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The Potential Environmental and Social Impacts of Autonomous Trucking

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1. Introduction

There has been a notable volume of recent discussion and anticipation in the autonomous trucking industry about the potential for this technology to have direct positive effects in both environmental and social contexts. This document outlines our current understanding of these impacts and is meant to be a forward-looking aid to investors, customers, and others interested in this technology.

TuSimple's mission is to make long-haul trucking significantly safer as well as more reliable, efficient, and environmentally friendly, creating significant benefits for all who rely on the freight system to deliver essential goods.

We have engaged various partners to collaborate on our mission, including studies completed with the University of California San Diego, UPS North America Air Freight, Geotab, and Smartway. This has uncovered benefits ranging from increased fuel efficiency, reduced greenhouse gas emissions, and fewer hours spent by truckers on driving empty miles and idling in the cabs.

We believe our SAE Level 4 autonomous trucks will not only make the roads safer for all, but will also make meaningful contributions toward the trucking industry's environmental and social impact.

2. Environmental Impact

A. Powertrains, Fuel, and Emissions

An Introduction to the Truck Powertrain

The powertrain of a class-8 semi-truck contains the engine and drivetrain. As of Spring 2022, most semi-trucks are powered by internal combustion engines (ICEs), electric motors, or a combination of the two. In turn, internal combustion engines are powered by the combustion of fuels. Trucks with internal combustion engines are typically fueled by either gasoline or diesel.

The Environmental Cost of a Powertrain

The U.S. Environmental Protection Agency (EPA) reported in 2019[1] that medium and heavy duty trucks contribute 24% of annual U.S. transportation greenhouse gas emissions. The main contributor to a truck's GHG emissions is its powertrain.

The major greenhouse gases are carbon dioxide (CO_2), nitrous oxides (NO_x), and particulate matter (PM). While both CO_2 and NO_x are key contributors to global warming, PM is not a direct contributor, but causes several problems with adverse health-related effects, such as water pollution and haze.

The composition of these GHGs differs between gasoline and diesel. Diesel engines tend to emit less CO_2, but more NO_x and PM, than gasoline engines do.

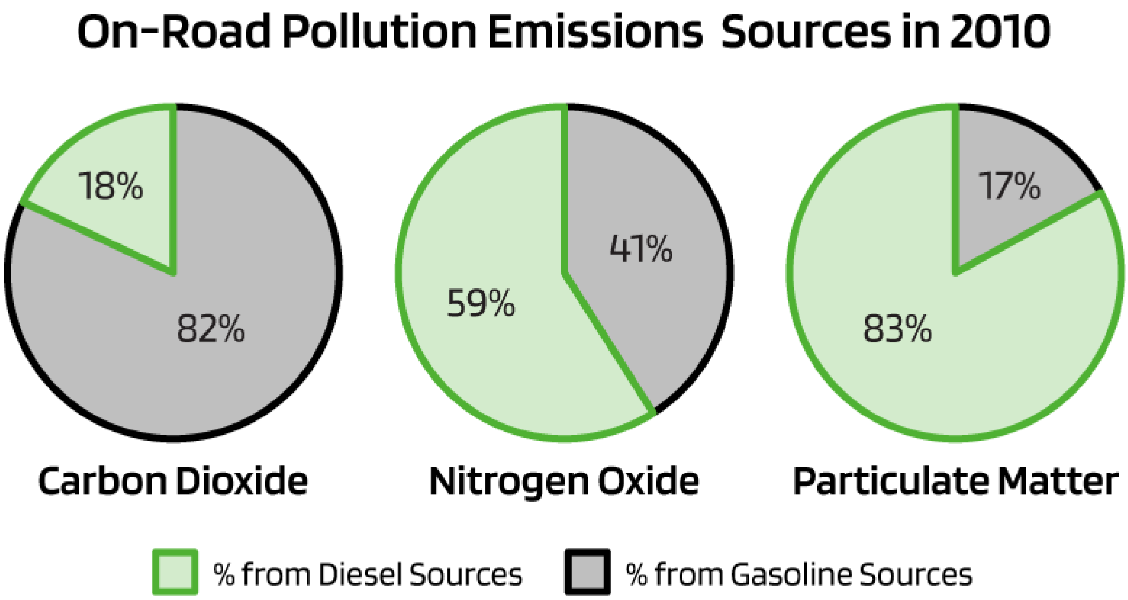

Figure 1: On-road pollution emissions from gasoline and diesel sources in 2010 (Access Magazine[2])

Regulating Emissions, Internal Combustion Engines (ICEs), and Fuel Economy

Regulations on GHG emissions vary across each greenhouse gas as well as across countries.

Carbon Dioxide (CO_2)

- Europe leads the way as average CO_2 emissions from fleet-wide new passenger cars and vans registered in the EU will have to be 37.5%[3] lower in 2030 (95 g CO_2/mi or 59 g CO_2/km), compared to the limits in 2021 (153 g CO_2/mi or 95 g CO_2/km). For new vans specifically, the reduction target would be 31% by 2030 (compared to 237 g CO_2/mi or 147 g CO_2/km in 2021)
- China's regulation targets are set at 118 g CO_2/mi (or 117 g CO_2/km[4]) in 2020 and 150 g CO_2/mi or 93 g CO_2/km by 2030, and
- North America's current fuel economy targets are set at over 50 mpg[5] following passenger-vehicle Corporate Average Fuel Economy (CAFE) standards (159 g CO_2/mi or 99 g CO_2/km) for 2025

In the U.S., the Environmental Protection Agency (EPA), the National Highway Traffic Safety Administration (NHTSA), and the California Air Resources Board (CARB) are responsible for setting federal and state standards for vehicle emissions and fuel economy.

The EPA has rolled out CO_2 emissions standards in two phases that specifically impact medium- and heavy-duty trucks. Figure 2 illustrates how Phase 2 standards for CO_2 emissions will change between 2021 and 2027, measured per ton mile. A "ton mile" represents one ton of freight being transported one mile.

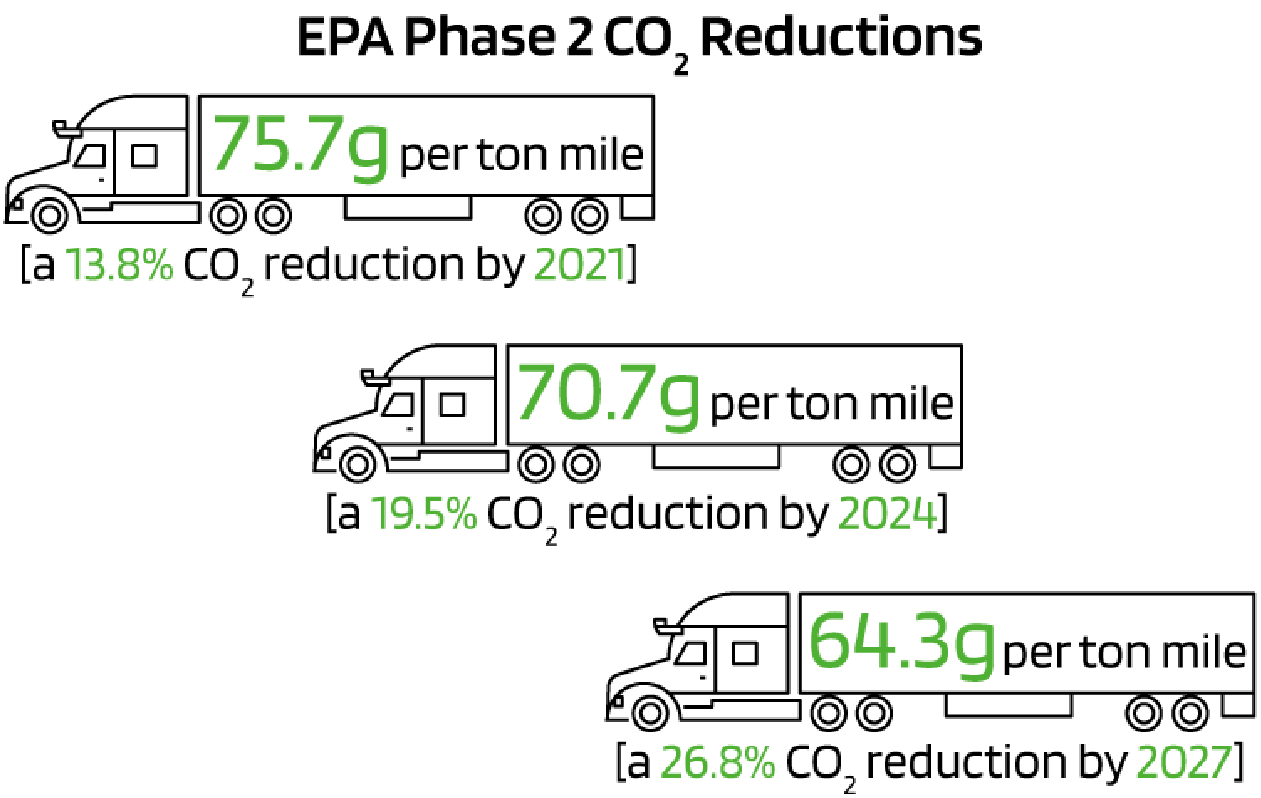

Figure 2: EPA phase 2 CO_2 reductions (Eaton[6])

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Overview of Scope 1, 2, and 3 Emissions

The EPA tracks and works to reduce three types of GHG emissions.

