Crashes and KABCO-Level Injuries, by Heavy Vehicle Type

Heavy Vehicle Type	*Number Among Persons Involved in the First Harmful Crash Event*							
	Crashes	*Fatalities*	*Incapacitating Injuries*	*Non-Incapacitating Injuries*	*Possible Injuries*	*Not Injured*	*Injured, Severity Unknown*	*Not Known Whether Injured*
Single-unit straight truck or cab chassis	6,284	43	157	980	2,199	11,740	45	0
Truck tractor	3,791	118	593	917	1,714	6,259	80	0
Other	1,424	11	28	363	618	2,789	0	1

Source: Annualized figures from 2010-2012 FARS and GES

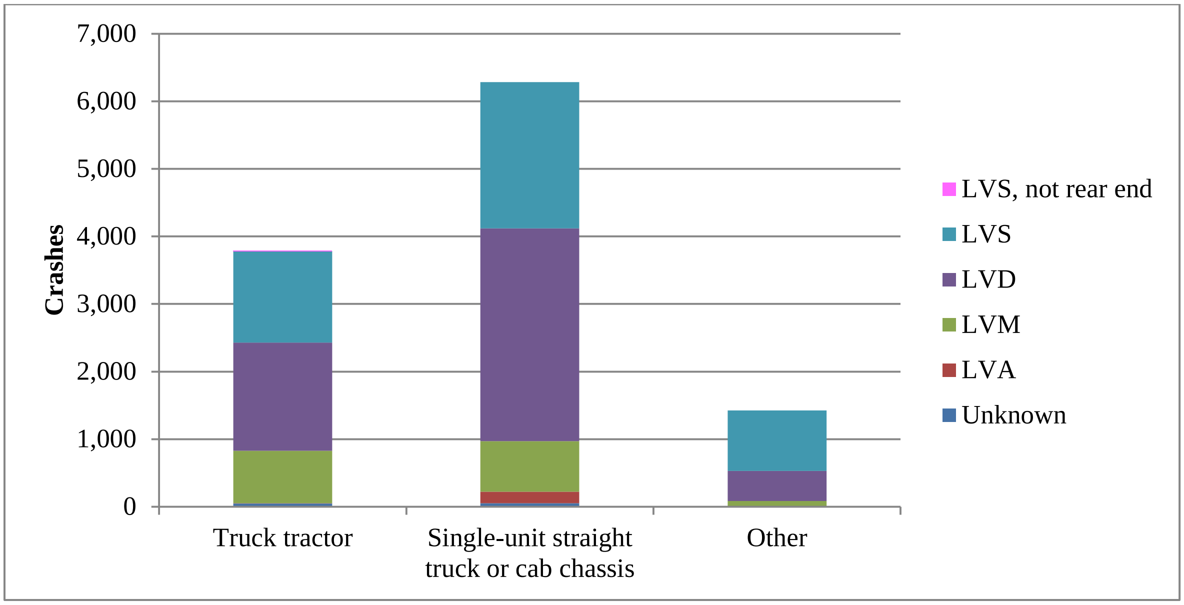
Table 39 in the Appendix presents a finer breakout of body types.

b. Characteristic: Scenario (Lead Vehicle Pre-Event Movement)

The table and figure in this section use the following acronyms in describing crash scenarios:

LVS: Lead Vehicle Stopped
LVD: Lead Vehicle Decelerating
LVM: Lead Vehicle Moving
LVA: Lead Vehicle Accelerating

Figure 17: Lead Vehicle Pre-Event Movement in the Target Population



Source: Annualized figures from 2010-2012 FARS and GES

Table 36: The Numbers of Targeted Crashes and KABCO-Level Injuries, by Heavy-Vehicle Type and Scenario

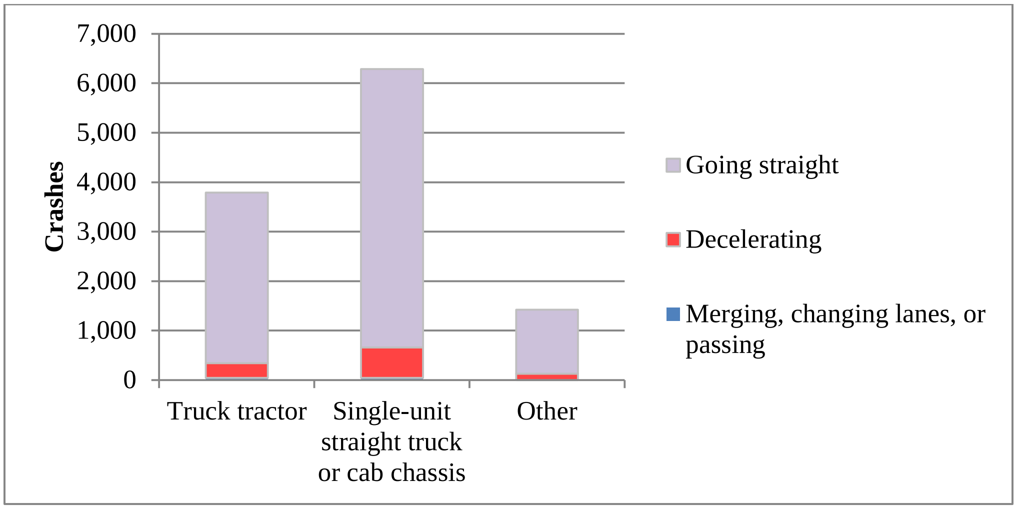
Heavy Vehicle Type	*Scenario*	*Crashes*	*Number Among People Involved in the First Harmful Crash Event*							
			Fatalities	*Incapacitating Injuries*	*Non-Incapacitating Injuries*	*Possible Injuries*	*Not Injured*	*Injured, Severity Unknown*	*Not Known Whether Injured*
Truck tractor	LVS	1,355	52	79	174	458	2,115	72	-
Truck tractor	LVD	1,603	25	414	545	624	2,579	8	-
Truck tractor	LVM	775	31	90	185	583	1,483	-	-
Truck tractor	LVA	3	2	2	2	24	1	-	-
Truck tractor	LVS, not rear-end	8	5	5	1	1	7	-	-
Truck tractor	Unknown	48	3	3	10	24	74	-	-
Straight truck	LVS	2,166	24	107	595	860	3,933	9	-
Straight truck	LVD	3,150	7	48	199	759	6,404	22	-
Straight truck	LVM	747	11	1	128	301	1,134	14	-
Straight truck	LVA	171	2	-	1	239	178	-	-
Straight truck	LVS, not rear-end	-	-	-	-	-	-	-	-
Straight truck	Unknown	50	-	-	57	40	92	-	-
Step van	LVS	18	-	-	20	-	18	-	-
Step van	LVD	18	-	-	-	19	19	-	-
Step van	LVM	-	-	-	-	-	-	-	-
Step van	LVS, not rear-end	-	-	-	-	-	-	-	-
Step van	LVA	-	-	-	-	-	-	-	-
Step van	Unknown	-	-	-	-	-	-	-	-

