Restating the National Highway Transportation Safety Administration's National Motor Vehicle Crash Causation Survey for Automated Vehicles

Casualty Actuarial Society Automated Vehicles Task Force

EXECUTIVE SUMMARY

The National Highway Transportation Safety Administration (NHTSA) concluded its National Motor Vehicle Crash Causation Survey (NMVCCS) in 2008. The NMVCCS analyzed the events leading up to a motor vehicle crash to determine what was causing automobile accidents. This study, which found that 93% of accidents are caused by human error, is often referenced to justify and quantify automated vehicles' accident reduction potential. However, this study was never intended to be applied to automated vehicles.

Currently celebrating its 100th year, the Casualty Actuarial Society fulfills its mission to advance actuarial science through a singular focus on research and education for property/casualty actuarial practice. Among its 6,200 members are experts in property-casualty insurance, reinsurance, finance, risk management, and enterprise risk management. The Casualty Actuarial Society has created an Automated Vehicles Task Force (CAS AVTF) to research the technology's risks and their implications for insurance and risk management. To this end, the Task Force has re-evaluated the NMVCCS in the context of an automated vehicle world. It found that 49% of accidents contain at least one limiting factor that could disable the technology or reduce its effectiveness. The safety of automated vehicles should not be determined by today's standards; things that cause accidents today may or may not cause accidents in an automated vehicle era. Rather, things like the vehicle's failure rate (after accounting for any fail-safes, infrastructure investments, and driver interactions) and unavoidable accidents (e.g., falling rocks) should be the gauge by which they should be measured. Safety metrics should also consider additional criteria that would not be part of today's standards and safety concerns, as automation introduces additional risks to consider.

This report details the CAS AVTF's re-evaluation of the NMVCCS and notes areas for future research.

1. INTRODUCTION

John Capp, director of electrical and control systems at General Motors R&D recently stated, "Someone has to get this story straight—that it's going to take a long time before we see the true autonomous vehicle. There's so much to do before we can tell a customer as he leaves the dealer's lot, 'Just close your eyes. It's good to go.[1]'" The problem with Mr. Capp's statement is that no clear safety benchmark has been or is being established. Company XYZ may conclude that their product is safe for consumers while Company ABC may believe more testing is required. This may be because Company XYZ has more advanced technology than ABC, has performed different tests, or has a different safety standard. If the technology is safe, a delay in its implementation can result in accidents, including fatal ones, which could have been avoided with the technology. If it's unsafe, its introduction not only puts lives at risk, it also risks delaying future technological advancements.

The absence of any clearly established safety benchmark has led interested parties to rely on the National Highway Transportation Safety Administration (NHTSA) National Motor Vehicle Crash Causation Survey's (NMVCCS) conclusions. The NMVCCS found that 93% of accidents are caused by human error. Publications such as *The New York Times* and many of the witnesses testifying before the U.S. Senate and House have suggested that automated vehicles have the potential to reduce all of these accidents. However, the NMVCCS's conclusions have no bearing on automated vehicles' potential. The study analyzed the risks of today's driving environment. A future of automated vehicles will look much different and involve different risks. As drivers rely more on the vehicle's technology and less on themselves, the accident causation variables will change. An accurate baseline requires a new analysis that looks at these variables through a lens of automated vehicle performance.

The Casualty Actuarial Society's Automated Vehicles Task Force (CAS AVTF) has re-evaluated the NMVCCS data through just such a lens. The new benchmark illuminates and quantifies a broad array of risks that need to be overcome before the technology can reach its potential; however, this benchmark is merely the first step in the creation of a process that will ensure the product's safety. The quantification of the risks allows stakeholders to identify and prioritize areas of concern. A more robust analysis also allows them to make more accurate cost-benefit decisions, thereby optimizing their investments. Ultimately, increasing the risks' transparency also increases Company XYZ's ability to prove the technology's safety and benefits. In turn, this can inform decisions on how to support the development of a revolutionary product while balancing safety and innovation concerns.

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[1] http://www.nempa.org/events/2014/engineering-safer-drivers/

2. BACKGROUND AND OBJECTIVE

For many people, getting into a motor vehicle is their greatest everyday risk. Each year, automobile accidents result in 50 million injuries and 1.2 million deaths worldwide. Automated vehicles have the potential to make our roads dramatically safer. However, as the technology reduces some risks, others may be increased and new risks may be introduced. The Casualty Actuarial Society has formed an Automated Vehicles Task Force to study these risks and identify opportunities for stakeholders and the insurance industry to improve the product.