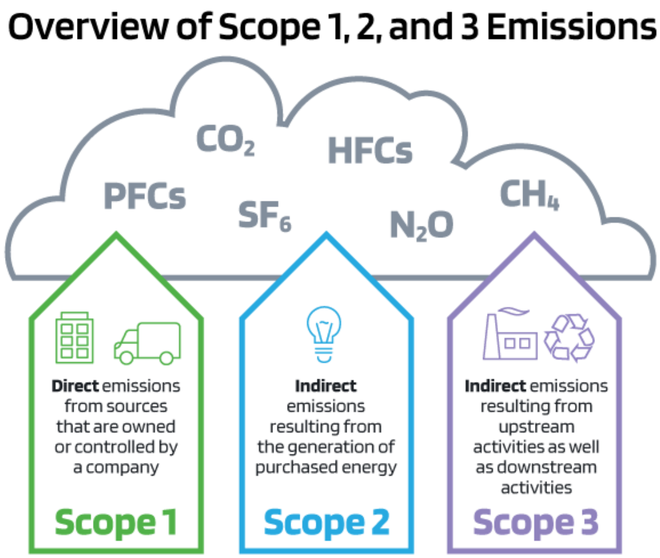

Figure 3: Overview of scope 1, 2, and 3 emissions, (Walmart's Project Gigaton[7])

- **Scope 1: Emissions are direct emissions from sources that are owned or controlled by a company** such as factories, office buildings, and company-owned fleet vehicles
- **Scope 2: Emissions are indirect emissions resulting from the generation of purchased energy**, primarily electricity
- **Scope 3: Emissions are indirect emissions resulting from upstream activities** such as production of goods and services purchased by the company, **as well as downstream activities** such as consumer use and disposal of products sold by the company

Nitrous Oxides (NO_x)

The EPA launched the Cleaner Trucks Initiative in 2018 to update NO_x emissions standards for heavy-duty trucks. On August 5, 2021, EPA announced a series of rulemakings to be rolled out over the next three years. The first rulemaking, to be finalized in 2022, will apply to heavy-duty vehicles starting in model year 2027. The CARB is working in parallel to reduce NO_x emissions per ton mile to 0.05g, or 75%, by 2024 and to 0.02g, or 90%, by 2027.

Particulate Matter (PM)
The EPA has established National Ambient Air Quality Standards to regulate particulate pollution by all vehicles, including heavy-duty trucks, and retain primary standards to protect public health, and secondary standards to protect public welfare.

Primary standards differ for fine particles and coarse particles, measured by micrograms per cubic unit of air (μg/m^3), as seen in Figure 4:

EPA Particulate Matter Standards

	Primary Standards		Secondary Standards	
Pollutant	**Level**	**Averaging Time**	**Level**	**Averaging Time**
Particulate Matter, PM_{10} (Coarse)	150 μg/m^3	24-hour	150 μg/m^3	24-hour
Particulate Matter, $PM_{2.5}$ (Fine)	12 μg/m^3	Annual	15 μg/m^3	Annual
	35 μg/m^3	24-hour	35 μg/m^3	24-hour

Figure 4: Particulate matter standards (EPA[8])

Fuel Economy
In 2015, EPA and NHTSA announced proposed rules for the second phase of fuel economy standards for medium and heavy-duty vehicles, including semi-trucks.

Phase 2 standards call for an 8-24%[9] increase in fuel efficiency, depending on the vehicle's size and purpose, between the years 2018 and 2027.

How TuSimple Can Make a Difference

Reducing GHG Emissions

Autonomous trucks can reduce GHG emissions -- more specifically, Scope 1 GHG emissions -- by increasing asset utilization. This should reduce emissions produced by deadhead and idling. Subsequent sections go into detail about how our technologies are designed to enable these emissions reductions.

Besides using our technologies to tackle the emissions associated with driving trucks across the country, TuSimple has also demonstrated our commitment to this cause by becoming the first autonomous trucking company to be recognized as a SmartWay Certified Carrier[10].

SmartWay is a voluntary public-private program run by EPA that helps the freight transportation sector improve supply chain efficiency and reduce transportation-related emissions. In 2021, we received the EPA's SmartWay High Performer award. This award recognizes the top 10%[11] of lowest CO_2 emitting fleets participating in the program.

Extending the Life and Fuel Economy of a Powertrain

In an autonomous vehicle, the powertrain should be subject to less aggressive driving[12] such as harsh acceleration, braking and cornering. Autonomy should improve general driving performance including benefits from a reduction of these less safe and inefficient performance behaviors. This will likely reduce wear and tear extending the lifetime of the engine, drivetrain, and its associated components, resulting in maintenance cost savings for carriers.

In an autonomous vehicle, the deployment of vehicle control methods, such as eco-drive, is more efficient. This changes the powertrain operation in response to driving conditions leading to better fuel economy. A 2018 study[13] by Hitachi Automotive systems found a 9% improvement in fuel economy associated with an autonomous vehicle traveling at an average speed of 60 mph, as compared to a vehicle operating under conventional adaptive cruise control. This could translate into annual fuel cost savings[14] of close to $3,760 per truck.

By testing our autonomous driving system over 160,000 miles in real-world conditions[15] for the UPS North American Air Freight Services, we have been able to exceed the already substantial fuel savings data observed in the study[16] conducted by the University of California San Diego.

As a result of our testing with UPS North American Air Freight, our TuSimple autonomous driving system delivered over 13% fuel savings compared to human drivers when operated in the optimal long-haul operating band from 55 to 68 miles per hour.

Looking Toward the Long Term

While autonomous driving technology can optimize the performance of existing powertrains, carriers will need to look toward the evolution of powertrains in order to attain long-term environmental sustainability. The key lies in striking a balance between driving distances, infrastructure, emissions, and fuel economy.

Natural gas has been touted as an alternative semi-truck fuel source to diesel, with some players[17] in the autonomous truck industry already embarking on a mission to develop driver-in, supervised autonomous trucks powered by natural gas. At TuSimple, we view natural gas as an interim solution, utilizing a fuel with less emissions as a step in the evolution to full electric vehicles. Considering it as a temporary solution, it's important to note that while natural gas does reduce GHG emissions, it also reduces the driving range of a vehicle[18] due to the lower energy density of natural gas -- not ideal for trucks that need to traverse long distances daily. More importantly, they retain the use of ICEs, which is at odds with regulatory developments that have begun to impact the mobility industry.

Several countries have already announced dates for the phase-out of ICEs in vehicles.

