Title

Reducing the Carbon Footprint of Freight Movement through Eco-Driving Programs for Heavy-Duty Trucks

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EXECUTIVE SUMMARY

Freight movement has become an important economic factor in the ever-increasing international trade and global supply chain. In the United States, approximately 70% of freight is moved by commercial trucks. In typical commercial trucking operations, fuel costs are usually one of the largest expenses, accounting for about 30% to 40% of the total operating cost. Not only do freight trucks consume a large amount of fuel, they also produce a significant amount of greenhouse gas (GHG) and criteria pollutant emissions, about 22% of the U.S. GHG emissions from transportation sector. Therefore, both the trucking industry and government agencies have good reasons to improve fuel efficiency and reduce GHG emissions from trucking operations.

A significant portion of fuel consumed by commercial trucks is wasted because of inefficient operation and insufficient maintenance of the truck. One strategy that can improve fuel efficiency and reduce GHG emissions from trucking operations is eco-driving. A truck eco-driving program encourages or incentivizes truck drivers to embrace fuel-efficient vehicle operation and maintenance practices, such as avoiding hilly routes and heavy traffic, using moderate highway speeds, minimizing hard acceleration and braking, reducing unnecessary idling, and keeping the tires properly inflated, among others.

Truck eco-driving programs generally consist of three main elements: 1) driver education and training, 2) vehicle maintenance and technology support, and 3) policy support. A concerted effort to implement these elements is critical to the success of any truck eco-driving programs.

Key Findings

Truck eco-driving is a strategy that can be implemented quickly. Evidence from Europe, Asia, and North America suggests that truck eco-driving programs can save fuel and reduce greenhouse gases in the range of 5% to 15%.

Some of the challenges that independent truckers and trucking companies face in adopting eco-driving include resistance to change, volatile fuel prices, high turnover rates of drivers, and the pressure to balance fuel savings with safety and productivity goals.

Public policies that can help address these challenges include conducting educational eco-driving campaigns, incorporating eco-driving as part of the commercial driver's licensing process, providing financial subsidies for retrofitting existing trucks with eco-driving technologies, and mandating eco-driving technologies in new trucks.

Research is needed to improve our understanding of the air quality and safety co-benefits of truck eco-driving as well as its potential impacts on traffic flow. Research is also needed to further advance eco-driving technologies and analyze potential impacts of the public policies recommended above.

Limited evidence from Europe, Asia, and North America suggest that truck eco-driving can save fuel and reduce GHG emissions in the range of 5% to 15%. Mechanisms for ensuring long-term engagement in eco-driving behavior are needed in order to maintain fuel savings and GHG reduction benefits.

Driver education and training is fundamental to any truck eco-driving programs. Knowledge and tips about eco-driving practices need to be conveyed to truck drivers with positive branding messages in order to encourage acceptance and adoption. Truck eco-driving education may also be supplemented by driver training, either in a classroom setting, with a driving simulator, or on-road through one-on-one coaching. In addition, recognition or rewards may be offered to truck drivers to incentivize adoption and sustained eco-driving behaviors.

There are various technologies that can facilitate truck eco-driving practices. For example, a speed limiter can be set to limit the top speed of a truck, ensuring no speeding. An auxiliary power unit can be used to heat or cool the truck cab instead of idling the engine while parked for rest stops. In-vehicle driver feedback instruments can be installed to provide real-time fuel efficiency information and driving advice to the driver. Some of these technologies are currently more prevalent than others. Making them more broadly available to truck drivers can accelerate the adoption and increase the effectiveness of truck eco-driving practices.

A wide range of policies can be implemented to support truck eco-driving programs. For example, eco-driving awareness campaigns may be conducted by government agencies at any level (federal, state, regional, or local). Eco-driving education and training may be incorporated as part of the commercial driver's licensing process. Free access to air pumps for tire inflation may be made available at truck stops and rest areas. Financial subsidies may be provided for the purchase of technologies that facilitate eco-driving practices. Truck manufacturers may be encouraged or mandated to include eco-driving technologies, such as in-vehicle driver feedback instrumentation, in new model year trucks.

In addition, government agencies can invest in additional research on truck eco-driving. Example research topics include quantification of air quality and safety co-benefits of truck eco-driving, investigation of potential impacts of large-scale adoption of truck eco-driving behaviors on traffic flow, further advancement of truck eco-driving technologies, and analysis of the truck eco-driving supporting policies recommended above.