Automated Vehicle Background

Advancements over the past decade have brought autonomous cars out of the realm of science fiction and onto our public roads. Google, Audi, and Continental have received licenses in Nevada to test their automated vehicles on public roadways. Volvo is conducting road tests in Sweden and Nissan is doing the same in Japan. Mercedes Benz has tested its technology in Germany. Great Britain will allow automated vehicles to be tested on public roads in January 2015.

Regulators have tried to keep pace with the technological advancements. In the United States, California, Florida, Michigan, and Washington D.C. have passed bills regarding automated vehicle testing. The NHTSA has issued a preliminary policy statement on automated vehicles. As the technology advances, there will be further legislative and regulatory developments.

National Motor Vehicle Crash Causation Survey

The U.S. Congress authorized the NHTSA to conduct a National Motor Vehicle Crash Causation Survey to understand the events leading up to a motor vehicle crash. In 2008, the NHTSA reported its findings to Congress. These findings were specific to the current, non-autonomous transportation environment. There are a number of reasons why these conclusions are not applicable to automated vehicles.

First, the NHTSA did not collect information on all accidents. Minor accidents and accidents occurring between 12:00 a.m. and 5:59 a.m. were not analyzed; care needs to be taken when extrapolating the results to a set of accidents that were not analyzed. Second, automobiles have undergone a number of changes since the evaluation period. Approximately 40% of vehicles on today's roads have electronic stability control, up from 10% in 2005 when the study began. Forward collision avoidance systems, like Volvo's autonomous braking system City Safe, have become much more prevalent in recent years. Third, the study left out variables important to determining the success of automated vehicles. More specifically, the location was not tracked in the dataset; therefore, we cannot develop as granular or as accurate a baseline as will be required to make actual cost-benefit decisions. For example, a countrywide estimate of snow's impact on accidents is not applicable to San Diego. Lastly, automated vehicles represent a fundamental change in transportation risk: one in which the driver depends on his car rather than himself. This requires a complete paradigm shift in the way the data is analyzed.

Goal

There is a need for a clear, accurate, and applicable baseline to estimate the technology's potential benefits, and more importantly, what actions can help the technology reach its potential. The CAS AVTF has chosen to use the NMVCCS to establish this baseline for two reasons. First, the NMVCCS contains over 600 data elements from 5,471 accidents. This allows us to analyze a wide range of causation variables. Second, it allows us to demonstrate the impact from simply changing the study's focus. Ultimately, it represents merely the first step on the path towards creating the optimal testing approach and risk management structure.

3. SCOPE

The NHTSA collected over 600 data elements on 6,950 crashes from January 1, 2005, through December 31, 2007. The Report to Congress used the data on the 5,471 crashes that occurred over the two-and-a-half year period, July 3, 2005, through December 31, 2007. The NHTSA collected information on accidents with the following characteristics:

- The crash must have resulted in a harmful event associated with a vehicle in transport on a traffic way.
- Emergency medical services must have been dispatched to the crash scene.
- At least one of the first three crash-involved vehicles must be present at the crash scene when the NMVCCS researcher arrives.
- The police must be present at the scene of the crash when the NMVCCS researcher arrives.
- At least one of the first three vehicles involved in the crash must be a light passenger vehicle that was towed or will be towed due to damage.
- A completed police accident report for this crash must be available.

The Report to Congress further states: "To make the NMVCCS sample representative of all similar types of crashes for the whole of the United States each of the 5,471 investigated crashes has been assigned a certain weight based on the sample design used in this survey." The recalculation of these weights falls outside the scope of this project. Therefore, the report will show both the unweighted (observed) and weighted (extrapolated) frequencies.

The CAS AVTF also restricted its analysis to these accidents. Since this report is interested in quantifying potential risks to automated vehicles' accident reduction, the Task Force focused on identifying instances in which the technology would be inoperable, disengaged, or involve a risky behavior that requires additional research. In order to determine whether the accident would be prevented, the Task Force asked two questions: would the technology have been operable and would the technology have been operated safely? Specifically, the following variables were identified as potential hurdles:

Variable	Dataset	Description
Traffic way	ENV	Used to determine when the technology would be disabled due to environmental conditions • Values of Roadway Immersed, Heavy Snow, Heavy Rain, and Dust Storm assumed to disable technology
Weather	ENV	Used to determine when the technology would be disabled due to environmental conditions • Values of Snow, Rain, Sleet, Blowing Snow assumed to disable technology
Vehicle Condition	PCAEXT	Used as a proxy for vehicle failures. If the vehicle or technology fails and the driver is not properly engaged, the accident could still occur. The frequency of errors is likely to increase as the vehicle shoulders more of the driving responsibility.
Traffic Control Device	TCD	Tells us if a traffic control device (TCD) was present and operable at the accident. • If the TCD was inoperable, the automated vehicle technology may not have been able to correctly interpret its environment to prevent the accident.
Alcohol	PCAEXT	Used to determine if alcohol was present in any of the drivers in the accident
Drug	DRUGS	Used to determine what other drugs were present in any of the drivers in the accident
Critical Event	PCA	NHTSA's variable, identifying what they believed to be the critical reason for the accident • Values of Sleeping, Heart Attack/Other Physical Impairment, External Distraction, Internal Distraction, and Inattention were identified as potential risks for automated vehicle use

