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Operational and Vehicular Strategies for Reducing Fuel Consumption and GHG Emissions from Trucking

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Operational and Vehicular Strategies for Reducing Fuel Consumption and GHG Emissions from Trucking

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Abstract

Operational and Vehicular Strategies for Reducing Fuel Consumption and GHG Emissions from Trucking

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Reducing fuel consumption and greenhouse gas emissions is becoming increasingly important in the United States, and new legislation can be expected in the near future that will affect trucks either directly or indirectly. This work is a qualitative examination of operational strategies for reducing fuel consumption from freight trucking, and also compares them with vehicular strategies. A focus is placed on who implements, benefits from, and pays for each strategy, and what type of trucking each strategy is applicable to.

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I. INTRODUCTION

Traffic congestion, fuel consumption and vehicle emissions are all growing concerns domestically and internationally, and freight trucks are large contributors to all three. Truck traffic in the U.S. is expected to double in 25 years, and currently the mode contributes 19% of national transport greenhouse gas emissions and 6% of total emissions (EPA, 2006). A number of regulatory changes are currently being debated in both the energy and transportation arenas. Carbon taxes and cap-and-trade systems are being considered for limiting carbon emissions. New methods for direct usage charges are being considered to replace existing fuel taxes. Vehicle size and weight regulations are being reconsidered because of the energy savings and environmental benefits that would be achieved through operation of higher productivity vehicles.

Now that it is clear that greenhouse gases will be regulated at the federal level, it is important to quantify the savings and cost that can be expected from a variety of trucking operational strategies , and whether these strategies can contribute to meeting future carbon caps. In addition, it will be useful to know how these strategies compare with each other, and with vehicle-based strategies.

While there have been many studies focusing on vehicle technology strategies for reducing fuel consumption and emissions[1] from the transportation sector, there has been little focus on operational strategies (and even less focus on freight operational strategies). TTI (2009) estimated that congestion in the U.S. is annually responsible for

[1] In this report, "emissions" will refer to GHG emissions, unless stated otherwise.

4.2 billion hours of delay and 2.8 billion gallons[2] of wasted fuel. Of course, in addition to reducing fuel consumption, many of these operational strategies could improve traffic flow. Moreover, reducing fuel consumption is most often a secondary goal to improving traffic flow.

Operational strategies include improved logistics, truck-only facilities, the relaxation of vehicle size and weight restrictions, driver training, regulation of maximum vehicle operating speed, idle reduction, compact packaging, and port access improvements. All of these strategies are at different stages of development. The potential of some of these strategies to reduce congestion and fuel consumption has not yet been quantified, thus making the relative impacts of these strategies (on both emissions and traffic flow) unknown. Furthermore, some of these may even result in a net increase in emissions. For example, if the level of congestion still allows steady (but lower) speeds, reducing congestion may increase emissions by allowing higher steady speeds. Of course, an improvement in congestion that is characterized by frequent acceleration and deceleration will likely result in reduced fuel consumption and emissions.

When weighing all of these strategies, it is important to consider the great variety in trucking trips, vehicle ownership, and trip purpose: short haul, long haul, and drayage trucking; owner-operators, private carriers, and for-hire fleets; just-in-time shipping

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[2] U.S. consumed 176 billion gallons in 2007, 22% of which were from trucks. Congestion wastes 1.6% of total U.S. fuel consumption (FHWA 2008).

versus distribution center stocking. Because of this variety within trucking, most strategies will only apply to a portion of U.S. truck miles.

Importance of Reducing Fuel Consumption

The per capita oil consumption in the United States and Canada, 3 gallons per capita, is nearly 6 times that of the world average per capita oil consumption, and twice that of other industrialized nations (EIA, 2003). Of that, 70% is used for transportation, and heavy duty vehicles represent roughly 20% of the transportation demand. This share is likely to increase because freight traffic is growing at a faster rate than passenger traffic. In addition, heavy-duty vehicle fuel economy is currently unregulated. While passenger vehicle fuel economy continues to improve, fuel economy of combination trucks has not improved over the last 30 years. Decreasing fuel consumption will reduce our dependence on a non-renewable resource and our dependence on other countries for our source of energy. In addition, saving fuel means saving money, which is of great importance to an industry with low profit margins.