Introduction

Freight movement has become an important economic factor in the ever-increasing international trade and global supply chain. In the United States, approximately 70% of freight is moved by commercial trucks (*1*), making trucking a multi-billion dollar industry. In typical commercial trucking operations, fuel costs are usually one of the largest expenses along with driver wages. As shown in Figure 1, between 2008 and 2012 fuel costs accounted for about 30% to 40% of the total operating cost (*2*). Therefore, it is not surprising that trucking companies and independent truckers always look for ways to increase fuel efficiency of their operations in order to improve their business' bottom line.

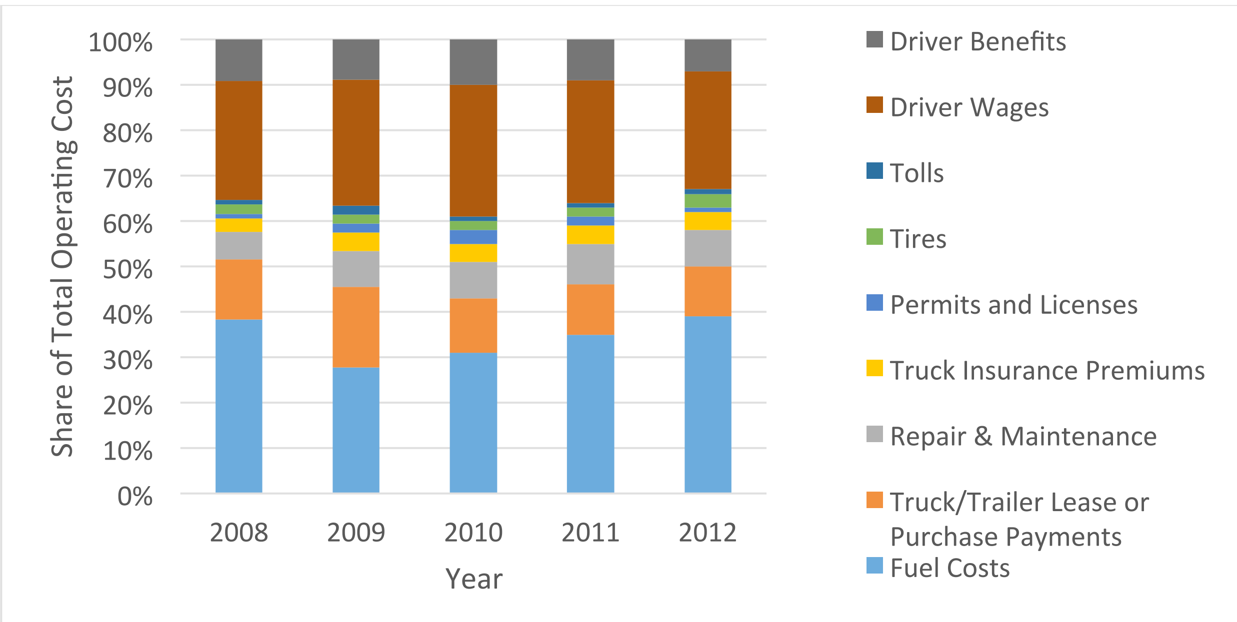

Figure 1. Operating costs of commercial trucking in the U.S. (*2*)

Not only do freight trucks consume a large amount of fuel, they also produce a significant amount of greenhouse gas (GHG) and criteria pollutant emissions. As shown in Figure 2, between 1990 and 2011 medium- and heavy-duty trucks, which were used mostly for freight movement, accounted for 22% of the U.S. GHG emissions from the transportation sector (*3*). This was equivalent to about 6% of the entire U.S. GHG emissions inventory during that period. Therefore, government agencies have been trying to develop and implement programs to reduce fuel consumption and GHG emissions from these trucks as part of the effort to become energy independent and combat climate change. One example is the enactment of federal GHG and fuel efficiency standards for medium- and heavy-duty vehicles in 2011, which will be updated this year (*4*). Another example is the establishment of the SmartWay Program (*5*), which provides resources and support to trucking companies on strategies for improving fleet fuel efficiency.