The new baseline is limited to the data elements collected in the NVMCCS. However, additional variables will be required to calculate the true baseline. A few of the variables that will be needed are:

Location: As noted above, location is a key variable for establishing a reasonable cost-benefit analysis. It is likely that separate baselines will be needed for city driving, highway driving, and country driving. Cities with different environmental risks will also have different cost-benefit relationships to consider.

Animal accidents: The majority of the 1.2 million annual animal hits occur in the Midwest. The dataset does not contain a variable detailed enough to break out the unavoidable animal hits from the avoidable ones. The lack of a location identifier also reduces the value of any observed variable.

Volvo is reportedly working on advancing its automated braking system to recognize and stop for deer, which may further reduce the risk.

Other risks: The engineering and coding risks are obviously one of the largest hurdles that need to be overcome. The process risk involved in the tests—the risk that the tests differ from reality—should also be quantified and adjusted for.

Differences from NMVCCS

The CAS AVTF's accident level evaluation differs slightly from the NMVCCS for two reasons:

- The data file used to produce the statistics in the Report to Congress was compiled at April 30, 2008. The final file available at the NMVCCS website is a later version (compiled on October 28, 2008) and is slightly different from the data file used for the report to Congress.
- The CAS AVTF's focus caused some accidents to be categorized differently. For example, if any vehicle in the accident had a pre-identified risk feature then the entire accident was segmented into that risk bucket.

4. RESULTS

The results have been divided into two sections, technological issues and behavioral issues. These groups of risks are then further segmented by the actual risk:

- Technological issues: Weather, Vehicle Condition/Error, Inoperable Traffic Control Devices
- Behavioral issues: Aggressive Driving/Driver Disables, Alcohol & Illicit drugs, Sleeping, Physical Issues/Heart Attack, Distraction

4.1 Technological Issues

Technological issues are ones where the technology may be inoperable or may inaccurately interpret the environment. Therefore, the technology's presence would not have prevented these accidents.

4.1a Weather

Based on publicly available information at the time of this writing, automated vehicles are inoperable in inclement weather. Therefore, no accident could be prevented if it occurred in such weather, regardless of the crash's actual cause. "Inoperable weather" is defined as snow, sleet, rain, or blowing snow as well as times when the road was immersed in water, heavy snow, heavy rain, or a dust storm.

Weather	Unwtd Freq	Wtd Freq	Unwtd Freq	Wtd Freq
No weather issues	4,868	1,921,312	89.0%	87.8%
Inoperable weather	602	267,657	11.0%	12.2%
Grand Total	**5,470**	**2,188,970**	**100%**	**100%**

Accounting for weather in the analysis reduces the number of preventable accidents by over 12%. However, the value to overcoming this hurdle varies dramatically depending where you live. For example, San Diego and San Francisco average less than 65 days of precipitation a year. However, Seattle averages approximately 150 days of precipitation a year.

Automakers and technology companies may develop an in-vehicle solution to inclement weather, reducing the vehicles' risk and increasing their benefits. In the meantime, a number of tests are being conducted that may offer alternative ways to overcome this hurdle. Volvo's experiments with road magnets indicate that certain infrastructure investments might neutralize this risk. The University of Michigan is building a fake city in Ann Arbor to test automated vehicles. These tests may yield additional insights to help overcome the inclement weather issue.

4.1b Vehicle Conditions

NHTSA tracked if a vehicle error or deficiency occurred. For example, NHTSA noted if there was an issue with the braking system even if it was not the main cause of the crash. While some of these conditions may be easily overcome, others could be dramatically worse as the technology becomes more advanced and human involvement decreases. In a fully autonomous world, the driver is free to read, text, or even sleep. Currently, an engaged driver may be able to overcome a braking system error or a blown tire. However, in the automated vehicle world, the driver may not be sufficiently engaged to overcome such issues. These accidents will require additional research to ensure that the automated vehicle will be able to interpret the incident and make any necessary adjustments to avoid a crash. Rather than make any assumption about the unknown accidents, we will exclude all of the accidents where we do not know whether the technology could have prevented the accident.