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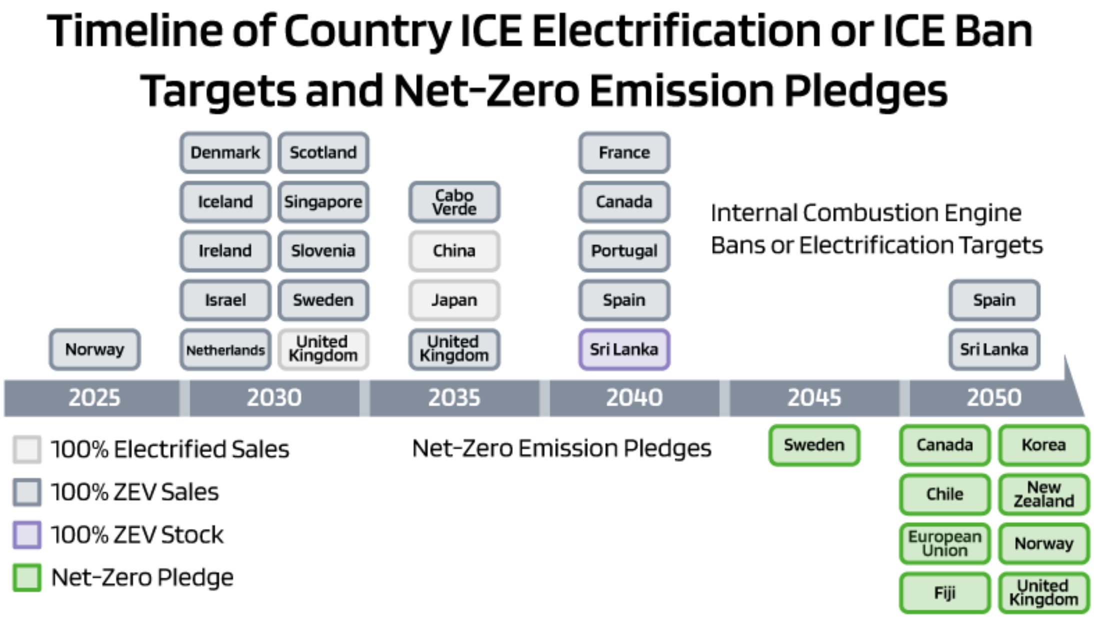

Figure 5: Timeline of country ICE electrification or ICE ban targets and net-zero emission pledges (IEA[19])

California is the only U.S. state to have declared a definitive requirement[20] for truck manufacturers to sell clean, zero-emission trucks in the state—from 5% of Class 7/8 tractors in 2024 to 40% by 2035.

The latest focus in the overall mobility space is the electrification of the powertrain. Hybrid powertrains in long-haul combination trucks represent an attractive step toward electrification and are estimated[21] to provide up to $3,900 fuel savings and cut GHG emissions by 13 metric tons per truck, per year. They combine an internal combustion engine with one or more electric motors powered by batteries. Fully electric powertrains replace the ICEs altogether.

B. Tires

An Introduction to Commercial Tires

Tires make up approximately 3%[22] of a truck's annual per-mile expenses. They have an average lifespan of 6 to 10 years[23], and are typically retreaded until they can no longer be used. While the number of heavy truck tires headed for scrap has come down in recent years, it still stands at about 6% of all scrap tires[24], or 18.9 million tires per year.

A typical tire[25] is made up of natural rubber, synthetic rubber, carbon black filler, and other functional agents. It is estimated that anywhere from 4 to 10 gallons (or 15 to 38 liters[26]) of petroleum are required to produce a standard tire. For the 18.9 million tires[27] that are scrapped a year, this means that approximately 74.9 to 189.7 million gallons of petroleum are being put to waste each year.

What's more important, however, is the environmental impact of tires -- not only from using a fossil fuel such as petroleum during their production, but also in the emissions and waste produced as part of tire wear and tear during and after use.

The Environmental Costs of a Tire

The environmental impact of a tire resonates through the supply chain from the production of its raw materials, use, and end of life. These environmental impacts have repercussions to our air, ocean, and land.

Air - The production of tire raw materials currently generates[28] four times as much CO_2 emissions per tire than the manufacturing process of the tire itself. During on-road vehicle usage, tires also produce Non-Exhaust Emissions (NEE). This is air pollution due to particles released from brake wear, tire wear, road surface wear and resuspension of road dust while driving.

Between 3 and 7%[29] of fine particulate matter ($PM_{2.5}$) in the air is estimated to have come from tire wear and tear. This effect is exacerbated in non-urban areas, where freeways tend to be located.

In cities, buildings act as wind barricades and cars drive more slowly, but in rural areas, higher speeds and more wind allow particles to get kicked up more easily. In the United States, that effect is exaggerated in dry Western states[30], as compared to the more humid Southern states.

Ocean - Tire wear and tear also releases microparticles and chemicals into the ecosystem. Tires contribute 5-10%[31] to the total global amount of microplastics ending up in our oceans. When these microparticles and chemicals make it into rivers or oceans, they can have adverse and even fatal effects on aquatic and marine life.

6PPD is a chemical used in tires to prevent them from breaking down too quickly. 6PPD creates a byproduct called 6PPD-quinone which has been identified as the cause of coho salmon deaths[32] in freshwater streams in Puget Sound, Washington and has been detected in roadway runoff from Los Angeles and urban creeks near San Francisco.

Land - Around 18.9 million commercial tires from heavy-duty trucks were scrapped in 2019. Once a tire has surpassed its useful life, it can be disposed of in sustainable ways. They can be converted into fuel and or used in reclamation projects. Despite this, inefficient end of life and recycling programs result in 25% of those scrap tires ending up stockpiled in landfills[33]. This continues the downstream environmental impact of tires. Stockpiled scrap tires can leach toxins into the soil continuously during the 50-to-80-year decomposition cycle[34]. Though many states throughout the country had fewer than one million tires stockpiled (Figure 6), Arizona, New Mexico, Colorado and Texas each had an estimated one million to twenty million tires stockpiled in landfills in 2020.

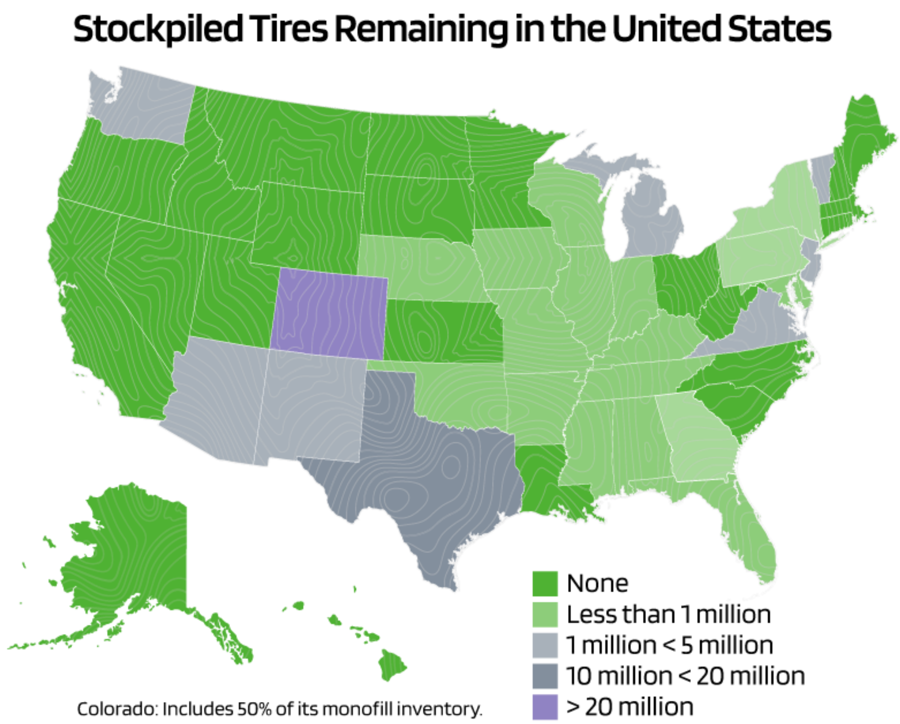

Figure 6: Stockpiled tires remaining in the U.S. (U.S. Tire Manufacturers Association[35] 2020)

How TuSimple Can Make a Difference

Two of the biggest benefits of autonomous trucks are the autonomous driving system's ability to conduct trip planning and eliminate unnecessary driving and the reduction in unnecessary maneuvers such as lane changing and braking. Fewer unnecessary driving and steering maneuvers means less wear and tear on tires, which will reduce the release of NEE and microplastics into the atmosphere and waters and the general rate of tire replacement. Lowering the rate of tire replacement could slow down the rate of tire scrap reducing soil pollution. This should minimize health-related risks that tire wear and tear and disposed tires can cause to humans and our ecosystem. To quantify this and work to maximize the benefits of autonomous trucks on tires, we are currently planning to conduct a tire wear study in partnership with Goodyear.

Besides the numerous environmental benefits, less tire wear should lower tire maintenance costs, decrease the rate of tire replacement, and improve safety. Between 2016 and 2018, approximately 0.3-0.4% of fatal crashes involving trucks were attributed to truck tire-related issues[36], such as tire blowout. Tire blowout is primarily caused by overworn tires. Given the increased and more comprehensive pre-trip and post-trip inspections, we believe tires are less likely to be left overworn on autonomous trucks.