City bus	LVS	498	-	-	-	258	1,295	-	-
City bus	LVD	245	-	-	-	-	511	-	-
City bus	LVM	23	-	-	26	-	23	-	-
City bus	LVA	-	-	-	-	-	-	-	-
City bus	LVS, not rear-end	-	-	-	-	-	-	-	-
City bus	Unknown	-	-	-	-	-	-	-	-
Intercity bus	LVS	-	-	-	-	-	-	-	-
Intercity bus	LVD	1	2	2	-	-	-	-	-
Intercity bus	LVM	-	-	-	-	-	-	-	-
Intercity bus	LVA	1	1	2	56	-	-	-	-
Intercity bus	LVS, not rear-end	-	-	-	-	-	-	-	-
Intercity bus	Unknown	-	-	-	-	-	-	-	-
Van-based bus	LVS	2	2	2	3	1	1	-	-
Van-based bus	LVD	-	-	-	-	-	-	-	-
Van-based bus	LVM	54	-	-	-	57	57	-	-
Van-based bus	LVA	-	-	-	-	-	-	-	-
Van-based bus	LVS, not rear-end	-	-	-	-	-	-	-	-
Van-based bus	Unknown	-	-	-	-	-	-	-	-
School bus	LVS	2	2	5	1	22	-	-	-
School bus	LVD	55	2	15	92	1	110	-	1
School bus	LVM	-	-	-	-	-	-	-	-
School bus	LVA	-	-	-	-	-	-	-	-
School bus	LVS, not rear-end	-	-	-	-	-	-	-	-
School bus	Unknown	-	-	-	-	-	-	-	-
Med/heavy pickup	LVS	374	2	1	159	131	615	-	-
Med/heavy pickup	LVD	120	-	-	-	125	125	-	-
Med/heavy pickup	LVM	7	-	-	-	-	15	-	-
Med/heavy pickup	LVA	-	-	-	-	-	-	-	-
Med/heavy pickup	LVS, not rear-end	-	-	-	-	-	-	-	-
Med/heavy pickup	Unknown	-	-	-	-	-	-	-	-
Unknown truck type	LVS	-	-	-	-	-	-	-	-
Unknown truck type	LVD	5	-	-	5	5	-	-	-
Unknown truck type	LVM	-	-	-	-	-	-	-	-
Unknown truck type	LVA	-	-	-	-	-	-	-	-
Unknown truck type	LVS, not rear-end	-	-	-	-	-	-	-	-
Unknown truck type	Unknown	-	-	-	-	-	-	-	-

Source: Annualized figures from 2010-2012 FARS and GES

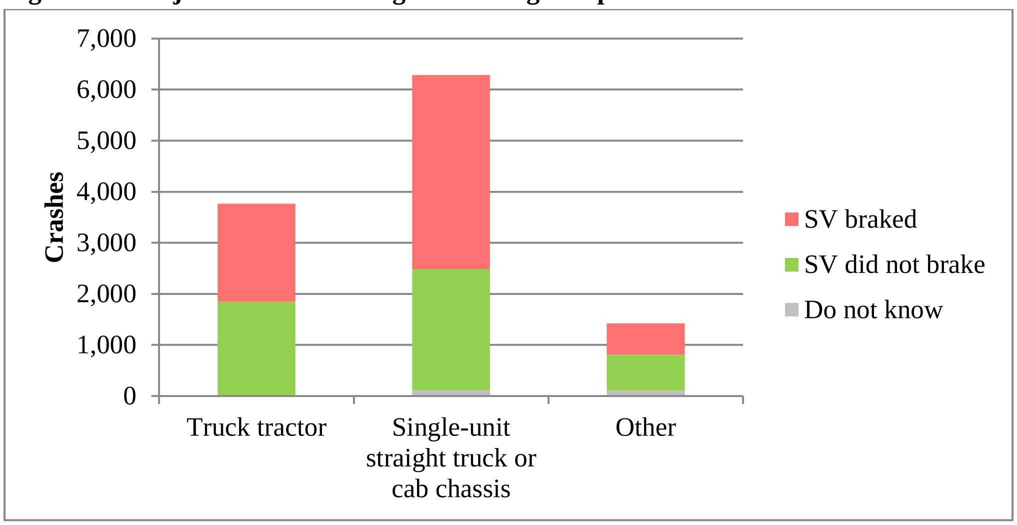
c. Characteristic: Subject Vehicle Movement