Vehicle Condition Present	Unwtd Freq	Wtd Freq	Unwtd Freq	Wtd Freq
Not Present	4,351	1,769,134	79.5%	80.8%
Present*	681	254,948	12.4%	11.6%*
Unknown if present	438	164,888	8.0%	7.5%
Grand Total*	**5,470**	**2,188,970**	**100%**	**100%**

*Removing the Unknowns from the subset decreases the total number of accidents from 5,470 to 5,032 and increases the percentage of accidents with a vehicle condition present to 12.6%.

4.1c Traffic Control Devices (TCD)

For a small number of accidents, the traffic control device operating the intersection was not working properly. Automated vehicle technology communicates with the traffic control devices to determine the correct action. In these scenarios, it is unknown whether the technology will correctly interpret the inoperable TCD and respond correctly.

Traffic Signal	Unwtd Freq	Wtd Freq	Unwtd Freq	Wtd Freq
Not operating properly	22	7,933	0.4%	0.4%
Not present/Operating properly	5,447	2,180,736	99.6%	99.6%
Unknown	1	300	0.0%	0.0%
Grand Total	**5,470**	**2,188,970**	**100%**	**100%**

These numbers, though tiny, may underestimate the impact inoperable traffic control devices will have on automated vehicles. First, an "inoperable traffic control device" may be defined differently for an automated vehicle than for a human driver. Google's automated vehicles use extremely detailed maps to navigate safely. If a TCD is not at the regulated height or is moved slightly, it may now be "inoperable" from a technological perspective while it works just fine for a human driver. Second, if humans do a better job of identifying and adjusting to inoperable TCDs, then NHTSA's numbers will underweight these accidents in the future state.

The University of Michigan's study might also provide more insights into this risk. Maintaining the roadways and the maps might decrease the amount of technology the vehicles require while also increasing their safety.

4.1d Summary of Technology Issues

If automated vehicle technology cannot overcome the weather, vehicle errors, and inoperable traffic control devices, it will only be able to address 78% of the accidents on the roads. While human error accounts for an even greater part of these remaining crashes, it means that the upper bound is limited to 78% accident reduction and not the 93% that is often stated. The difference between a 78% accident reduction and a 93% accident reduction is 830,000 accidents or $45 billion, using the Eno Center for Transportation's accident and cost estimates.[2]

Note: the total does not match the sum of the pieces. This is because the same accident could have more than one disqualifying identifier on it. An accident that occurs in inoperable weather and has a vehicle issue present will be counted in each variable's numbers, but, as it is a single accident, it will only be counted once when it is rolled up to "Total AV Inoperable Accidents."

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[2] Eno Center assumes 5.5 million crashes per year with an average economic cost of $55K per crash.

Disabling Factor	UnWtd Freq	Wtd Freq	UnWtd Freq	Wtd Freq
Inoperable Weather	602	267,657	11.0%	12.2%
Vehicle Issue Present	681	254,948	12.4%	11.6%
TCD Not Operating Properly	22	7,933	0.4%	0.4%
AV Inoperable Accidents	**1,183**	**466,269**	**21.6%**	**21.3%**
All Accidents*	**5,470**	**2,188,970**	*100%*	*100%*

*Removing the accidents where Vehicle Issues and TCD Operability are unknown decreases the subset of accidents from 5,470 to 5,031. It also decreases the UnWtd (unweighted) Frequency of Inoperable Weather accidents to 543 and TCDs to 20. AVs are inoperable in 1,183 of UnWtd accidents or 22.1% of Wtd accidents.

4.2 Behavioral (Driver) Issues

Simply because the technology works does not mean it will be used or used effectively. Seat belts have not only been proven to reduce the risk of severe to fatal crashes by up to 50%, their use is also required by law in most states. In spite of seat belts' availability, safety, and legality, one in seven adults still refuses to buckle up.

While it is impossible to perfectly predict how people will react to and use automated vehicles, it is possible to identify risky scenarios and develop policies to minimize that risk. For example, automated vehicles that do not speed may not only encourage their drivers to disengage the system but may also be a risk to other drivers on the road (e.g., Chicago's highways, where the speed limit is 55mph but the average non-congestion speed is typically closer to 70 mph-80 mph). It remains to be seen how this may be addressed in practice: for example, via "automated vehicle only" lanes, allowing automated vehicles to speed, or removing the driver from the loop entirely (e.g., Google's new automated vehicle). Different solutions could be developed in different environments depending on the relative risks. For example, drivers may be less inclined to take control back from a law-abiding automated vehicle while in the city versus one that is on a highway.

While Google's approach appears to eliminate this risk by removing the driver from the equation, its solution does not prevent other automakers from producing a system that allows or requires the individual to maintain some control over the driving function. Using NHTSA's NMVCCS, we can identify scenarios where the driver's involvement may prevent the technology from eliminating the accident.