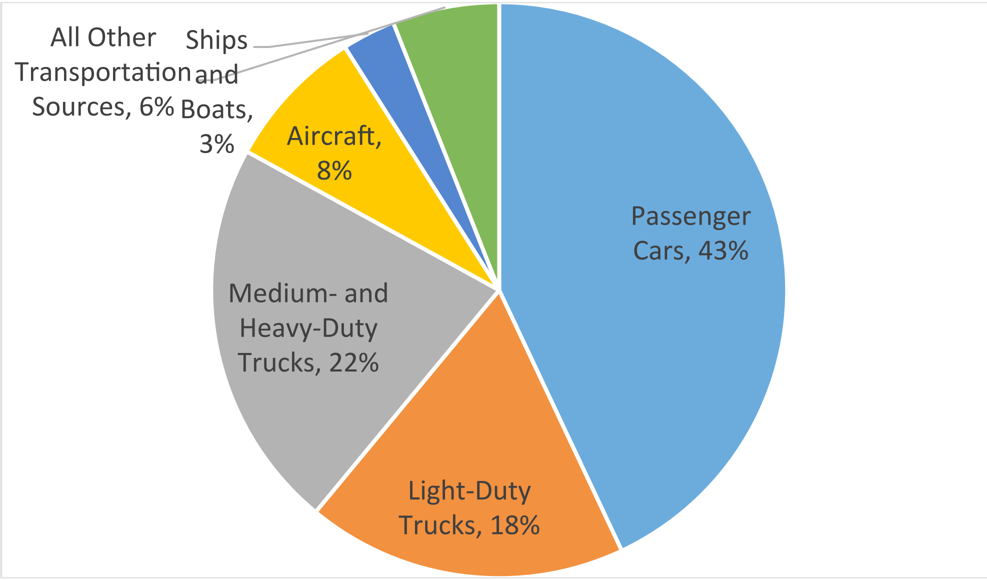

Figure 2. U.S. greenhouse gas emissions 1990-2011 by transportation source (*3*)

One strategy that can improve fuel efficiency and reduce GHG emissions from trucking operations is eco-driving. This strategy encourages drivers to embrace fuel-efficient driving practices. By driving more smoothly, choosing appropriate speeds, and minimizing hard acceleration and braking, vehicle fuel consumption can be significantly reduced (see Figure 3). While a number of studies have been conducted to evaluate the effectiveness of eco-driving, most of them were focused on light-duty vehicles for passenger transport. Few studies have specifically looked at the effectiveness of eco-driving for heavy-duty vehicles used in freight movement.

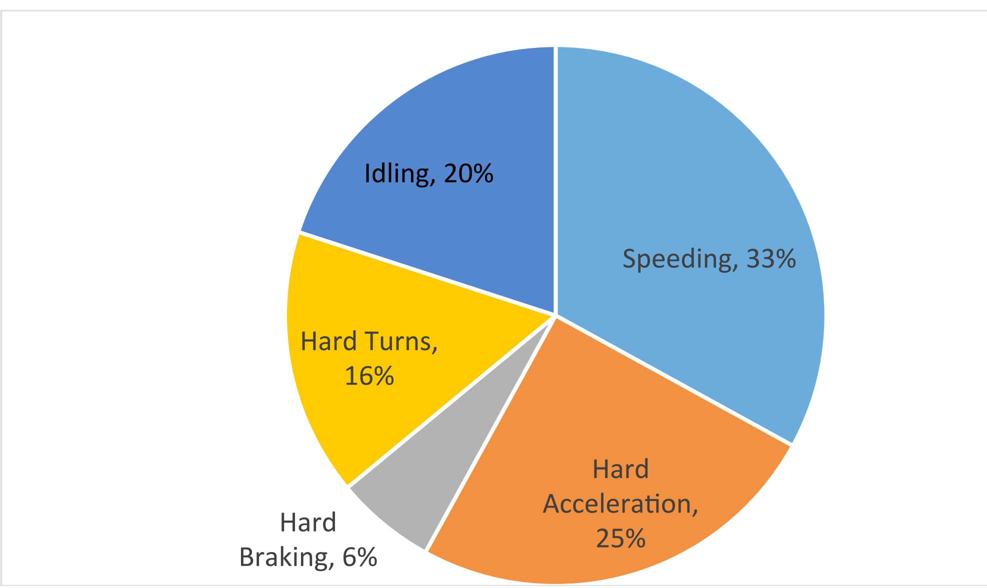

Figure 3. Reasons for fuel waste for a typical freight truck (*6*)

This white paper is geared towards an audience who is involved or interested in sustainable transportation policies, especially those related to the freight transportation sector. The white paper first reviews the state-of-the-knowledge on eco-driving practices that are applied to heavy-duty trucks. It then presents the elements of truck eco-driving programs, summarizes the effectiveness of programs that have been tested or implemented, and discusses key challenges and barriers in implementing and sustaining a successful truck eco-driving program. Finally, the white paper concludes by identifying research needs and policy implications of this important energy efficiency improvement and climate change mitigation strategy.