C. Speed and Driving Behavior Monitoring

An Introduction to Speed and Driving Behavior Monitoring

In 2018, 32.3% of fatal crashes involving large trucks (trucks over 10,000 lbs gross vehicle weight rating[37]), recorded at least one driver-related factor. 6.8% of these incidents were due to speeding[38].

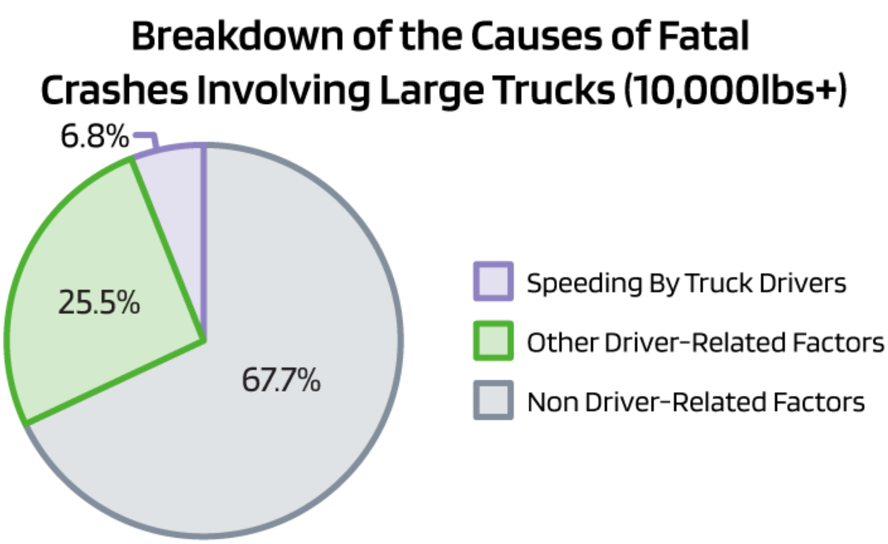

Figure 7: Breakdown of fatal crashes by driver vs. non driver-related factors.
Non driver-related factors include other parties and vehicle-related factors (US DOT[39])

In 2019, the Senate introduced a bill[40] requiring all new commercial motor vehicles weighing 26,001 pounds or more to be equipped with speed-limiting devices set to a maximum of 65 mph. As of May 2021, the bill has been re-introduced in the U.S. House of Representatives; it also includes a provision[41] for the limit to go up to 70 mph if certain safety technologies, such as an adaptive cruise control system and an automatic emergency braking system, are in use.

However, it is key to note that speed limiting devices are not the same as speed monitoring. These devices cannot eliminate unnecessary increases or decreases in speed below the given speed limit. On the other hand, speed monitoring devices can help reduce the number of "driver events" such as harsh braking, accelerating, or cornering. Harsh acceleration and harsh braking occur when more force than normal or necessary is applied to the vehicle's accelerator or braking system to adjust the speed of the vehicle. Harsh cornering takes place when a driver takes a turn or curves too fast, putting top-heavy vehicles at risk of overturning[42]. These actions can increase the risk of accident or injury to fleet drivers and others sharing the road.

The Environmental Cost of Speeding and Harsh Driving

Aggressive driving at highway speeds can impact fuel economy by as much as 20%[43]. Aggressive driving can also[44] increase maintenance, replacement, and repair costs as it increases vehicle wear and tear, decreases the lifespan of the brakes and wears out the brake pads, places more pressure on the ball joints, suspension, wheel bearings and more.

Harsh braking can also have adverse environmental effects. When braking, some of the worn materials deposited on roadways become airborne as PM. Scientific Reports' research[45] has shown that 20% to 50% of worn material during braking become airborne particles in road transport. Friction materials on brake pads are also non-degradable and currently disposed of in landfills and through combustion, leading to additional CO_2 emissions.

How TuSimple Can Make a Difference

Speeding and the three types of harsh driving events are typically classified as "driver events," because they are initiated by the driver at the wheel. The key difference between autonomous trucks and conventional ones is that the former do not have a human at the wheel, and thus are not prone to these "driver events."

A 55-60% reduction in unsafe events, including harsh braking and acceleration, by drivers of sleeper cabs (i.e. long-haul drivers) has been shown to lead to a 5.4% gain in fuel economy[46]. Figure 8 shows the results of a joint study between TuSimple and Geotab that has already uncovered substantial improvements in harsh braking, harsh acceleration, and harsh cornering by autonomous trucks, as compared to manually-driven trucks.

TuSimple's trucks achieve these improvements through their autonomous driving technology which includes perception, motion planning, control, and mapping. These components leverage data and information from TuSimple's proprietary sensor system that includes cameras, LiDARs, RADARs, and ultrasonic sensors.

Trucking Performance on Harsh Events

Number of Events per 10,000 Miles

Event Type	TuSimple Autonomous Technlogy	Industry Human-Operated Driving
Harsh Braking[1]	0 - 2	8 - 10
Harsh Acceleration[2]	11 - 16	99 - 106
Harsh Cornering[3]	4 - 10	118 - 189

[1] Harsh Braking occurs when a driver uses more force than necessary to control the vehicle. The presence of harsh braking often indicates aggressive or distracted driving that can lead to costly accidents, as well as increased maintenance issues.

[2] Harsh Acceleration is defined as acceleration greater than $3.35 m/s^2$ in the forward direction. In the vehicle, the driver would feel like they were pushed back in the seat and the load of the vehicle would shift to the rear.

[3] Harsh Cornering is an event that exceeds certain values of Geolab's GO device's accelerometer, specifically side-to-side values (G-Force). This action increases the amount of force on the vehicle, putting top-heavy vehicles at risk of overturning.

Figure 8: Comparison of how TuSimple trucks perform on harsh events against manually driven trucks' performance, Geotab and TuSimple (2021)

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D. Idling

An Introduction to Idling

Idling refers to the continuous operation of a truck's main propulsion engine while the truck is parked and not in active service. Many truckers idle their engines overnight for heating, cooling, and electricity for appliances[47]. This can have several negative impacts on the environment such as heightened diesel fuel consumption which leads to higher emissions of CO_2 and other diesel pollutants.

A survey conducted by the American Transportation Research Institute (ATRI) found[48] that sleeper cabs (long-haul trucks) and day cabs (short-haul trucks) idled an average of 28 hours and 6 hours a week, respectively. Within the 28 hours spent idling by sleeper cabs, the chart below shows the breakdown by location. This idling time includes activities such as cooling and heating the cab, warming the engine, powering in-cab appliances, etc.

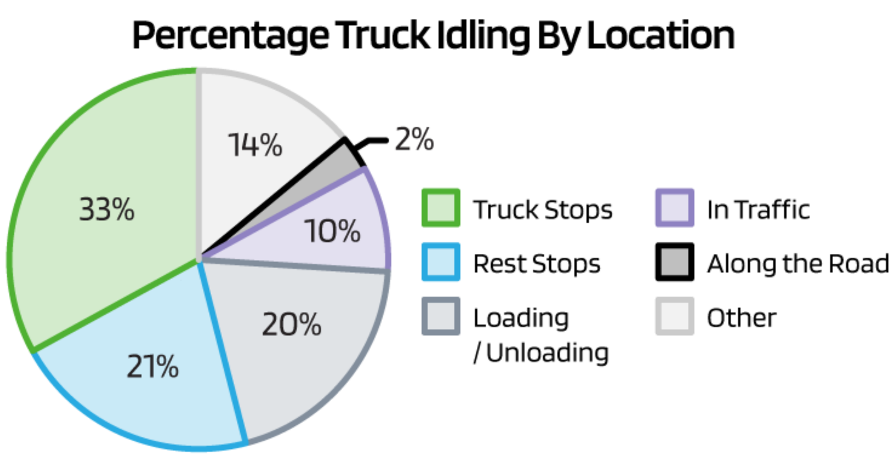

Figure 9: Percentage of truck idling by location (The American Transportation Research Institute[49])

The Financial and Environmental Cost of Idling

A heavy-duty truck consumes about 0.8 gallons of fuel per hour[50] that is spent idling. At an average fuel cost of $3/gallon, fuel for a 10-hour rest period will cost $24. On an annual basis, a truck idles about 1,800 hours a year, using ~1,500 gallons of diesel which leads to $4,500 of annual diesel fuel costs.