4.2a Aggressive Driving

With approximately 41 million people receiving speeding tickets each year, drivers regularly prioritize speed over safety. While a fleet of automated vehicles may create a more efficient transportation system, a law-abiding automated vehicle's restrictions may encourage the driver to take over in situations in which speed is the main concern.

The NMVCCS report breaks out accidents where aggressive driving was present and lists the reason for the aggressive driving. The reasons included the following: anger, frustration, always drive this way, other, in a hurry/late, fleeing, and racing. Of these, it seems plausible that drivers who were in a hurry, fleeing, or racing would not engage an automated vehicle that follows the speed limit. Drivers who "always drive this way" are also problematic, as they could believe that they will drive better than the technology or that their driving will lead to a better result. If it seems unlikely that anyone will believe that, remember that 64% of Americans believe they are "excellent" or "very good" drivers.

The 3.1% estimate below may be too conservative as some of the "other" aggressive driving actions could also lead a driver to disengage the system. Removing these 808 accidents from the subset slightly increases the estimate to 3.6%. While this may not seem like a large number, with 5.5 million crashes occurring each year, it represents approximately 170,000-200,000 accidents and $9.3 billion to $10.8 billion in economic costs, using the Eno Center's estimates.

Aggressive Driving Reason	**UnWtd Freq**	**Wtd Freq**	**UnWtd Freq**	**Wtd Freq**
Always drive this way	95	52,155	1.7%	2.4%
Racing	12	2,472	0.2%	0.1%
Fleeing	26	6,666	0.5%	0.3%
In a hurry	27	7,254	0.5%	0.3%
Total – Driver Disables*	**152**	**67,304**	**2.8%**	**3.1%**
All Accidents	**5,470**	**2,188,970**		

*Note, the total does not equal the sum of the pieces as more than one aggressive driving may be given per accident.

4.2b-f Driver Engagement Issues

In the event the technology follows NHTSA's levels of automation, from level 0 (no automation) to level 4 (fully autonomous car),[3] the driver will remain an integral part of the equation throughout much of its development. The driver could still be an integral piece to the driving solution in a level 4 vehicle if BMW's or Mercedes Benz's vision, which will always allow the individual take over the driving, is implemented. Therefore, having a sober and engaged driver who is able to take over control when needed remains an important piece to the accident reduction equation. The driver may not be able to perform this task if he has been drinking or was already distracted.

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[3] See Appendix A for a more detailed explanation of NHTSA's levels of automation.

4.2b Alcohol

Alcohol was found to be present in approximately 8% of all accidents. However, the risk increases dramatically at night, where it was present in approximately one out of five accidents. We have assumed that if alcohol wasn't tested for (an unknown accident) then it wasn't involved. Therefore, we group these accidents with the "no alcohol" accidents.

Alcohol Present	Unwtd Freq	Wtd Freq	Unwtd	Wtd Freq
No/Unknown	5,115	2,016,577	93.5%	92.1%
Yes	355	172,393	6.5%	7.9%
Grand Total	**5,470**	**2,188,970**	**100%**	**100%**

Partially automated vehicles may decrease the risk of drunk drivers by transferring some of the driving responsibility from the impaired driver to the unimpaired system. However, it may also increase the risk in two key ways. First, it may increase the pass-off risk of a partially automated vehicle. An inebriated driver may not be as capable of taking over the driving task as a sober person. Second, it may increase the incidence of alcohol in the driver's seat. An individual may be less likely to have a designated driver or call a cab if he believes he will not have to drive the automated vehicle. While this may decrease the accident frequency of each drinking and driving occurrence, it may expand the subset of inebriated drivers on the road.

The chart below shows how much the presence of alcohol changes based on the time of day. The large discrepancy between alcohol presence in daytime accidents and nighttime accidents calls into question extrapolating our results to accidents occurring between 12:00 a.m. - 5:59 a.m., which are not included in the NMVCCS dataset, as noted above.

Day/Time	Alcohol present	Unwtd Freq	Wtd Freq	Unwtd	Wtd Freq
Daytime	no/unknown	3,394	1,301,946	97%	97%
	Yes	95	44,723	3%	3%
Weekday Night*	no/unknown	557	237,227	82%	79%
	Yes	120	61,253	18%	21%
Weekend Day	no/unknown	1,059	426,213	90%	88%
	Yes	113	56,011	10%	12%
Weekend Night**	no/unknown	105	51,191	80%	83%
	Yes	27	10,405	20%	17%
Grand Total		**5,470**	**2,188,970**		

***Weekday night: 6:30 p.m. – 11:59 p.m.**
**Weekend night: 9:00 p.m. – 11:59 p.m.

4.2c Illicit drugs

In addition to alcohol, NHTSA tracked if the driver had taken any other drugs. The types of drugs ranged from ones as innocuous as Lipitor to illegal drugs like cocaine. For a number of legal drugs, like Nyquil, it is recommended not to drive while taking them. We have broken out the illegal drugs from the drugs that may cause drowsiness to estimate a range of impacts.