Eco-Driving Practices for Heavy-Duty Trucks

The Oxford Dictionaries define eco-driving as "the practice of driving in such a way as to minimize fuel consumption and the emission of carbon dioxide" (*7*). In a broader sense, eco-driving may also include non-driving activities such as pre-trip planning (of route and schedule) and vehicle maintenance. While the core principles of eco-driving are similar across different types of vehicles, some eco-driving techniques are specifically applied to heavy-duty trucks due to certain unique aspects of truck engines' operation. Below is a summary of eco-driving practices for heavy-duty trucks (*8*).

Pre-Trip Planning

- Plan driving route to steer clear of winding roads, hilly routes, and mountainous terrain.
- Check weather and stay away from conditions that make truck engine work harder, such as heavy snow, low temperature, and strong head wind and cross wind.
- Plan driving schedule to take a rest during the time when temperature is mild in order to save fuel on cab heating and cooling.
- Try not to drive through cities, on roads with heavy traffic, and during rush hours to avoid stop-and-go driving.
- Use map or GPS navigation to help plan pickup and delivery sequence in a logical order.
- Plan the trip backward from the specified delivery time. Build in some margin for unexpected delays or problems.
- For fleets with multiple trucks, use computerized routing and scheduling such as automated dispatching software to select drivers, trucks, and routes that would be most fuel-efficient.

Driving

- Start the engine at zero throttle. If the engine does not start immediately, then keep cranking time to no more than 30 seconds. In cold weather, place the transmission in neutral and depress the clutch to start the engine.
- Warm up the engine per the owner's manual, normally three to five minutes. Do not rev the engine on start-up and during warm-up.
- Begin driving in a gear that can move the truck without using the throttle.
- Apply progressive shifting technique by shifting to the next higher gear as soon as engine speed is high enough to do so.

- Change gear with double-clutching technique by first applying the clutch to change into the neutral gear before applying the clutch again to change into the next gear.
- Use moderate highway speed or set a speed limiter. A truck can consume up to 10% more fuel for every 6 mph over 55 mph.
- Maintain constant speed or use cruise control.
- Accelerate and brake mildly. Use engine retarder or engine brake to help slow down the truck as appropriate such as on downhill slopes.
- Avoid unnecessary idling or use idle reduction technologies such as auxiliary power unit.
- Cool down the engine per the owner's manual, normally three to five minutes if the truck has been running on the highway.
- Be alert to traffic situations around and anticipate traffic ahead.

Vehicle Maintenance

- Have trucks serviced at regular intervals.
- Check tire pressure at least once a week and inflate tires to manufacturer-recommended level.
- Tune electronic control module settings to improve fuel efficiency.
- Retrofit trucks with fuel saving technologies that improve aerodynamics of tractor and trailers, cut down engine idling time, reduce weight of truck components, reduce tires' rolling resistance, and provide fuel efficiency feedback to driver.

More detailed information on fuel-efficient truck operation and maintenance practices can be obtained from online resources or truck manufacturer-specific guides (*8, 9*).

Truck Eco-Driving Programs

Elements

Truck eco-driving programs generally consist of three main elements: 1) driver education and training, 2) vehicle maintenance and technology support, and 3) policy support.

Since the fuel efficiency of truck operation has a lot to do with how the drivers operate their trucks, eco-driving education and training is fundamental to any truck eco-driving programs. Knowledge and tips about eco-driving practices need to be conveyed to truck drivers. It is important to use creative outreach and marketing tools, through a variety of media, to develop positive branding for eco-driving in order to encourage acceptance and adoption (*10*). Websites with driving tips, videos, and virtual games involving fuel-efficient driving skills are increasingly available (see an example in Figure 4), and can be accessed by independent truckers. For truck fleets, it is generally easier for fleet managers to disseminate information to truck drivers in their fleets. Thus, it is also important to raise awareness of truck eco-driving and its benefits among fleet managers. In addition, truck eco-driving education can be supplemented by driver training, either in a classroom setting, on-road through one-on-one coaching, or with a driving simulator such as in Figure 5.