Figure 18: Subject Vehicle Pre-Event Movement in the Target Population



Source: Annualized figures from 2010-2012 FARS and GES

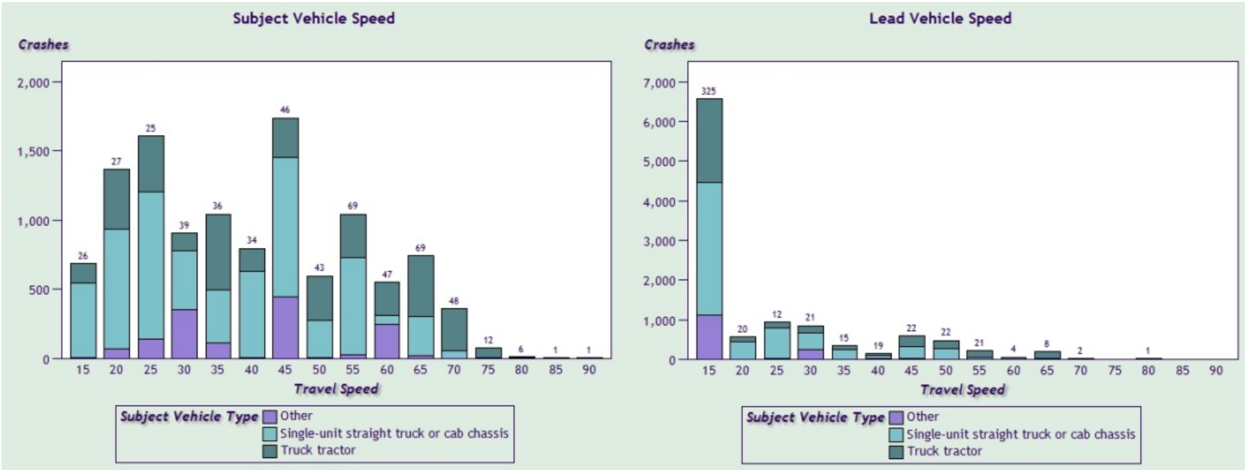
Figure 19: Subject Vehicle Braking in the Target Population



Source: Annualized figures from 2010-2012 FARS and GES

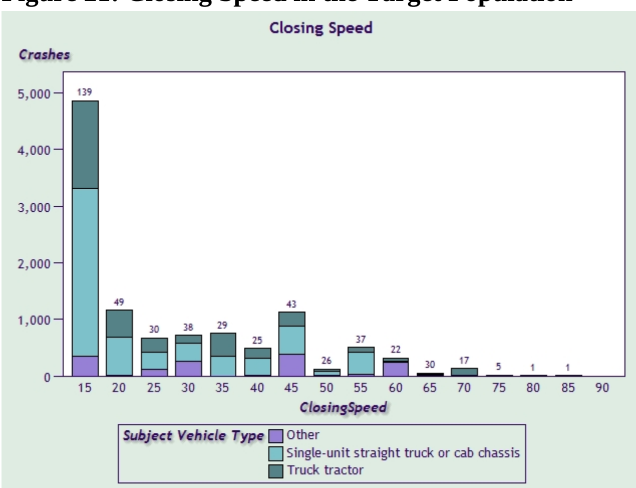
d. Characteristic: Speed

Figure 20: Subject and Lead Vehicle Speed in the Target Population



Source: Annualized figures from 2010-2012 FARS and GES

Figure 21: Closing Speed in the Target Population



Source: Annualized figures from 2010-2012 FARS and GES

e. Characteristic: Miscellaneous

Subject Driver Distraction and Impairment in the Target Population

About 15 percent of subject vehicle drivers were noted on police reports as being distracted or inattentive, and less than 1 percent were noted as impaired. The figures were comparable for straight trucks and tractors.

Subject and Lead Vehicle Crash Types

Most, but not all, of our targeted crashes fall in the FARS/GES accident types of 20-43 (rear-ends and forward impacts in the same travel direction). The ones outside of this range are predominantly crashes into stationary vehicles.