Drug Use	UnWtd Freq	Wtd Freq	UnWtd Freq	Wtd Freq
Illegal	103	45,132	1.9%	2.1%
Drowsy	78	44,788	1.4%	2.0%
Drowsy or Illegal	181	89,920	3.3%	4.1%
Alcohol or Illegal*	431	205,920	7.9%	9.4%
Alcohol, Illegal or Drowsy*	502	241,596	9.2%	11.0%
All Accidents	**5,470**	**2,188,970**	*100.0%*	*100.0%*

*The total won't equal the sum of the pieces as more than one drug may be present in each accident.

The following drugs were defined to be "drowsy" and "illegal."

Drowsy		
Amphetamine	Codeine	Opiate
Baclofen	Morphine	Oxycodone
Barbiturates	Nyquil	Percocet

Illegal	
Cocaine	Marijuana
Crack cocaine	PCP
Heroin	

4.2d Heart attack or other physical impairment of the ability to act

A driver who is suffering a heart attack or other physical impairment is similarly unable to take control of a partially automated vehicle. Observing that 2% of accidents are caused when some sort of physical impairment, such as a heart attack, inhibits the driver's ability to effectively control his vehicle may suggest some important risk management controls. Depending on the trip and the automated vehicle's response, the technology could produce either a better or worse result for the car's passenger. If the heart attack causes only a minor accident or forces the driver to pull off the road, having the driver in control may actually save his life. In these instances, the driver may get medical attention more quickly than if he were to continue all the way to his destination, assuming, of course, that his destination is not a hospital.

On the other hand, an automated vehicle will likely provide better protection to the other drivers. Additionally, if the driver's destination is close at hand, delivering the driver safely to his destination may allow for medical attention to be delivered in a much safer way than causing a minor accident or forcing the driver to pull over.

Critical Reason	Unwtd Freq	Wtd Freq	Unwtd Freq	Wtd Freq
Heart attack or other physical impairment	138	49,868	2.5%	2.3%
Other	5,332	2,139,101	97.5%	97.7%
Grand Total	**5,470**	**2,188,970**	**100%**	**100%**

4.2e Sleeping

A sleeping driver was the cause of almost 3% of the accidents studied. Disengaging the driver further may increase the frequency of this occurrence. Volvo's Driver Alert system could be used to minimize this risk, but only if the driver is given enough time to become alert and fully engaged.

Critical Reason	Unwtd Freq	Wtd Freq	Unwtd Freq	Wtd Freq
Sleeping, that is, actually asleep	159	62,974	2.9%	2.9%
Other	5,311	2,125,996	97.1%	97.1%
Grand Total	**5,470**	**2,188,970**	**100%**	**100%**

4.2f Driver distraction

The ability to divert your attention away from the task of driving to something more interesting or productive is one of automated vehicles' key attractions. However, it can also compound the driver inattention problem if the driver needs to become an active participant at random times through the vehicle's trip. Almost 17% of all accidents are caused by distractions or driver inattention. Removing the times when alcohol or illicit drugs are involved decreases this to 15.3% of all accidents. For partially automated vehicles, where the driver is required to remain part of the driving loop, these are the accidents where a successful pass-off is paramount to the technology's success.

Critical reason	Unwtd	Wtd	Unwtd Freq	Wtd Freq
External distraction	235	75,917	4.3%	3.5%
Inattention	217	73,059	4.0%	3.3%
Internal distraction	477	216,460	8.7%	9.9%
Total	**929**	**365,436**	**17.0%**	**16.7%**
Total Excluding Alcohol and Drugs	866	334,314	15.8%	15.3%
Total	**5,470**	**2,188,970**	**100%**	**100%**

Excluding alcohol and drugs from the subset of distracted drivers allows us to focus on its prevalence among sober individuals. Over 15% of accidents are caused by distraction even though the driver is not under any influence of alcohol or drugs.

4.2g Summary of Behavioral Issues

Initial research into today's technology supports the claim that continued technological advancements will reduce the impact of human error. The Highway Loss Data Institute (HLDI) found Volvo's autonomous braking system, City Safe, to reduce the accident risk and insurance claims by 20%.