Environmental Effects of Diesel Fuel Consumption

There are four main greenhouse gases (GHGs) emitted by human activities: CO_2, CH_4, nitrous oxide (NO_2) and fluorinated gases. In general, heavy duty vehicles are responsible for the emission of 19% of mobile source and 6% of total GHGs in the U.S. (EPA, 2006). The average gallon of gasoline combustion causes 19.4 lbs CO_2/gallon to be released into the atmosphere, and diesel combustion causes 22.2 lbs CO_2/gallon (EPA

2009). While not a significant contributor to CH4 and fluorinated gases, emissions from heavy-duty vehicles are a significant source of CO2 and NO2.

GHGs are believed to be a major cause of the global rise in temperature, and if GHG emissions remain at current levels, or increase, the temperature will continue to rise (IPCC 2007). In addition to the overall rise in temperature, precipitation patterns are expected to change. The effects of these changes may be beneficial or troublesome depending on geographic region, and severity will also differ by region. However, globally speaking, the consequences of climate change are expected to be negative and impose substantial societal costs (IPCC 2007). On April 17th, 2009, the EPA announced that CO2, methane, nitrous oxide, and hydrofluorocarbons are harmful to public health (Miller, 2009). This declaration requires federal regulation of these pollutants under the Clean Air Act. Though the details are still unclear, the regulation will likely take the form of either a cap-and-trade system or taxing.

U.S. Fuel and Emissions Regulations

In early 2007, President Bush announced his "Twenty in Ten" plan to reduce fuel use by 20% over ten years (White House 2007). Shortly thereafter, the Energy Independence and Security Act of 2007 was passed which includes increased production of biofuels, an increased national fuel economy standard of 35 miles per gallon (mpg) for light duty vehicles (LDV) sales by 2020, and tax incentives for those who wish to purchase hybrid vehicles (Sissine 2007). In mid-May of 2010, President Obama ordered the U.S. Department of Transportation and Environmental Protection Agency to develop fuel consumption and GHG emissions regulations for medium- and heavy-duty trucks, as well as develop stricter passenger vehicle fuel economy standards that would require 35.5 mpg by 2016 (Transport Topics, 2010). The standards are expected to be final by July 30, 2011, and would be effective starting with model year 2014.

The Clean Air Act of 1970 authorized the regulation of stationary and mobile source emissions in the United States. Soon after, the Environmental Protection Agency (EPA) was established enforce these regulations. In 1990, Title II, Provisions Relating to Mobile Sources, tightened emissions of mobile sources starting in model year 1994 and regulated the sulfur content of diesel fuel by allowing no more than 0.05% by weight starting in 1993 (EPA 2008).

The U.S. Environmental Protection Agency (EPA) and the California Air Resources Board (CARB) have placed limits on pollutants emitted from mobile sources. In 2000, the EPA passed new diesel emissions standards that began with phase 1 in 2004, phase 2 in 2007 and phase 3 in 2010. Table 9 summarizes CARB, 2004 EPA and 2010 EPA emissions standards. Phase 1 in 2004 reduced NOx emissions standard by 50%, and the end result of the 2010 standards will be equal to eliminating 90% of heavy-duty vehicle miles (EPA 2000). Other than PM standards which will be fully implemented in the year 2007, standards of NOx and NMHC will be implemented in a phased manner by sales with 50 % of the engines sold expected to meet standards in the year 2007-2009 and all of them meeting the standards by the year 2010.

Greenhouse gases (GHG) have now been identified by EPA as a public health threat requiring regulation at the federal level (Miller, 2009). In the last year, several federal proposals for carbon cap-and-trade and taxing policies have been considered (Bean and White, 2008). In June 2009, the American Clean Energy and Security Act was passed by the House of Representatives which, if passed by Senate and President Obama, will set nationwide GHG reduction targets of 17% below 2005 levels by 2020, and 83% below 2005 levels by 2050. Reaching these targets would be achieved in part by a cap-and-trade system that would include energy and industrial sectors, and possibly others. While policy details remain unclear, GHG and fuel regulations that will affect trucking can be expected in the near future.