Table 37: The Crash Types in the Target Population

Subject Vehicle Crash Type	*Lead Vehicle Crash Type*	*Crashes*
D20-Same Trafficway, Same Direction-Rear-End-Stopped	D21-Same Trafficway, Same Direction-Rear-End-Stopped, Straight	3,968
D20-Same Trafficway, Same Direction-Rear-End-Stopped	D22-Same Trafficway, Same Direction-Rear-End-Stopped, Left	581
D20-Same Trafficway, Same Direction-Rear-End-Stopped	D23-Same Trafficway, Same Direction-Rear-End-Stopped, Right	36
D24-Same Trafficway, Same Direction-Rear-End-Slower	D25-Same Trafficway, Same Direction-Rear-End-Slower, Going Straight	1,433
D24-Same Trafficway, Same Direction-Rear-End-Slower	D26-Same Trafficway, Same Direction-Rear-End-Slower, Going Left	14
D24-Same Trafficway, Same Direction-Rear-End-Slower	D27-Same Trafficway, Same Direction-Rear-End-Slower, Going Right	1
D28-Same Trafficway, Same Direction-Rear-End-Decelerating (Slowing)	D29-Same Trafficway, Same Direction-Rear-End-Decelerating (Slowing), Going Straight	4,714
D28-Same Trafficway, Same Direction-Rear-End-Decelerating (Slowing)	D30-Same Trafficway, Same Direction-Rear-End-Decelerating (Slowing), Going Left	39
D28-Same Trafficway, Same Direction-Rear-End-Decelerating (Slowing)	D31-Same Trafficway, Same Direction-Rear-End-Decelerating (Slowing), Going Right	452
D32-Same Trafficway, Same Direction-Rear-End-Specifics Other	D32-Same Trafficway, Same Direction-Rear-End-Specifics Other	46
D33-Same Trafficway, Same Direction-Rear-End-Specifics Unknown	D33-Same Trafficway, Same Direction-Rear-End-Specifics Unknown	23
E42-Same Trafficway, Same Direction-Forward Impact-Specifics Other	E42-Same Trafficway, Same Direction-Forward Impact-Specifics Other	1
F44-Same Trafficway, Same Direction-Angle, Sideswipe-Straight Ahead on Left	F45-Same Trafficway, Same Direction-Angle, Sideswipe-Straight Ahead on Left/Right	5
F45-Same Trafficway, Same Direction-Angle, Sideswipe-Straight Ahead on Left/Right	F44-Same Trafficway, Same Direction-Angle, Sideswipe-Straight Ahead on Left	1
F45-Same Trafficway, Same Direction-Angle, Sideswipe-Straight Ahead on Left/Right	F46-Same Trafficway, Same Direction-Angle, Sideswipe-Changing Lanes to the Right	18
F45-Same Trafficway, Same Direction-Angle, Sideswipe-Straight Ahead on Left/Right	F47-Same Trafficway, Same Direction-Angle, Sideswipe-Changing Lanes to the Left	6
F46-Same Trafficway, Same Direction-Angle, Sideswipe-Changing Lanes to the Right	F45-Same Trafficway, Same Direction-Angle, Sideswipe-Straight Ahead on Left/Right	24
F48-Same Trafficway, Same Direction-Angle, Sideswipe-Specifics Other	F48-Same Trafficway, Same Direction-Angle, Sideswipe-Specifics Other	19
I66-Same Trafficway, Opposite Direction-Angle, Sideswipe-Specifics Other	I66-Same Trafficway, Opposite Direction-Angle, Sideswipe-Specifics Other	1
L86-Intersecting Paths-Straight Paths-Striking from the Right	L87-Intersecting Paths-Straight Paths-Struck on the Right	52
L88-Intersecting Paths-Straight Paths-Striking from the Left	L89-Intersecting Paths-Straight Paths-Struck on the left	59
M98-Other Crash Type	M98-Other Crash Type	7

Source: Annualized figures from 2010-2012 FARS and GES

Appendix

Table 38: Derivation of the Target Population

Filter	***Limbs***		***Crashes***	***Injuries***	***Fatalities***
0	All crashes (2010-2012 FARS/GES, annualized)		5,457,387	2,314,432	33,033
1. Heavy vehicle?	Crashes involving at least 1 **heavy vehicle**		341,827	120,857	4,101
	Crashes with **no heavy vehicles**		5,115,132	2,193,113	28,496
	Crashes with an **unknown vehicle type**.		428	462	436
2. Frontal?	Crashes where the first impact of at least one heavy vehicle was **frontal**		127,454	60,986	2,631
	All heavy vehicles have **non-frontal** first impacts		214,327	59,805	1,422
	Crashes where can't tell		46	66	48
3. First Event?	Crashes whose **first harmful event** involves the frontal impact of a heavy vehicle.		123,840	55,677	2,419
	All heavy vehicle frontal impacts happen in **subsequent** crash events.		3,615	5,309	212
3a. Limit to First Event Injuries	Crashes whose **first harmful event** involves the frontal impact of a heavy vehicle.	WE LIMIT INJURIES AND FATALITIES FROM HERE FORWARD TO THOSE PERSONS INVOLVED IN THE CRASH's FIRST HARMFUL EVENT.	123,840	51,566	2,300
4. Object/area struck	heavy vehicle hits the rear of a vehicle	LV was moving prior to the critical event	29,204	11,313	190
	heavy vehicle hits the rear of a vehicle	LV was stopped, both pre-event and pre-crash	19,363	7,606	96
	heavy vehicle hits the rear of a vehicle	LV had no driver pre-event, and was stopped pre-crash	80	48	5
	heavy vehicle hits the rear of a vehicle	LV had no driver pre-event, not known if moving pre-crash	-	-	-
	heavy vehicle hits the rear of a vehicle	LV was stopped pre-event, not known to be stopped pre-crash	202	1	0