Figure 4. Truck eco-driving game in the form of mobile app [photo credit: http://corporate.renault-trucks.com/en/press-releases/2012_10_22_an-application-for-learning-how-to-eco-drive-a-truck.html]


Figure 5. Truck eco-driving training in driving simulator environment [photo credit: https://www.iru.org/en_policy_co2_response_ecodriving]

A number of truck eco-driving practices involve proper vehicle maintenance and the use of fuel saving technologies. Therefore, it is important to provide truck drivers with support in these areas. For example, government agencies can provide free access to air pumps for tire inflation at truck stops and rest areas. A government-run program, such as the SmartWay Program (*5*), can also help accelerate the availability, adoption, and market penetration of advanced fuel efficient technologies in the freight supply chain. For truck fleets, vehicle maintenance is usually centrally managed so it is often easier to streamline preventive maintenance routines. Fleet managers can also decide to invest in fuel saving technologies and provide truck drivers with training and support on the use of these technologies.

In addition to the focus on driver and vehicle, a wide range of public policies can also be implemented to support truck eco-driving programs. For instance, voluntary or educational eco-driving campaigns can be conducted by organizations (such as nonprofit) or government agencies at any level (federal, state, regional, or local). Eco-driving can be included as part of commercial driver licensing process. Financial subsidies can be provided for the retrofit of existing trucks with technologies that improve fuel efficiency. Truck manufacturers can be encouraged or mandated to include fuel saving technologies such as in-vehicle fuel efficiency feedback instruments in the new model year trucks. For truck fleets, an internal policy can be established to recognize or reward truck drivers for embracing eco-driving practices and improving their fuel efficiency performance.

Effectiveness

Truck eco-driving evaluation studies have been conducted in Europe, Asia, Australia, and North America. Examples of these studies are provided in Table 1 (*6, 11-16*). The reported fuel savings or improvements in fuel economy vary greatly, ranging from approximately 5% to 40%. The high variation is due to several factors including the method of delivering eco-driving training (e.g., class versus individualized coaching), the setting for evaluating fuel economy improvement (e.g., closed driving course versus actual real-world route), the number of truck driver samples, and their baseline driving performance prior to receiving eco-driving training, among others. For instance, the two studies that reported the most fuel economy improvements in Table 1 involved the lowest numbers of drivers and conducted the fuel economy evaluation on prescribed driving routes. The fuel economy improvements may not be the same for a larger truck driver population driving on actual real-world routes.

For truck eco-driving evaluation studies that involve a large number of drivers, on the order of hundreds or thousands, the reported improvements in fuel economy are in the range of 5% to 15%. For instance, the use of a truck driving simulator in providing eco-driving training to more than 600 drivers in the United Kingdom was found to yield an average fuel economy improvement of 3.5% (*11*). In Japan, an eco-driving seminar given to about 3,000 truck drivers was found to improve fuel economy of these drivers by 8.7% on average (*15*). A truck eco-driving evaluation study in Europe that provided eco-driving training class to 322 drivers, some of which were followed up with monthly feedback on fuel-efficiency performance and regular refreshing class, resulted in a fleet average fuel economy improvement of 9.4% (*14*). Lastly, a truck eco-driving evaluation study in the United States based on the use of individualized coaching in conjunction with an in-vehicle real-time feedback system was found to improve fuel economy of 695 participating drivers by an average of 13.7% (*6*).

In addition to education and training, incentives also play a role in the effectiveness of a truck eco-driving program. A study of 46 U.S. truck drivers found that providing financial incentives on top of individualized coaching and using an in-vehicle real-time feedback system approximately doubled the fuel economy improvements. Specifically, the fuel economy improvement of sleeper cab trucks increased from 2.6% without financial incentives to 5.4% with financial incentives. And the fuel economy improvement of sleeper cab trucks increased from 5.2% to 9.9% (*16*).