II. ROAD-USER CHARGING

With increasing fuel economy and political opposition to raising state and federal fuel taxes, and rising traffic congestion, transportation policy makers are considering road-user charging strategies as an alternative to more traditional methods of managing traffic and financing transportation infrastructure. These strategies include toll roads, high-occupancy vehicle toll (HOT) lanes, truck-only toll (TOT) lanes, cordon and area-wide charging, and mileage-based[3] fees. While many of these strategies have been implemented to some degree in Europe, only traditional tolling and HOT lanes have been implemented in the United States.

Now that many states and localities have goals to reduce GHG emissions, these strategies are also being considered as a means of meeting these goals, in addition to funding the facility and reducing congestion. In general, congested traffic produces more emissions per vehicle-mile than does free flow traffic, and so, reducing congestion is expected to reduce emissions. Of course, real scenarios are more complex, and there are many factors that can affect a strategy's effectiveness in reducing emissions, including:

- the severity of congestion prior to the strategy's implementation,
- the severity of congestion after the strategy's implementation,
- the specific pollutant being targeted,
- a strategy's future impact on land use, vehicle ownership, number and destination of trips, mode, time and route of travel, travel speed, and traffic flow.

[3] Also known as pay-as-you-drive (PAYD) fee, VMT fee, or VMT tax.

Table 1 shows the potential impacts of various user-charging strategies. It can be seen that the impacts of some strategies are more complex than others.

Table 1: Potential Transportation Responses to Tolling and Pricing. (Source: Cambridge Systematics and CH2M Hill, 2009a)

Strategy	Potential Impact								
	Land Use (Housing, Business)	Number and Type of Vehicles	Number of Trips	Destination of Trips	Mode of Travel	Time-of-Day of Travel	Route of Travel	Travel Speed	Congestion/ Traffic Flow
Traditional Road and Bridge Tolls	●		●	●	●		●	●	
HOT Lanes						●	●	●	●
Express Toll Lanes	●		●		●	●	●	●	●
TOT Lanes							●	●	●
Cordon or Area	●	●	●	●	●			●	●
Tollways Areawide	●	●	●	●	●		●	●	
Mileage or Carbon Fee	●	●	●	●	●		●	●	●

Studies examining the effectiveness of these user charging strategies to reduce fuel consumption and emissions have yielded varying results, and it should not be assumed that the use of these strategies will always result in reductions. Even in cases where charging strategies are effective in reducing emissions on the facility they manage, some are not likely to be effective in achieving large statewide reductions. For example, recent estimates suggest that HOT lanes have the potential to reduce fuel consumption in an urban area by just 1.4-2.5%. If HOT lane systems were implemented in urban areas nationwide, national fuel consumption could decrease by 0.5-1.1% (Cambridge Systematics and CH2M Hill, 2009a). To meet the targets in many state and regional climate action plans, much larger reductions will be needed from the transportation sector.

The exception to this is mileage-based charging, which can be implemented statewide, and has greater potential for reductions than other charging strategies that are typically limited to certain facilities.

Mileage Pricing

Fuel taxes have remained at the same level since 1993 while vehicle fuel economy has increased (FHWA, 2008). While this improvement in fuel economy is beneficial for reducing our nation's dependence on oil and contribution to climate change, it has negatively impacted transportation funding. As vehicle fuel economy increases, the amount of tax collected per mile driven decreases. At the same time, inflation and the rising cost of construction materials further limit the collected fuel tax. Mileage pricing is a concept that consists of replacing fuel taxes with a fee that is based on the number of miles a vehicle is driven.

Charging of this sort is not practiced anywhere in the U.S., though it has been studied and tested in various states. Illustration 1 shows states that are currently, or have previously, conducted studies on VMT pricing. In 2006, a pilot study sponsored by the Minnesota Department of Transportation and the Federal Highway Administration showed that VMT pricing had a measurable, though small, impact on miles traveled (Cambridge Systematics, 2006). Shortly after, Oregon also had a pilot test that showed that a GPS-based mileage fee system is feasible, and that it could also be used to charge variable fees based on time of day (Rufolo and Kimpel, 2008). The results of this test showed decreased driving for the case of variable fees.