Filter	*Limbs*		*Crashes*	*Injuries*	*Fatalities*
	heavy vehicle hits the rear of a vehicle	LV pre-event mvmt described as other	9	11	0
	heavy vehicle hits the rear of a vehicle	LV pre-event mvmt unknown	859	373	14
	heavy vehicle hits the front of a vehicle	LV was stopped, both pre-event and pre-crash	561	132	2
	heavy vehicle hits the side of a vehicle	LV was stopped, both pre-event and pre-crash	846	72	7
	heavy vehicle hits the top or bottom of a vehicle	LV was stopped, both pre-event and pre-crash	2	4	2
	heavy vehicle hits a vehicle, but do not know where	LV was stopped, both pre-event and pre-crash	-	1	-
	heavy vehicle hits the front of a vehicle	LV had no driver pre-event, and was stopped pre-crash	3	1	-
	heavy vehicle hits the side of a vehicle	LV had no driver pre-event, and was stopped pre-crash	188	4	1
	heavy vehicle hits the front of a vehicle	LV had no driver pre-event, not known if moving pre-crash	176	-	-
	heavy vehicle hits the side of a vehicle	LV had no driver pre-event, not known if moving pre-crash	39	-	-
	heavy vehicle hits the front of a vehicle	LV was moving prior to the critical event	16,495	11,052	771
	heavy vehicle hits the side of a vehicle	LV was moving prior to the critical event	36,328	15,400	719
	heavy vehicle hits a vehicle, but do not know where	LV was moving prior to the critical event	828	233	2
	Event not harmful to other vehicle	LV was moving prior to the critical event	237	9	-
	heavy vehicle hits the front of a vehicle	LV was stopped pre-event, not known to be stopped pre-crash	6	6	-
	heavy vehicle hits the side of a vehicle	LV was stopped pre-event, not known to be stopped pre-crash	1	1	-
	heavy vehicle hits the front of a vehicle	LV pre-event mvmt described as other	84	13	5
	heavy vehicle hits the front of a vehicle	LV pre-event mvmt unknown	357	86	4
	heavy vehicle hits the side of a vehicle	LV pre-event mvmt described as other	11	6	4
	heavy vehicle hits the side of a vehicle	LV pre-event mvmt unknown	1,492	39	5

Filter	***Limbs***		***Crashes***	***Injuries***	***Fatalities***
	heavy vehicle hits the top or bottom of a vehicle	LV pre-event mvmt described as other	0	0	0
	heavy vehicle hits the top or bottom of a vehicle	LV pre-event mvmt unknown	-	-	-
	heavy vehicle hits a vehicle, but do not know where	LV pre-event mvmt unknown	1,195	18	-
	heavy vehicle hits a fixed object, such as a wall, tree, utility pole, jersey wall, bridge, or guardrail	Not applicable	9,618	3,375	196
	heavy vehicle hits a pedestrian, bicyclist, horse rider, skateboarder, train, deer, animal-drawn conveyance, or other moving object. (Animal-drawn conveyances share the same code as ridden animals in FARS and GES.)	Not applicable	5,634	1,745	276
	Do not know what happened in first event	Not applicable	20	20	0

5. LV Type	Crashes where the front of a heavy vehicle hits the rear of a **passenger vehicle, large limo, or light-truck-based motorhome** in the first harmful crash event.	45,305	16,861	219
	The front of a heavy vehicle hits the rear of a **heavy vehicle** (in the first harmful crash event).	5,231	2,290	73
	LV is **construction or farm equipment other than trucks**	7	11	5
	LV is a **motorcycle, snowmobile, golf cart, LSV or 3-wheeled auto**	130	28	7
	LV is **some other type of vehicle, possibly a go-cart, fork lift, street sweeper or dune buggy (can't differentiate)**	2	2	0
	LV type is unknown.	859	373	13

6. SV/LV Pre-Crash Location	Y: SV stayed in original lane between the time of the critical event and the impact.	Y: LV stayed in original lane pre-crash	37,037	14,357	221
	Y: SV stayed in original lane pre-crash	Y: LV had no driver pre-crash	207	46	5
	N: SV left travel lane or roadway, remained off roadway, or entered roadway pre-crash	Y: LV stayed in original lane pre-crash	5,522	1,474	18
	N: SV left travel lane or roadway, remained off roadway, or entered roadway pre-crash	N: LV left travel lane or roadway, remained off roadway, or entered roadway pre-crash	829	186	12
	N: SV left travel lane or roadway, remained off roadway, or entered roadway pre-crash	N: LV stayed on road pre-crash but don't know if left lane, or pre-crash location unknown	139	34	0
	N: SV left travel lane or roadway, remained off roadway, or entered roadway pre-crash	Y: LV had no driver pre-crash	88	6	1

Filter	*Limbs*		*Crashes*	*Injuries*	*Fatalities*
	Y: SV stayed in original lane pre-crash	N: LV left travel lane or roadway, remained off roadway, or entered roadway pre-crash	4,731	2,505	35
	N: SV stayed on road pre-crash but don't know if left lane, or pre-crash location unknown	N: LV left travel lane or roadway, remained off roadway, or entered roadway pre-crash	147	60	1
	N: SV had no driver pre-crash	N: LV left travel lane or roadway, remained off roadway, or entered roadway pre-crash	97	1	0
	N: SV stayed on road pre-crash but don't know if left lane, or pre-crash location unknown	N: LV stayed on road pre-crash but don't know if left lane, or pre-crash location unknown	442	56	1
	N: SV stayed on road pre-crash but don't know if left lane, or pre-crash location unknown	Y: LV had no driver pre-crash	70	0	0
	N: SV stayed on road pre-crash but don't know if left lane, or pre-crash location unknown	Y: LV stayed in original lane pre-crash	725	210	2
	Y: SV stayed in original lane pre-crash	N: LV stayed on road pre-crash but don't know if left lane, or pre-crash location unknown	343	226	1
	N: SV had no driver pre-crash	Y: LV had no driver pre-crash	95	.	.
	N: SV had no driver pre-crash	Y: LV stayed in original lane pre-crash	71	0	0