However, there is a large difference between today's technology, which supports the driver and leaves the driver in full control of the vehicle, and Level 3 and Level 4 automated vehicles, which shift the burden of driving and decision making from the driver to the vehicle. Part of automated vehicles' potential value comes from their predictability. Vehicles are able to travel very closely together at high speeds, enabling them to increase highway capacity and fuel efficiency. However, the more involved the driver is, the less predictable the driving becomes. In our current environment, over 30% of accidents involve a behavioral characteristic that may cause the automated vehicle to be used incorrectly.

Disabling Factor	**UnWtd Freq**	**Wtd Freq**	**UnWtd Freq**	**Wtd Freq**
Driver disables*	152	67,304	2.8%	3.1%
Alcohol or Illicit Drugs	502	241,596	9.2%	11.0%
Heart Attack/Physical Impairment	138	49,868	2.5%	2.3%
Sleeping	159	62,974	2.9%	2.9%
Distraction	929	365,436	17.0%	16.7%
AV Usage Questioned**	**1,742**	**709,153**	**31.8%**	**32.4%**
All Accidents***	**5,470**	**2,188,970**	*100%*	*100%*

* Driver is in a hurry/late, fleeing, racing, or "always drives aggressively"
** The sum of the pieces won't equal the total as an accident could involve many of the risk characteristics.
***If we remove the accidents where the aggressive driving reason was unknown, the AV Usage Questioned Totals increase to 34.3% of accidents.

4.3 Overall Results

Contrary to statements such as those made in *The New York Times*, *Forbes*, *The Economist*, and even those made by professionals in front of the U.S. Senate and House, the NMVCCS's results do not conclusively determine the number of accidents automated vehicles will eliminate. The NMVCCS data can, however, provide insight into the risks this technology faces and hurdles that must be overcome before it can reach its full safety potential.

Restating the NVMCCS allows us to identify and quantify potential risks that could limit automated vehicles' benefits. Based on the new benchmark we conclude that:

- Technological advances are required to address 21.3% of accidents.
- Some issues, like inclement weather risk, will need to be measured and addressed on a local level.
- The driver remains a vital part of the accident-reduction equation.
- Success is not only dependent on the technology's operation but also on the circumstances surrounding its use. Driver behavioral issues may interfere with optimal implementation of the technology in over 30% of the accidents.

Category	Disabling Factor	UnWtd Freq	Wtd Freq	UnWtd Freq	Wtd Freq
Technology Issues	Inoperable Weather	602	267,657	11.0%	12.2%
	Vehicle Issue Present	681	254,948	12.4%	11.6%
	Inoperable Traffic Control Device	22	7,933	0.4%	0.4%
	Total Technology Issues	**1,183**	**466,269**	**21.6%**	**21.3%**
Behavioral (Driver) Issues	Driver Disables	152	67,304	2.8%	3.1%
	Alcohol/Illicit Drugs	502	241,596	9.2%	11.0%
	Physical Impairment (heart attack)	138	49,868	2.5%	2.3%
	Sleeping	159	62,974	2.9%	2.9%
	Distraction	929	365,436	17.0%	16.7%
	Total Usage Issues	**1,742**	**709,153**	**31.8%**	**32.4%**
	Total AV Issues	**2,644**	**1,070,757**	**48.3%**	**48.9%**
	Total Accidents	**5,470**	**2,188,970**	**100.0%**	**100.0%**

5. IMPLICATIONS FOR TESTING

The new baseline indicates that a more robust, transparent, and collaborative effort is needed to optimize automated vehicles' safety. The technology's safety depends not only on its engineering and coding but also consumers' use of it. Our work suggests two issues worthy of consideration with respect to test data collection.

More comprehensive collection of real-world test data: Some states[4] and the District of Columbia have already passed laws governing the testing of these vehicles on public roads. California's Department of Motor Vehicles requires testers to report all instances when the automated vehicle technology was disengaged.[5] In order to understand the technology's risks, the entire set of miles driven must be analyzed. More disengagements do not necessarily equate to a faultier product if Company XYZ is performing more tests or more difficult tests than Company ABC.

Limitations of simulator tests: Testing approaches that rely significantly on computer simulations involve a great deal of model risk, i.e., the risk that the test model does not accurately reflect reality. Over 30% of accidents involve a behavior risk that is very difficult to test in a simulator. An inebriated individual may react very differently in a simulator test than in real life. Testers are also unlikely to be in a hurry or race when using a computer simulation, while they may in real life. Removing responsibility from the driver altogether, as Google is doing, is one way to overcome this risk.

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[4] California, Florida, Michigan, and Nevada

[5] http://apps.dmv.ca.gov/about/lad/pdfs/auto_veh2/adopted_txt.pdf section 227.46

6. CONCLUSION

Automated vehicles have the potential to transform our world, making transportation safer, cheaper, quicker, and greener. The technology could also transform transportation risk by shifting the driving responsibility and decision making from the individual to the technology. This will reduce or eliminate some risks while others will be increased or introduced.