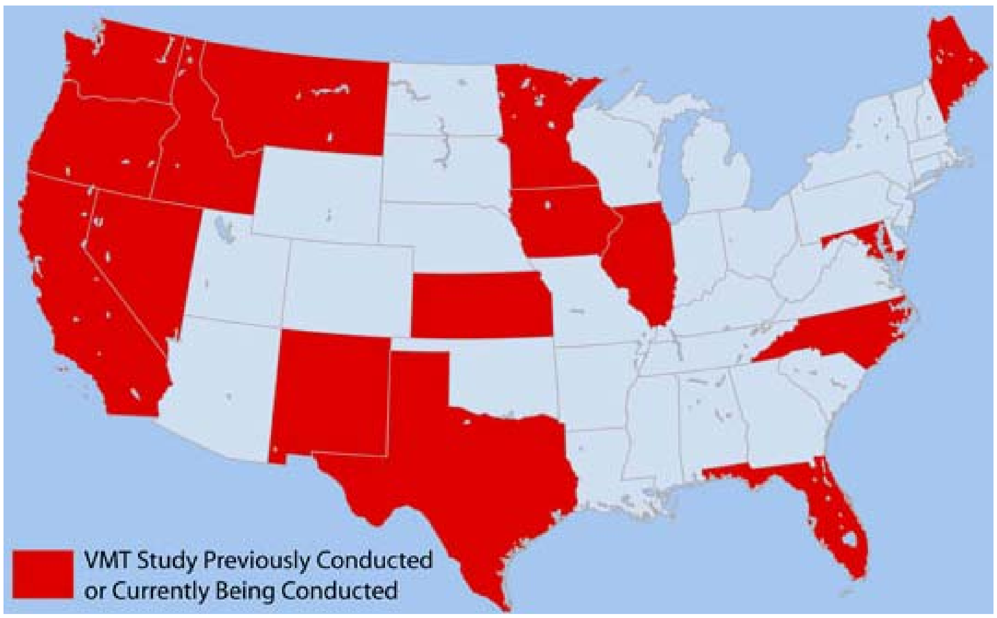

Illustration 1: States Conducting VMT Pricing Studies. (Source: www.vmtfeenv.com)

Of all pricing strategies, variable VMT pricing has the greatest potential for reducing fuel consumption and GHG emissions. Flat rate VMT pricing could reduce overall vehicle miles traveled, which obviously directly reduces fuel consumption. Variable VMT pricing would have the added benefit of shifting a portion of trips from peak periods to off-peak periods. This will reduce congestion and fuel consumption related to idling and stop-and-go traffic. What makes VMT fees truly unique among pricing strategies is the ability to impact travel on all roadways within a large boundary (e.g. state or country borders).

The trucking industry is heavily opposed to VMT fees, as stated by American Trucking Association Vice President, Bob Pitcher (PR Newswire, 2010). One reason for this is the fact that heavy truck fuel economy has remained nearly the same since 1993, so the same amount of tax is being collected per mile (ICF, 2009). Of course, this justification doesn't address the loss in revenue due to inflation, but a VMT fee won't either unless there is a provision to increase the fee with the rate of inflation. While this is a valid point, a VMT fee would replace fuel taxes, not supplement them. Overall, trucks would not be paying any more money with a VMT tax than with a fuel tax. In addition, without VMT fees, trucks will be paying an increasing share of fuel taxes as passenger vehicle fuel economy improves.

VMT fees for trucks have many advantages, relative to passenger vehicle VMT fees. Most trucks already have the necessary equipment installed. Driver privacy is not an issue because fleets have the right to know the location of their trucks (except for owner-operators), and there are fewer sources from which to collect the fees. A pilot study for truck VMT fees in New York state will attempt to develop a revenue-neutral system for collecting truck VMT fees, and is planning to test the system with the voluntary participation of truck fleets in late 2010 (Mudge, 2010).