Table 1. Examples of truck eco-driving evaluation studies

Year	Country	Training Method	Evaluation Setting	No. of Drivers	Fuel Economy Improvement	Refer-ence
2005	U.K.	Driving simulator	Driving simulator	>600	3.5% immediately after training	(*11*)
2007	U.S.	Class	Closed driving course	36	33.6% to 40.5% immediately after training	(*12*)
2009	Australia	Class	Prescribed real-world route	12	27.3% immediately after training; 26.9% after 3 months	(*13*)
2010	European countries	Class followed by monthly feedback and regular refreshing class	Actual real-world routes	322	9.4% over an unknown period	(*14*)
2011	U.S.	Individualized coaching and in-vehicle real-time feedback system	Actual real-world routes	695	13.7% after 2 months	(*6*)
2013	Japan	Class	No information available	~3,000	8.7% immediately after training	(*15*)
2014	U.S.	Individualized coaching and in-vehicle real-time feedback system (plus financial incentives)	Actual real-world routes	46	2.6% (5.4% with financial incentives) for sleeper cabs and 5.2% (9.9% with financial incentives) for day cabs after 2 months	(*16*)

There has been suggestion and evidence that the fuel savings benefit of eco-driving could fade over time as drivers revert back to the old habits of driving (*17*). Therefore, it is also important to put in place mechanisms that continuously incentivize or reinforce eco-driving behaviors in order to ensure sustained fuel savings benefit in the long term. One example is to regularly recognize drivers for their fuel-efficient driving performance or provide financial reward based on the amount of fuel they save. Another example is to use in-vehicle feedback systems to continually evaluate drivers' fuel efficiency performance and provide real-time advice while they are driving, periodic driver scorecards, and other types of feedback.

Over recent years, many truck fleets have deployed telematics systems that monitor location, speed, acceleration, gear shifting, fuel consumption, etc. of their trucks in real time. Such telematics systems allow fuel efficiency performance of truck drivers to be monitored, which opens an opportunity for the impacts of truck eco-driving programs to be measured over a long period of time under actual real-world operating conditions. As more trucking companies adopt these telematics systems, it is expected that more information will become available on the effectiveness of truck eco-driving programs in general as well as the best practices for ensuring long-term eco-driving behavior in order to maintain fuel savings benefit.

Challenges and Barriers

There are challenges to a successful implementation of truck eco-driving programs. One challenge is that driving habits, like any other habits, are hard to break unless there is a strong incentive to do so. Another related challenge is sustaining the positive changes in driving habits (to be more fuel-efficient) in the long term. The extent of these challenges may be different for independent truckers than for company drivers, and may depend on who pays for the fuel and maintenance costs.

Economic incentive is perhaps the most influential factor for encouraging independent truckers and trucking companies to adopt eco-driving. For instance, a 5% improvement in fuel economy from 7 mpg to 7.35 mpg for a truck that travels 80,000 miles a year will translate to roughly $2,175 fuel cost savings at $4 a gallon. Such an incentive is strongly tied to fuel prices. When the fuel prices are low, the fuel cost savings from adopting eco-driving may not be enough to persuade independent truckers to change their driving habits and trucking companies to invest in eco-driving training and technologies. This is an important consideration, as the expected payback period for investment by trucking companies generally ranges from 18 months to five years (*18*).

Also, high turnover rates of truck drivers may lead many trucking companies to be reluctant to invest in eco-driving training because of the fear of losing trained drivers. For drivers, requirements that they adhere to tight delivery schedules may sometimes cause them to prioritize speed over fuel savings. Therefore, a well-structured driver performance monitoring program that balances fuel efficiency with productivity and other goals is required to keep the drivers' job satisfaction at a high level, which will in turn reduce the turnover rate.

In terms of barriers, most are likely to be institutional (*19*). For example, incorporating eco-driving training or an exam as part of the commercial driver's licensing process would involve substantial institutional change by government agencies. As another example, encouraging or mandating inclusion of fuel saving technologies such as in-vehicle fuel efficiency feedback instruments in the new model year trucks would require working closely with truck manufacturers and other stakeholders. And if successful, it would still take many years for the existing truck fleet to turn over before the trucks with fuel saving technologies become predominant in the fleet. Lastly, funding is needed in order to carry out educational eco-driving campaigns or to provide financial subsidies for the retrofit of existing trucks with fuel saving technologies. The lack of funding to support these programs is, thus, another potential barrier.

Research Needs

Because the concept of truck eco-driving is relatively new, the current understanding of its impacts are fairly limited. There are many aspects of truck eco-driving that require further research, some of which are outlined below.