7. SV/LV Movement Before the Critical Event	Y: SV was going straight, accel, decel, passing, starting, or stopped before the critical event	Y: LV was going straight, accel, decel, passing, stopped, parked, starting, or had no driver before the critical event	30,240	12,803	198
	Y: SV was going straight, accel, decel, passing, starting, or stopped before the critical event	Y: LV was backing up pre-event or its mvmt is described as other or unknown	849	23	2
	Y: SV was going straight, accel, decel, passing, starting, or stopped before the critical event	Y: LV was changing lanes or merging before the critical event	967	175	4
	Y: SV was changing lanes or merging before the critical event	Y: LV was going straight, accel, decel, passing, stopped, parked, starting, or had no driver before the critical event	361	65	2
	Y: SV pre-event mvmt is described as other or unknown	Y: LV was going straight, accel, decel, passing, stopped, parked, starting, or had no driver before the critical event	4	5	0
	Y: SV was changing lanes or merging before the critical event	Y: LV was backing up pre-event or its mvmt is described as other or unknown	0	0	0
	Y: SV was changing lanes or merging before the critical event	Y: LV was changing lanes or merging before the critical event	88	7	1
	N: SV was leaving/entering parking spot, turning, curving, or avoiding something before the critical event	N: LV was leaving/entering parking spot, turning, curving, or avoiding something before the critical event	436	200	4
	N: SV was leaving/entering parking spot, turning, curving, or avoiding something before the critical event	Y: LV was backing up pre-event or its mvmt is described as other or unknown	100	1	0

Filter	*Limbs*		*Crashes*	*Injuries*	*Fatalities*
	N: SV was leaving/entering parking spot, turning, curving, or avoiding something before the critical event	Y: LV was changing lanes or merging before the critical event	107	0	0
	N: SV was leaving/entering parking spot, turning, curving, or avoiding something before the critical event	Y: LV was going straight, accel, decel, passing, stopped, parked, starting, or had no driver before the critical event	2,758	521	9
	Y: SV was changing lanes or merging before the critical event	N: LV was leaving/entering parking spot, turning, curving, or avoiding something before the critical event	0	0	0
	Y: SV was going straight, accel, decel, passing, starting, or stopped before the critical event	N: LV was leaving/entering parking spot, turning, curving, or avoiding something before the critical event	1,333	603	6

8. Road conditions	Dry	27,830	10,981	186
	Wet	3,096	1,497	14
	Slush	44	69	0
	Non-Trafficway Area	2	2	0
	Other	76	0	0
	Unknown	3	3	0
	Not Reported	431	195	0
	Ice/Frost	440	192	3
	Snow	493	127	2
	Water (Standing or Moving)	7	6	0

9. Atmospheric conditions	Clear	25,053	10,151	164
	Cloudy	3,902	1,457	25
	Severe Crosswinds	21	41	1
	Rain	2,132	969	7
	Snow	191	67	1
	Fog, Smog, Smoke	56	53	2
	Blowing Sand, Soil, Dirt	34	1	0
	Sleet, Hail (Freezing Rain or Drizzle)	6	3	0
	Blowing Snow	2	0	0
	Other	83	5	0

The counts in this next category (Filter #10) do not quite sum to the previous surviving limbs, since a crash sometimes (albeit rarely) involves multiple visual obstructions.

Vision Obscured	No Obstruction Noted	27,237	11,105	180
	Reflected Glare, Bright Sunlight, Headlights	220	121	2

Filter	*Limbs*	*Crashes*	*Injuries*	*Fatalities*
	In-Transport Motor Vehicle (including load)	53	71	1
	Not In-Transport Motor Vehicle (parked, working)	1	-	-
	Obstructing Angles on Vehicle	3	5	-
	Obstruction Interior to the Vehicle	11	5	-
	Other Visual Obstruction	80	3	1
	Rain, Snow, Fog, Smoke, Sand, Dust	1	2	1
	Unknown	1,344	324	2
	Vision Obscured - No Details	21	6	1
	Curve, Hill or Other Roadway Design Feature	7	7	4

	The counts in this next category (filter #10a) do not involve multiple counting.			
10a. SV Vision Obscured by…	Y: No obstruction to SV driver vision noted	27,237	11,105	180
	Y: SV driver vision obstructed by something other than a curve, hill, or roadway design feature	390	212	4
	Y: Unknown whether SV driver vision was obstructed	1,344	324	2
	N: SV vision obscured by curve, hill, or roadway design feature(s)	7	7	4
Avoidance Maneuvers (Before	SV goes 15-97 mph; AND SV either takes no avoidance maneuver or takes one described as steering, braking, both steering and braking, or "other".	3,786	2,478	74
	SV goes 0-14 mph; OR SV accelerates to avoid crash.	4,897	910	2
	All other cases. For these cases the SV travel speed, and/or whether the SV tried to avoid the LV is unknown, but any known values do not put it in the 'No' category. For instance a stopped SV with unknown avoidance maneuver will be counted in the previous row, not this one.	20,287	8,253	110
Avoidanc e Maneuver	SV goes 15-97 mph; AND SV either takes no avoidance maneuver or takes one described as steering, braking, both steering and braking, or "other".	12,630	8,513	182
	SV goes 0-14 mph; OR SV accelerates to avoid crash.	16,340	3,127	4
Impact of Regulations	Target population, incorporating the effect of past and pending regulations	11,499	7,703	173

Source: Annualized figures from 2010-2012 FARS and GES

Table 39: The Numbers of Targeted Crashes and KABCO-Level Injuries, by Detailed Heavy Vehicle Type and Scenario