The North American Council for Freight Efficiency (NACFE), in their idle reduction confidence report[51], found that a 10% annual reduction in idling equals 1% fuel economy benefit which translates to a $500 to $700 annual savings assuming $3/gallon fuel prices and 100,000 miles/year. The American Trucking Associations estimated that idling doubles the wear and tear on engine parts versus normal driving and adds $2,000 in costs per truck annually[52].

In addition to the financial costs, idling also presents environmental costs. Heavy-duty vehicles account for 20%[53] of transportation-sector GHG emissions in the United States. Carbon monoxide emissions are highest in idle, low speed, and cold start conditions[54]. These conditions also contribute to emissions of other gases such as NO_x, total hydrocarbons (THC), and PM[55] (Figure 10). The Argonne National Laboratory estimates[56] that idling results in the emissions of about 11 million tons of CO_2, 55,000 tons of NO_x, and 400 tons of PM in the U.S.

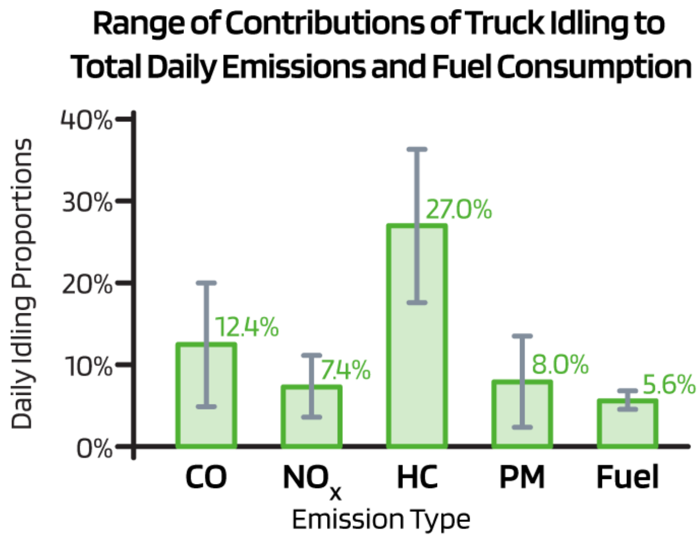

Figure 10: Range of contributions of truck idling to total daily emissions and fuel consumption for a truck idling for 8 hours a day. Error bars represent the average value ± one standard deviation. (DieselNet Technology Guide[57])

These emissions contribute to climate change and diminish local air quality, which affects the health of drivers and their communities. Idling emissions can contribute to[58] premature mortality, bronchitis, hospital admissions, respiratory symptoms, asthma attacks, work loss days, and minor restricted activity days. For more detail, refer to the Public Health section of this report.

How TuSimple Can Make a Difference

Up to 54% of idling by heavy-duty trucks could be eliminated through self-driving capabilities, as autonomous trucks will not idle at truck stops and rest stops[59]. This has the potential to reduce a large source of emissions and unlock cost savings for trucking companies.

In addition to increasing a fleet's capacity utilization and decreasing trip times, self-driving trucks can help fleets reduce their carbon footprint. The NACFE found[60] that a 10% annual reduction in idling equals 1% improvement in fuel economy. Given this metric, and the above metric that an estimated 54% of idling occurs at truck stops and rest stops, locations where autonomous trucks should not stop at, TuSimple's autonomous trucks can potentially result in ~5% improvement in fuel economy by reducing idling alone. Fleet owners can then drive incremental savings from reduced idling-related fuel costs.

E. Deadhead

An Introduction to Deadhead

Deadhead miles, or "backhaul," are empty miles that are driven without a load. These typically occur when there are no nearby loads that are headed in the same direction as the driver.

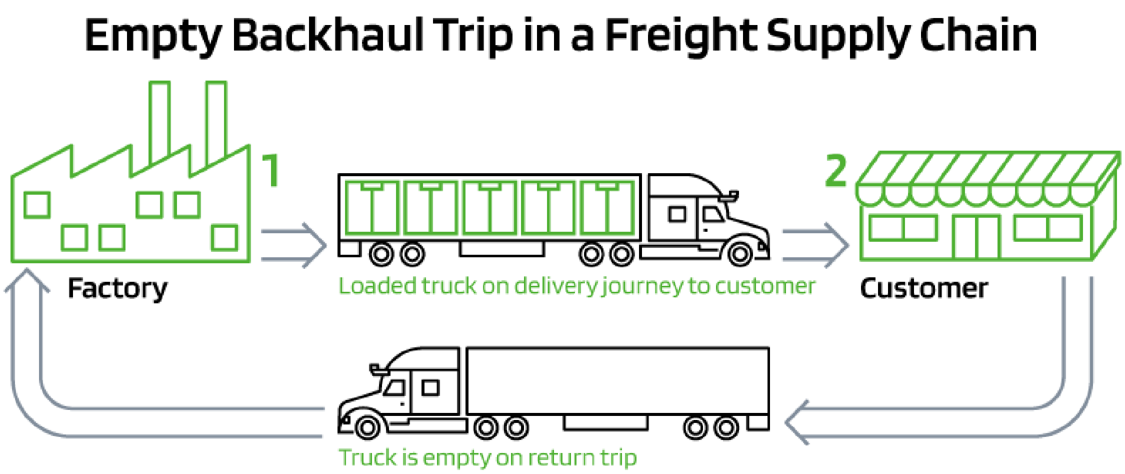

Figure 11: Empty backhaul trip in a freight supply chain

The American Transportation Research Institute[61] found that in 2019, approximately 20.1% of miles travelled by non-private fleets were considered backhaul, whereas the National Private Truck Council[62] has reported up to 28% for private fleets.

Deadhead miles also occur when carriers would rather do an empty backhaul trip than take on a cheap load. Most importantly, for manually driven trucks, it arises because drivers need to return to their point of origin.

The Environmental Cost of Deadhead

Environmental costs associated with backhaul are essentially the same as those incurred by the regular driving of heavy-duty trucks -- GHG emissions, fuel consumption, truck wear and tear -- but are exacerbated because they are incurred despite a lack of associated economic activity.

Heavy-duty full truckload freight accounts[63] for more than 205 million metric tons of CO_2 emissions per year. This includes 72 million metric tons of CO_2-equivalent emissions resulting from empty miles. By the EPA's estimates[64], 20,000 empty miles per year consumes an equivalent of 750 gallons of diesel fuel.

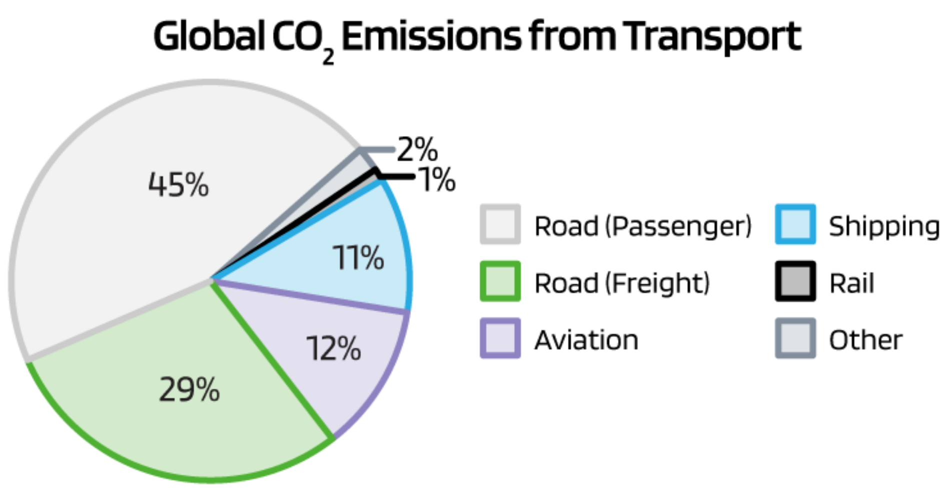

Figure 12: Global CO_2 emissions from transport (Our World in Data[65])

In earlier sections, we addressed the issues of truck wear and tear, namely in the powertrain and tires. As is the case with other vehicles, truck vehicle miles traveled (VMT) also contribute to the deterioration of highways, which requires regular maintenance to ensure that driving conditions remain safe for all drivers.

How TuSimple Can Make a Difference

Autonomous trucks will not completely eliminate deadhead miles, but they can accelerate the realization of benefits associated with load matching practices. This can be done by eliminating the need to return a driver to their point-of-origin, as an autonomous truck can be redirected to pick up its next load immediately, instead of driving non-revenue generating miles when a driver heads back to their point-of-origin.