In order to properly assess the risk, accurate risk measures need to be established. While NHTSA's NMVCCS found that human error is the main cause for over 90% of accidents using current technology, automated vehicles have a significantly different risk profile. Inclement weather, technological errors, and infrastructure issues can reduce the technology's benefit. Risky driver behaviors may further deteriorate automated vehicles' safety. Understanding and quantifying these risks will allow all stakeholders to make better decisions.

The Casualty Actuarial Society's Automated Vehicles Task Force believes the best way to balance the competing aims of safety, cost, and innovation is through robust, transparent testing and the application of statistical analysis appropriate to the data. Actuarial insights can support all stakeholders in making decisions to help the technology reach its potential and ensure it is brought to market as safely and efficiently as possible.

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APPENDIX A—NHTSA'S LEVELS OF AUTOMATION[6]

Level 0—No Automation

The driver is in complete and sole control of the primary vehicle controls (brake, steering, throttle, and motive power) at all times, and is solely responsible for monitoring the roadway and for safe operation of all vehicle controls. Vehicles that have certain driver support/convenience systems but do not have control authority over steering, braking, or throttle would still be considered "level 0" vehicles. Examples include systems that provide only warnings (e.g., forward collision warning, lane departure warning, blind spot monitoring) as well as systems providing automated secondary controls such as wipers, headlights, turn signals, hazard lights, etc. Although a vehicle with V2V warning technology alone would be at this level, that technology could significantly augment, and could be necessary to fully implement, many of the technologies described below, and is capable of providing warnings in several scenarios where sensors and cameras cannot (e.g., vehicles approaching each other at intersections).

Level 1—Function-Specific Automation

Automation at this level involves one or more specific control functions; if multiple functions are automated, they operate independently from each other. The driver has overall control, and is solely responsible for safe operation, but can choose to cede limited authority over a primary control (as in adaptive cruise control), the vehicle can automatically assume limited authority over a primary control (as in electronic stability control), or the automated system can provide added control to aid the driver in certain normal driving or crash-imminent situations (e.g., dynamic brake support in emergencies). The vehicle may have multiple capabilities combining individual driver support and crash avoidance technologies, but does not replace driver vigilance and does not assume driving responsibility from the driver. The vehicle's automated system may assist or augment the driver in operating one of the primary controls—either steering or braking/throttle controls (but not both). As a result, there is no combination of vehicle control systems working in unison that enables the driver to be disengaged from physically operating the vehicle by having his or her hands off the steering wheel AND feet off the pedals at the same time. Examples of function-specific automation systems include cruise control, automatic braking, and lane keeping.

Level 2—Combined Function Automation

This level involves automation of at least two primary control functions designed to work in unison to relieve the driver of control of those functions. Vehicles at this level of automation can

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[6] http://www.nhtsa.gov/About+NHTSA/Press+Releases/U.S.+Department+of+Transportation+Releases+Policy+on+Automated+Vehicle+Development

utilize shared authority when the driver cedes active primary control in certain limited driving situations. The driver is still responsible for monitoring the roadway and safe operation and is expected to be available for control at all times and on short notice. The system can relinquish control with no advance warning and the driver must be ready to control the vehicle safely. An example of combined functions enabling a Level 2 system is adaptive cruise control in combination with lane centering. The major distinction between Level 1 and Level 2 is that, at Level 2 in the specific operating conditions for which the system is designed, an automated operating mode is enabled such that the driver is disengaged from physically operating the vehicle by having his or her hands off the steering wheel AND foot off pedal at the same time.

Level 3—Limited Self-Driving Automation

Vehicles at this level of automation enable the driver to cede full control of all safety-critical functions under certain traffic or environmental conditions and in those conditions to rely heavily on the vehicle to monitor for changes in those conditions requiring transition back to driver control. The driver is expected to be available for occasional control, but with sufficiently comfortable transition time. The vehicle is designed to ensure safe operation during the automated driving mode. An example would be an automated or self-driving car that can determine when the system is no longer able to support automation, such as from an oncoming construction area, and then signals to the driver to reengage in the driving task, providing the driver with an appropriate amount of transition time to safely regain manual control. The major distinction between Level 2 and Level 3 is that at Level 3, the vehicle is designed so that the driver is not expected to constantly monitor the roadway while driving.

Level 4—Full Self-Driving Automation

The vehicle is designed to perform all safety-critical driving functions and monitor roadway conditions for an entire trip. Such a design anticipates that the driver will provide destination or navigation input, but is not expected to be available for control at any time during the trip. This includes both occupied and unoccupied vehicles. By design, safe operation rests solely on the automated vehicle system.