Heavy Vehicle Type	*Scenario*	*Crashes*	*Number Among People Involved in the First Harmful Crash Event*						
			Fatalities	*Incapacitating Injuries*	*Non-Incapacitating Injuries*	*Possible Injuries*	*Not Injured*	*Injured, Severity Unknown*	*Not Known Whether Injured*
Truck tractor	LVS	1,363	57	84	175	459	2,122	72	-
Truck tractor	LVD	1,603	25	414	545	624	2,579	8	-
Truck tractor	LVM	775	31	90	185	583	1,483	-	-
Truck tractor	LVA	3	2	2	2	24	1	-	-
Truck tractor	Unknown	48	3	3	10	24	74	-	-
Straight truck	LVS	2,166	24	107	595	860	3,933	9	-
Straight truck	LVD	3,150	7	48	199	759	6,404	22	-
Straight truck	LVM	747	11	1	128	301	1,134	14	-
Straight truck	LVA	171	2	-	1	239	178	-	-
Straight truck	Unknown	50	-	-	57	40	92	-	-
City bus	LVS	498	-	-	-	258	1,295	-	-
City bus	LVD	245	-	-	-	-	511	-	-
City bus	LVM	23	-	-	26	-	23	-	-
City bus	LVA	-	-	-	-	-	-	-	-
City bus	Unknown	-	-	-	-	-	-	-	-
Med/heavy pickup	LVS	374	2	1	159	131	615	-	-
Med/heavy pickup	LVD	120	-	-	-	125	125	-	-
Med/heavy pickup	LVM	7	-	-	-	-	15	-	-
Med/heavy pickup	LVA	-	-	-	-	-	-	-	-
Med/heavy pickup	Unknown	-	-	-	-	-	-	-	-
Van-based bus	LVS	2	2	2	3	1	1	-	-
Van-based bus	LVD	-	-	-	-	-	-	-	-
Van-based bus	LVM	54	-	-	-	57	57	-	-
Van-based bus	LVA	-	-	-	-	-	-	-	-
Van-based bus	Unknown	-	-	-	-	-	-	-	-
Step van	LVS	18	-	-	20	-	18	-	-
Step van	LVD	18	-	-	-	19	19	-	-
Step van	LVM	-	-	-	-	-	-	-	-
Step van	LVA	-	-	-	-	-	-	-	-
Step van	Unknown	-	-	-	-	-	-	-	-
School bus	LVS	2	2	5	1	22	-	-	-
School bus	LVD	55	2	15	92	1	110	-	1
School bus	LVM	-	-	-	-	-	-	-	-
School bus	LVA	-	-	-	-	-	-	-	-
School bus	Unknown	-	-	-	-	-	-	-	-
Intercity bus	LVS	-	-	-	-	-	-	-	-
Intercity bus	LVD	1	2	2	-	-	-	-	-
Intercity bus	LVM	-	-	-	-	-	-	-	-

Heavy Vehicle Type	Scenario	Crashes	Number Among People Involved in the First Harmful Crash Event						
			Fatalities	Incapacitating Injuries	Non-Incapacitating Injuries	Possible Injuries	Not Injured	Injured, Severity Unknown	Not Known Whether Injured
Intercity bus	LVA	1	1	2	56	-	-	-	-
Intercity bus	Unknown	-	-	-	-	-	-	-	-
Unknown truck type	LVS	-	-	-	-	-	-	-	-
Unknown truck type	LVD	5	-	-	5	5	-	-	-
Unknown truck type	LVM	-	-	-	-	-	-	-	-
Unknown truck type	LVA	-	-	-	-	-	-	-	-
Unknown truck type	Unknown	-	-	-	-	-	-	-	-

Source: Annualized figures from 2010-2012 FARS and GES

References

Allen, K. (2010). *The Effectiveness of ABS in Heavy Truck Tractors and Trailers, DOT HS 811 339.* Washington, DC: U.S. Department of Transportation.

Bendix Commercial Vehicle Systems. (n.d.). *Bendix® Wingman® Advanced™, A Powerful Combination of Collision Mitigation and Full Stability Technologies*. Retrieved April 15, 2014, from www.bendix.com/en/products/acb/wingmanadvanced_1.jsp

Bendix Commercial Vehicle Systems LLC. (2011a). *Bendix® Wingman® Advanced™ – A Collision Mitigation Technology, Questions & Answers.* Retrieved April 15, 2014, from www.bendix.com/media/documents/products_1/acb_1/wingmanadvanced/faqbendixwingmanadvanced_generic_0311_final.pdf.

Bendix Commercial Vehicle Systems LLC. (2011b). *Bendix® Wingman® Advanced™, A Collision Mitigation Technology.* Retrieved April 15, 2014, from www.bendix.com/media/documents/products_1/acb_1/wingmanadvanced/bw2855bxwingmanadvancedbrochurefinal32411.pdf.

Bendix Commercial Vehicle Systems LLC. (2011c). *Instructions for the Vertical and Lateral Alignment of Bendix Radar Sensors.* Retrieved April 15, 2014, from www.bendix.com/media/documents/products_1/acb_1/wingmanadvanced/acbalignmenttool.pdf

Bendix Commercial Vehicle Systems LLC. (2015). *Bendix® Wingman® Fusion™, The integration of camera, radar, and brakes delivers a new level of performance in North America.* Retrieved October 5, 2016, from www.bendix.com/media/documents/products_1/wingman_fusion/BW3025_Fusion_Brochure.pdf

Federal Highway Administration. (1998). *Final Rule - Parts and Accessories Necessary for Safe Operation; Antilock Brake Systems, docket no. FHWA-1997-2318-0026.* Washington DC: Federal Register, Vol. 83, No. 85.