This should, in turn, lead to a reduction in empty miles driven, increased asset utilization, and improved driver well-being as they should spend fewer hours on the roads away from their homes and families.

The EPA estimates[66] that a trucking fleet that optimizes their logistics by practices such as load matching as well as optimizing routes and delivery schedule can see a reduction in unnecessary truck trips and a reduction in fuel consumption by about 4.5%, resulting in 7.6 metric tons of CO_2 saved per truck.

Bundling shipments that would have been handled by multiple drivers into a job for a single driver has the potential to reduce empty miles from the industry standard of 35% to 19%. If the trucking industry as a whole can achieve the same efficiency improvements, it would reduce CO_2 emissions by 32 million metric tons[67].

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3. Social Impact

F. Safety

Scope of the Problem

Fatal Crashes: In 2018, 32.3% of fatal crashes involving large trucks (trucks over 10,000 lbs gross vehicle weight rating[68]), recorded at least one driver-related factor. Of these crashes[69], 5.3% were due to driver distraction, 4.4% due to driver impairment and 6.8% due to speeding. The leading driver distraction-related factor was inattentive driver behavior, and the leading driver impairment-related factor was found to be driver impairment from being under the influence of alcohol, drugs, or medications, followed by driver fatigue and sleep deprivation.

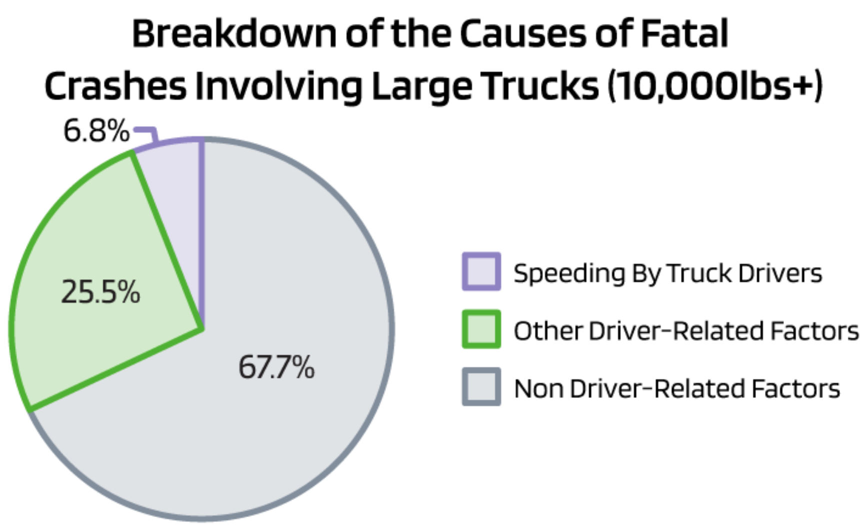

Figure 13: Breakdown of fatal crashes by driver vs. non driver-related factors. Non driver-related factors include other parties and vehicle-related factors (US DOT[70])

Driver Events: In addition to the extreme case of fatal crashes, "driver events" can also cause unsafe conditions on roads. Driver events include actions such as harsh braking, accelerating, or cornering. Harsh acceleration and harsh braking occur when more force than normal or necessary is applied to the vehicle's accelerator or braking system to adjust the speed of the vehicle. They increase the risk of accident or injury to fleet drivers and others sharing the road. Harsh cornering takes place when a driver takes a turn or curves too fast, putting top-heavy vehicles at risk of overturning[71].

Accident Reconstruction: Another key component of vehicle safety is accident reconstruction; allowing individuals to have full understanding of liability and creating the opportunity to make improvements on driving patterns or habits. Today, accident reconstruction is an intensive process that encompasses the retrieval of data from dash cameras and event data recorders (EDRs) of the vehicle(s) involved, collection of evidence, inspection of the vehicle(s) involved, interviews with witnesses/individuals involved, and simulation of the accident using software.

Safety Policy: Figure 13 above is based on the traditional automotive industry that has long established standards to prove safety and roadworthiness of human-driven vehicles. However, despite its significantly higher safety-criticality, the autonomous vehicle (AV) industry does not have this option yet. Today there are no wholly sufficient standards for autonomous vehicle roadworthiness, and no federal or state laws that mandate compliance to specific standards for testing autonomous driving technologies on public roads without a human driver in the vehicle cab.

The Social Cost of Unsafe Behavior

Speeding and harsh driving can lead to accidents culminating in property damage, injuries, or even loss of human life. In 2018[72], 6.8% of fatal crashes involving large trucks were found to have truck drivers who were speeding while 1.1% of the events were due to harsh driving behaviors like erratic vehicle operation or sudden speed changes.

TuSimple Addressing and Prioritizing Safety

Reducing Fatal Crashes: TuSimple's autonomous trucks have the potential to reduce the probability of an accident happening and the number of fatal accidents involving trucks by up to 32.3%. Amongst other factors, this 32.3% includes the 5.3% of fatal crashes that were due to driver distraction, the 4.4% due to driver impairment and potentially the 6.8% due to speeding. Theoretically, in an autonomous vehicle, given the extraction of the driver from the truck, driver distraction and driver impairment should be completely eliminated while driver speeding should be eliminated due to constant speed monitoring and control of the autonomous truck.

Superior Speed Control and Reaction Time: Further, The TuSimple Autonomous Driving System (ADS), powered by cameras, LiDARs and RADARs, and our artificial intelligence models, enables our trucks to have better speed control and shorter reaction times to other drivers and objects. Our sensor suite can see 1,000 meters[73] (or 0.6 miles), while a traditional human driver has an average detection range of 0.25 miles[74]. Additionally, our ADS has a reaction time of less than 0.1 seconds[75] as opposed to a reaction time of 0.75 - 1 second[76] for a human driver.

Minimizing Driver Events: Speeding and the three types of harsh driving events are typically classified as "driver events," because they are initiated by the driver at the wheel. The key difference between autonomous trucks and conventional ones is that the former do not have a human at the wheel, and thus are not prone to these "driver events". Figure 14 shows the results of a joint study between TuSimple and Geotab that has already uncovered substantial improvements in harsh braking, harsh acceleration, and harsh cornering by autonomous trucks, as compared to manually-driven trucks.

TuSimple's trucks are able to achieve these improvements through its autonomous driving technology which includes perception, motion planning, control, and mapping. These components leverage data and information from TuSimple's proprietary sensor system that includes cameras, LiDARs, RADARs, and ultrasonic sensors.

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Trucking Performance on Harsh Events

Number of Events per 10,000 Miles

Event Type	TuSimple Autonomous Technlogy	Industry Human-Operated Driving
Harsh Braking[1]	0 - 2	8 - 10
Harsh Acceleration[2]	11 - 16	99 - 106
Harsh Cornering[3]	4 - 10	118 - 189

[1] Harsh Braking occurs when a driver uses more force than necessary to control the vehicle. The presence of harsh braking often indicates aggressive or distracted driving that can lead to costly accidents, as well as increased maintenance issues.

[2] Harsh Acceleration is defined as acceleration greater than 3.35m/s^2 in the forward direction. In the vehicle, the driver would feel like they were pushed back in the seat and the load of the vehicle would shift to the rear.

[3] Harsh Cornering is an event that exceeds certain values of Geolab's GO device's accelerometer, specifically side-to-side values (G-Force). This action increases the amount of force on the vehicle, putting top-heavy vehicles at risk of overturning.

Figure 14: Comparison of how TuSimple trucks perform on harsh events against manually driven trucks' performance, Geotab and TuSimple (2021)

Accident Reconstruction: TuSimple's multi-sensor technology powered by cameras, LiDARs, and RADARs can enhance the scope of data collection, which is critical for accident reconstruction. Our cameras and sensors are continuously capturing data; from when the truck starts a mission to when it completes a mission. Our autonomous vehicles are capable of continuously capturing data, video as well as variation in speed, acceleration and braking over the entire journey, and preemptively adjusting the truck's movements as needed. This is in stark contrast to event data recorders (EDRs) and dash cams in traditional vehicles, which only capture data up to 5 seconds before and after a vehicle may experiences a significant event, such as a collision, pothole, or curb hit[77], or if a crash is significant enough to cause airbags to deploy.