Co-Benefits of Truck Eco-Driving

Eco-driving has been shown to save fuel and reduce GHG emissions. But it is also likely to reduce pollutant emissions as a result of smoother driving with milder acceleration and better vehicle maintenance. Since most heavy-duty trucks in the United States consume diesel fuel, they are also a major contributor of harmful emissions of smog-forming pollutants and air-borne particles (*20*). A strategy that can reduce these emissions from trucking operations would also be highly beneficial. In addition, many of the truck eco-driving tips go hand in hand with safe driving practices so there can be safety benefits from eco-driving as well. Thus, the quantification of these co-benefits of truck eco-driving is an important research topic.

Impacts of Truck Eco-Driving on Traffic Flow

While eco-driving has great potential to provide energy, climate, air quality, and safety benefits, its impact on mobility is unclear. Since eco-driving trucks will move slower and leave a larger gap from the vehicle ahead, the roadway capacity may decrease making it easier for traffic flow to break down, especially when there is a large number of eco-driving trucks on the roadway. If truck eco-driving programs inadvertently result in more traffic congestion, the fuel saving and emission reduction benefits for individual trucks may diminish and the net impact on traffic as a whole may become negative. This potential unintended consequence is likely to vary by the type of roadway, the level of traffic, and the adoption rate of eco-driving. Therefore, research is needed to evaluate the potential impacts of large-scale adoption of truck eco-driving under a variety of roadway and traffic scenarios.

Truck Eco-Driving Technologies

There is also more research to be done on eco-driving support devices and technologies for freight trucks. While there has been proliferation of such innovation for passenger cars in recent years, the same cannot be said of freight trucks. One possible research topic would be to adapt eco-driving support devices and technologies that have been developed for passenger cars and customize them for use in freight trucks. Another research topic would be to further advance eco-driving support devices by taking advantage of emerging Connected Vehicle technologies (*21*) that enable trucks to communicate with other vehicles as well as roadway infrastructure. On the other hand, research is also needed early on to identify and address any potential issues of these devices and technologies, such as driver distraction.

Truck Eco-Driving Supporting Policies

As suggested earlier, there is a wide range of policies that government agencies can implement to support truck eco-driving programs. These include conducting truck eco-driving awareness campaigns, incorporating eco-driving education and training as part of the commercial driver's licensing process, providing free access to air pumps for tire inflation at truck stops and rest areas, subsidizing the purchase of truck eco-driving technologies, and mandating truck manufacturers to include eco-driving technologies in new model year trucks. Research is needed to comprehensively analyze and prioritize these policies from the sustainability, economic, political, and institutional perspectives.

Conclusions

Both the trucking industry and government agencies have good reasons to improve fuel efficiency and reduce GHG emissions from trucking operations. Industry has economic incentives to realize and regulations to meet, while governments and society have energy independence and GHG reduction goals to achieve. One strategy for achieving these goals is eco-driving, which is one of the 25 energy efficiency policy recommendations made by the International Energy Agency (*22*): "Governments should ensure that measures to increase the operational efficiency of light- and heavy-duty vehicles, such as eco-driving, are a central component of initiatives to improve energy efficiency and reduce carbon dioxide emissions."

Truck eco-driving programs generally consist of three main elements: 1) driver education and training, 2) vehicle maintenance and technology support, and 3) policy support. A concerted effort to implement these elements is critical to the success of any truck eco-driving programs. Evidence from Europe, Asia, and North America suggest that truck eco-driving can save fuel and reduce GHG emissions in the range of 5% to 15%. Mechanisms for ensuring long-term engagement in eco-driving behavior are needed in order to maintain fuel savings and GHG reduction benefits.

Some of the challenges that independent truckers and trucking companies face in adopting eco-driving include resistance to change, volatile fuel prices, high turnover rates of drivers, and the pressure to balance fuel savings with productivity. There are many forms of policy support that government agencies can provide. These include conducting truck eco-driving awareness campaigns, making eco-driving an element of the commercial driver's licensing process, providing free access to air pumps for tire inflation at truck stops and rest areas, subsidizing the retrofit of existing trucks with fuel saving technologies, and encouraging or requiring truck manufacturers to equip in-vehicle fuel efficiency feedback instruments in new trucks.

There are also needs for additional research on truck eco-driving. These include, but are not limited to, quantification of air quality and safety co-benefits of truck eco-driving, investigation of potential impacts of large-scale adoption of truck eco-driving behaviors on traffic flow, further advancement of truck eco-driving technologies, and analysis of the truck eco-driving supporting policies recommended above.

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