Federal Motor Carrier Safety Administration, National Highway Traffic Safety Administration. (2006a). *Large Truck Crash Causation Study Analytical User's Manual.* Washington, DC: U.S. Department of Transportation.

Federal Motor Carrier Safety Administration, National Highway Traffic Safety Administration. (2006b). *Large Truck Crash Causation Study Codebook.* Washington, DC: U.S. Department of Transportation.

Jarossi, L., Hershberger, D., & Woodrooffe, J. (2012). *Trucks Involved in Fatal Accidents Codebook 2010.* Ann Arbor, MI: University of Michigan Transportation Research Institute.

Meritor WABCO Vehicle Control Systems. (2009a). OnGuard™ Collision Safety System Driver Tips. Troy, MI. Retrieved April 15, 2014, from www.meritorwabco.com/MeritorWABCO_document/SP0818.pdf

Meritor WABCO Vehicle Control Systems. (2009b). OnGuard™ Display Operating Instructions, Technical Bulletin, TP-08122. Troy, MI: Author.

Meritor WABCO Vehicle Control Systems. (2011). *Maintenance Manual MM-0951, OnGuard™ Collision Safety System.* Troy, MI: Author.

Meritor WABCO Vehicle Control Systems. (2013a). *Maintenance Manual MM-1306, OnGuard™ Collision Mitigation System.* Troy, MI: Author.

Meritor WABCO Vehicle Control Systems. (2013b). OnGuard™ Collision Mitigation System Driver Tips. Troy, MI. Retrieved April 15, 2014, from www.meritorwabco.com/MeritorWABCO_document/TP1320.pdf

Meritor WABCO Vehicle Control Systems. (2014a). OnGuard™ Collision Mitigation System, SP-0853. Troy, Michigan. Retrieved from www.meritorwabco.com/MeritorWABCO_document/SP0853.pdf

Meritor WABCO Vehicle Control Systems. (2014b, March). OnGuard™ System Retrofit Kit, Technical Bulletin TP-1440. Troy, MI: Author

Meritor WABCO Vehicle Control Systems. (n.d.). *OnGuard™ Collision Mitigation System*. Retrieved April 15, 2014, from www.meritorwabco.com/Product.aspx?product_1_id=2&product_id=15&product_level=2&AspxAutoDetectCookieSupport=1

National Highway Traffic Safety Administration. (2011). *Final Rule, Federal Motor Vehicle Safety Standards; Air Brake Systems, Docket No. NHTSA-2009-0083.* Federal Register Volume 76, Number 14. Washington, DC: Author.

National Highway Traffic Safety Administration. (2012). *Notice of Proposed Rulemaking, Federal Motor Vehicle Safety Standards: Electronic Stability Control Systems for Heavy Vehicles, docket NHTSA-2012-0065-0001.* Federal Register, Vol. 77, No. 100. Washington, DC: Author.

National Highway Traffic Safety Administration. (2013). *2012 Fatality Analysis Reporting System (FARS) and National Automotive Sampling System (NASS) General Estimates System (GES) Coding and Validation Manual.* (Report No. DOT HS 811 854). Washington, DC: U.S. Department of Transportation.

National Highway Traffic Safety Administration. (2014). *Fatality Analysis Reporting System (FARS) Analytical User's Manual 1975-2012.*(Report No. DOT HS 811 855). Washington, DC: U.S. Department of Transportation.

National Highway Traffic Safety Administration. (2014). *National Automotive Sampling System (NASS) General Estimates System (GES) Analytical User's Manual 1988-2012.* (Report No. DOT HS 811 853). Washington, DC: U.S. Department of Transportation.

National Highway Traffic Safety Administration. (2015). *Final Rule, Federal Motor Vehicle Safety Standards: Electronic Stability Control Systems for Heavy Vehicles, Docket No. NHTSA-2015-0056.* Federal Register, Volume 80, Number 120. Washington, DC: Author.

National Highway Traffic Safety Administration. (2014, August). *Automatic Emergency Braking System (AEB) Research Report, Docket No. NHTSA–2012–0057-0037.* Washington, DC: U.S. Department of Transportation.

National Highway Traffic Safety Administration. (2012, June). *Forward-Looking Advanced Braking Technologies Research Report, Docket No. NHTSA–2012–0057–0001.* Washington, DC: U.S. Department of Transportation.

National Highway Traffic Safety Administration. (2015, June). *Traffic Safety Facts: Large Trucks, 2013 Data.* (Report No. DOT HS 812 150). Washington, DC: U.S. Department of Transportation.

National Highway Traffic Safety Administration, Federal Motor Carrier Safety Administration. (2016). *Notice of Proposed Rulemaking, Federal Motor Vehicle Safety Standards; Federal Motor Carrier Safety Regulations; Parts and Accessories Necessary for Safe Operation; Speed Limiting Devices; Docket No. NHTSA-2016-0087, FMCSA-2014-0083.* Federal Register, Vol. 81, No. 173. Washington, DC: Author.

National Highway Traffic Safety Administration, Office of Regulatory Analysis and Evaluation. (2016, August). *FMVSS No. 140, Speed Limiting Devices, Preliminary Regulatory Impact Analysis and Initial Regulatory Flexibility Analysis.* Washington, DC: U.S. Department of Transportation.

Woodrooffe, J., Blower, D., Bao, S., Bogard, S., Flannagan, C., Green, P. E., et al. (2012). *Performance Characterization and Safety Effectiveness Estimates of Forward Collision Avoidance and Mitigation Systems for Medium/Heavy Commercial Vehicles.* Ann Arbor, MI: University of Michigan Transportation Research Institute.

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