Leading in Safety Policy: At TuSimple, our approach to safety is holistic, spanning not only our technology, but also our processes, organization, and operations. As such, we have recently constructed a Driver-Out Safety Case Framework[78] which outlines our explicit safety principles, from which we derive our overall Safety Case Framework, and take full advantage of available best practices and internal frameworks to enforce safety-first practices throughout the design and execution of our Driver-Out rides.

G. Public Health

Scope of the Problem

People who live near major roads, especially those with high trucking volumes, face an increased incidence and severity of health problems[79] associated with air pollution. Research has shown that among children with no parental history of asthma, living within 75 meters of a major road, 59%[80] of asthma cases were attributable to their proximity to these roads. Figure 15 shows a hot spot analysis that revealed a statistically significant clustering of elevated PM concentrations and asthma incidence in certain towns.

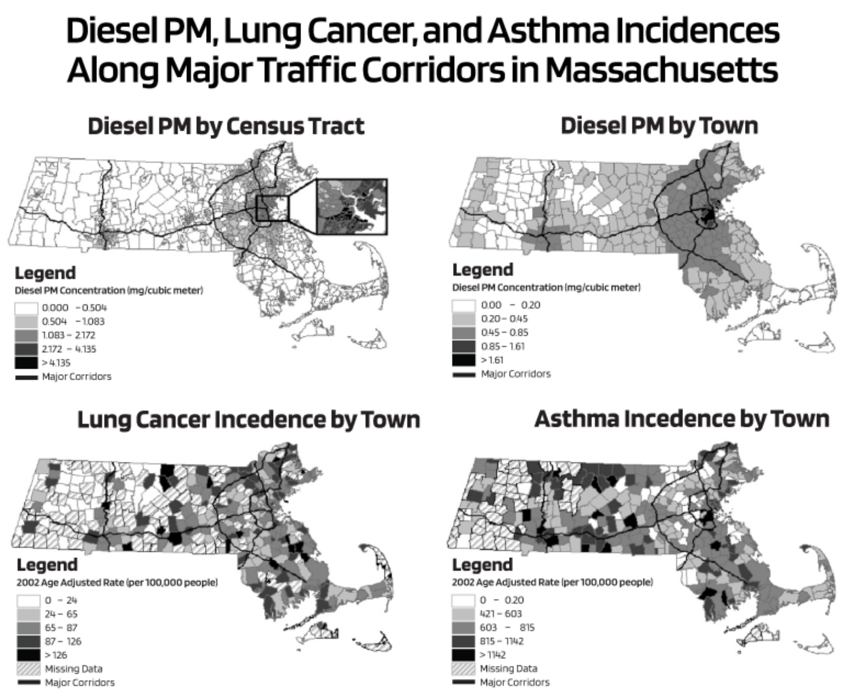

Figure 15: Diesel PM, lung cancer, and asthma incidences along major traffic corridors in Massachusetts (Health & Place[81])

In addition to asthma, other health impacts include[82]:

- Cardiovascular deaths and illness from both short-term and long-term exposure to traffic-related air pollution
- Lung cancer in people who have never smoked, linked to traffic pollution
- Breast cancer in post-menopausal women, linked to traffic pollution

TuSimple Minimizing the Negative Impact

The introduction of autonomous trucks can bring many benefits such as improved traffic flows, increased safety, and reduced freight costs. Yet, there are rising concerns[83] about the possibility of increased carbon emissions which can lead to increased health issues in the communities our trucks drive through.

To address these concerns, we continue to add to our development roadmap, identifying additional ways in which we can reduce the emissions generated by our autonomous trucks. This includes[84] improving the wear properties of materials, reducing the wear potential of tires, minimizing the output of CO_2, PM, and NO_x through reduced idling and increased fuel efficiency, off-peak trip starts, and speed optimization.

H. Food Waste and Food Insecurity

Scope of the Problem

In 2017, the United States generated approximately 206 billion pounds[85] of food waste, which equates to 30-40%[86] of its food supply. Food is discarded at every step along the food chain: on farms and fishing boats, during processing and distribution, in retail stores, in restaurants and at home. According to the Food and Agricultural Organization (FAO) of the United Nations, 14% of the world's food is lost between harvest and retail[87], including through on-farm activities, storage, and transportation.

Food insecurity[88] is the disruption of food intake or feeding patterns due to lack of money or other resources. It can affect people from all socioeconomic brackets, but is most commonly concentrated in impoverished neighborhoods. During the first few months of the 2020 COVID-19 pandemic, roughly 4 in 10 people[89] visiting food banks were seeking help for the first time, driving a 55% increase in year-on-year visits. Though a long-standing issue, the pandemic has spotlighted growing food waste.

The Social and Environmental Cost of Food Waste and Food Insecurity

Food waste inevitably results in "upstream" energy and water waste, as well as "downstream" GHG emissions. Wasted food makes up 21% of all freshwater used to grow food[90] and represents 2% of the USA's annual energy consumption[91].

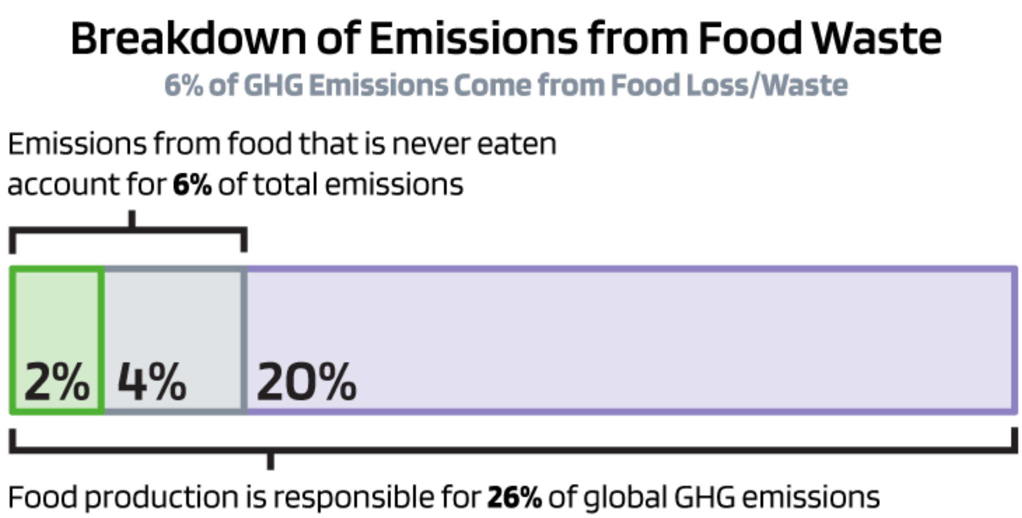

Figure 16: Breakdown of emissions from food waste (Our World in Data[92])

After being discarded, as food rots in a landfill, it emits methane, a greenhouse gas 28 to 36 times more potent[93] than the carbon that comes out of passenger vehicles. Food waste and losses across different stages of the supply chain also represents 6% of total global greenhouse gas emissions.

Along with these environmental impacts, food waste has the profound social implication of the lost opportunity to reduce food insecurity. Food insecurity can affect people from all socioeconomic brackets, but is most commonly concentrated in impoverished neighborhoods. In the U.S. alone, 10.5% of U.S. households[94] are considered to be food insecure. This includes more than 38 million[95] people, 12 million of which are children. One of the biggest challenges facing local communities experiencing food insecurity is the transportation of food to local pantries and food banks for distribution, a problem that can be aptly addressed by the trucking industry.

TuSimple Fighting Food Waste and Food Insecurity

TuSimple believes that autonomous trucks have the potential to solve the challenges of food waste. Over the past several years, we have been collaborating[96] with stakeholders and partners across the food industry including McLane[97] (a supply chain service leader for food and grocery) and Giumarra[98] (a produce marketing company supporting over 2,000 growers).

McLane has been a long-standing partner of ours and is excited about the potential for TuSimple's autonomous trucks to help address the driver staffing shortages in their supply chain[99]. As such, we have started with shuttle runs between Phoenix and El Paso and continue to identify opportunities to expand across the country.

Most recently, we worked with Giumarra and the Associated Wholesale Grocers[100] (AWG) to validate the benefit of autonomy for middle-mile applications by reducing the time by 42% for a middle mile load. Doing so allowed AWG to distribute fresh food more effectively to locally-owned grocery stores across the state. By being able to extend the shelf life of produce and reduce prices, we believe we can provide greater access to healthier food in communities located in "food deserts" and thereby improve the overall health of the community.

Figure 17: A TuSimple autonomous semi delivers to a food bank in El Paso, Texas.

Along with addressing food waste, we believe that our autonomous trucks can reduce food insecurity by providing a safe and efficient way to distribute food to the organizations that serve those most in need. Currently, we are partnered[101] with the Community Food Bank of Southern Arizona[102] in providing both food donations and freight transportation. Recognized as the top food bank in the US[103], the Community Food Bank of Southern Arizona serves 180,000 people annually through innovative programs that address food insecurity and health.

TuSimple's Partnership with the Community Food Bank of Southern Arizona

3.5 million	2.7 million	90+	39,000
pounds of food transported	meals delivered	truckloads of food hauled	miles traveled

Figure 18: Metrics highlighting TuSimple's partnership with the Community Food Bank of Southern Arizona

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As of December 31st, 2021, we have successfully delivered more than 3.5 million pounds of food, or 2.7 million meals, to communities in need in partnership with the Community Food Bank of Southern Arizona and look forward to continuing our partnership with them.

Beyond the ability to move food freight faster and to increase food accessibility, we believe there are many benefits that our autonomous trucks can provide, including reducing transportation costs by up to 50% per mile. This will allow food banks to funnel these savings towards procuring more meals and ensuring that households in need can access the programs.

As we expand our operational footprint, it's encouraging to think about the different ways TuSimple's autonomous trucks can help communities around the world. Tackling food waste and food insecurity in our communities is work that will take time, and the strong partnerships that we are building should enable us to continue creating a better path forward.

I. Human Trafficking

Scope of the Problem

Human trafficking is a global problem in which people are coerced into commercial sex acts or labor against their will. It is estimated that there are 40 million victims of human trafficking[104] globally, including thousands of children and adults in the United States, in what is currently a $150bn industry[105]. The scale of this crime calls for an equally sizable response, including that from a mobile army as large, widespread, and well-trained as the transportation industry. This is the opportunity that exists for the trucking industry, with its members uniquely positioned to make an impact.

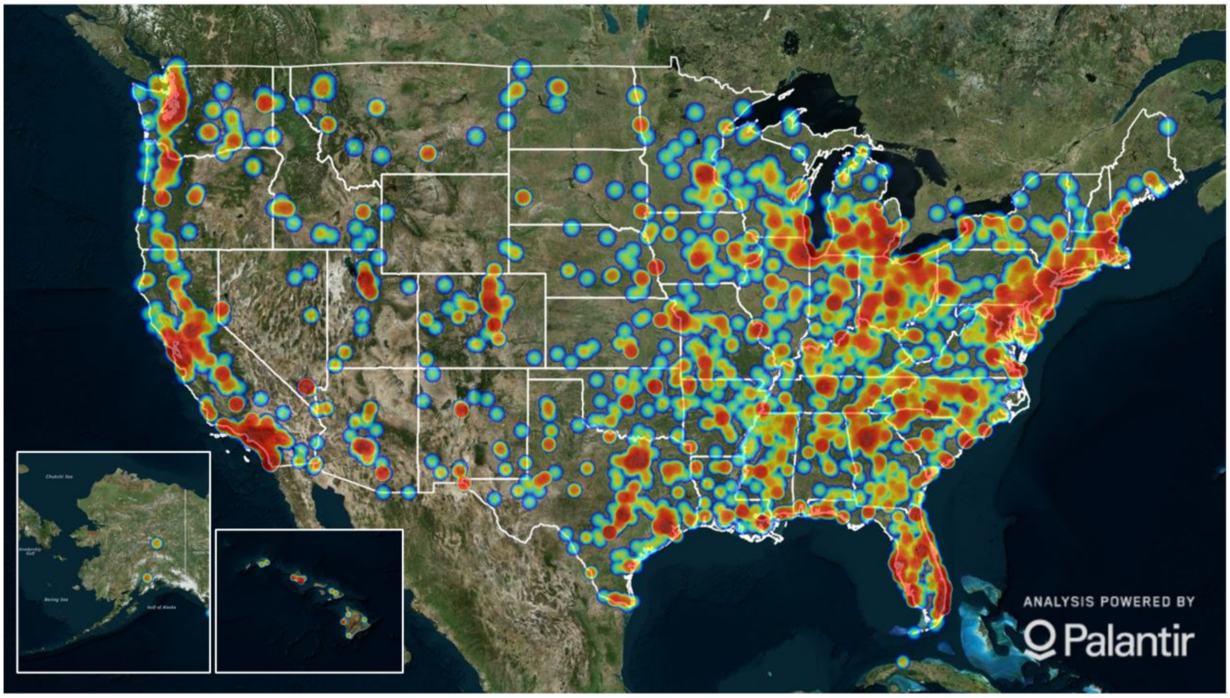

Figure 19: Heat map of human trafficking situations identified in 2019 (Polaris[106])

During their time on the roads, truck drivers move in and out of rest stops, restaurants, and hotels. This puts them in a unique position where they may be able to spot and report incidents of trafficking that take place at these locations. Truckers Against Trafficking (TAT) reported that over the past decade, truck drivers have made more than 2,000 calls to their hotline, helping to raise awareness of more than 600 likely cases and identify more than 1,000 potential victims[107].

The Social Costs of Human Trafficking

Human trafficking victims often experience poor physical and mental health, and also find that their past trauma can become obstacles to their efforts to secure stable employment due to the remnants of their trauma as well as the stigma associated with it. Afflictions include sexually transmitted infections and unsafe abortions, depression, and anxiety, as well as drug and alcohol addictions.

It is common for victims, especially those who are young women, to have left high school before graduation. An incomplete education provides limited opportunities for stable employment that are within reach -- this can be mitigated by targeted training programs[108], but will require time as victims recover from the effects of mental and physical abuse.

TuSimple Addressing Human Trafficking

While TuSimple is an autonomous trucking company, we will continue to have safety drivers and AV system operators on the roads on a regular basis who may encounter human trafficking incidents that should be reported. In addition to our safety drivers and AV system operators, we believe that our employees who are not out on the roads should also be aware of suspicious activity in their everyday lives and know how to take action.

TuSimple is the first autonomous trucking company to sign on as a sponsor of Truckers Against Trafficking (TAT). As part of our commitment toward combatting human trafficking[109], we recently had Laura Cyrus, the Director of Corporate Engagement at Truckers Against Trafficking, speak to our employees about what they can do both on the road and in everyday situations to spot signs of human trafficking and take action by making a call to the TAT hotline. We want to prepare our employees to help fight against human trafficking and become a part of the solution. In addition, all of TuSimple's safety drivers and AV system operators are required to complete the TAT training program on what red flags to look for as indicators that human trafficking may be taking place. As of January 2022, we have trained and certified over 60 safety drivers and AV system operators for TAT.

Beyond making affirmative commitments to combat human trafficking, we are looking into ways our trucks can help to tangibly address trafficking activity while on the road. We see the potential that our technology has in terms of increasing transparency and supporting law enforcement efforts to tackle this issue. By exploring ways to combine our technology with internal initiatives that empower our people to play a part, as well as partnerships with law enforcement and public service entities, we commit to using our technology as a force for good.

4. Conclusion

TuSimple's mission is to make long-haul trucking significantly safer as well as more reliable, efficient, and environmentally friendly. Autonomous trucking offers a multi-faceted solution to address environmental challenges such as greenhouse gas emissions and fuel wastage, as well as socioeconomic issues including public health, food waste and insecurity, and human trafficking. Through our technology, TuSimple is set to transform business "as is" and set the foundation for trucking to become both safer for our communities and cleaner for our environment.

5. Appendix

A. Glossary of Terms

ADS	Autonomous Driving System
AFN	Autonomous Freight Network
ATRI	American Transportation Research Institute
AWG	Associated Wholesale Grocers
CAFE	Corporate Average Fuel Economy
CARB	California Air Resources Board
CO_2	Carbon Dioxide
CVSA	Commercial Vehicle Safety Alliance
EDR	Event Data Recorders
EPA	Environmental Protection Agency
FAO	Food and Agricultural Organization
GHG	Greenhouse Gas
ICE	Internal Combustion Engine
NACFE	North American Council for Freight Efficiency
NEE	Non-Exhaust Emissions
NHTSA	National Highway Traffic Safety Administration

NO_x	Nitrous Oxide
PM	Particulate Matter
TAT	Truckers Against Trafficking
THC	Total Hydrocarbons
VMT	Vehicle Miles Traveled

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