Many countries have had success with truck tolling systems that charge based on a combination of distance, number of axles, and vehicle emissions class (e.g., Euro I through VI). Germany's truck tolling system, LKW-MAUT, charges heavy trucks driving on autobahn roadways based on distance, number of axles, and vehicle emissions category (but not based on weight). Overall, the tolling system is successful in generating revenue, encouraging purchase of lower emission vehicles, and more efficient use of truck trips (Broaddus and Gertz, 2008; Kossak, 2006).

Switzerland's truck toll, LSVA, charges trucks weighing over 3.5 tons, and rates vary by vehicle class and tailpipe emissions. The fee is charged per ton-km under the assumption that all trucks are always fully loaded (i.e., capacity weight is used to calculate fee, rather than actual weight) (Krebs, 2004). This has successfully encouraged trucks to take advantage of their capacity and operate more efficiently. VMT is decreasing while ton-kms are increasing (Krebs, 2004; Broadduss and Gertz, 2008). Austria has a similar scheme for trucks weighing more than 10 tons that charges per axle, and the charge varies by emissions rate. The scheme will begin including vehicles over 3.5 tons in 2010 (Fiala, 2009). The charge currently exists only on freeways, and there are plans to expand the charge to lower class roads.

Cordon Pricing

Cordon pricing schemes are those that charge for entering or traveling within a specified area, typically with an enclosing set of roadways as a boundary. Cordon schemes can be administered as a flat or variable rate, and can be designed to reduce congestion, emissions, or both within the cordon.

While there are no examples of cordon pricing in the U.S., there are many abroad, and mostly in Europe. The first cordon pricing scheme started in 1975 in Singapore as a daily charge, and was upgraded to a fully automated system in 1998. The upgrades included variable pricing by time of day. It successfully reduced traffic by 13% and increased travel speeds by 22% (FHWA, 2008).

In 2003, London, England, began congestion charging at a flat per-day rate on weekdays from 7 a.m. to 6 p.m., which resulted in 15% reduction in traffic and 30% reduction in delay with no significant overspill to roadways outside the cordon (FHWA, 2008). Many of the vehicle trips that were eliminated during the charge time either shifted to transit, changed their trip time, or did not make the trip. Significant environmental benefits were observed, including NOx and PM emissions reductions of 13% and 15%, respectively, in 2005 compared to 2002 (Wedlock, 2007).

Stockholm, Sweden began its cordon pricing in 2007, and has experienced an immediate 22% reduction in vehicle trips, 9% increase in transit ridership, 14% reduction of exhaust emissions within the cordon, and 2-3% emissions reduction within the bounds of Stockholm county (FHWA, 2008). Of course, this would be an even smaller nationwide reduction.

In addition to congestion charging, London also has a low-emissions zone (LEZ) charging scheme that started in 2008. Heavy trucks larger than 3.5 tons are charged a daily rate if they do not meet Euro III PM emissions standards by 2008, and Euro IV PM emissions standards by 2012 (TFL, 2009). Dozens of other cities in Europe have already introduced LEZs or are in the process of introducing them, as shown in Illustration 2.

Illustration 2: LEZs in Europe. (Source: LEZ, 2010)

Managed Lanes

Managed lanes allow certain types of vehicles, while restricting others, with the goal of maintaining improving traffic flow for those allowed vehicles. Some managed lanes rely on the vehicle restrictions and natural driving behavior to maintain traffic flow, such as bus-only lanes and HOV lanes. Others utilize financial incentives to control traffic flow, such as high-occupancy toll (HOT) lanes and truck-only toll (TOT) lanes.

TRUCK-ONLY LANES & FACILITIES

In addition to the benefits of user charging discussed previously, truck-only lanes and facilities have merits of their own. Separating heavy trucks from passenger vehicles would eliminate crashes involving both vehicle types along those corridors on which the strategy was implemented. In the long term, creating a separate network for trucks (and banning them from equivalent portions of the passenger vehicle network) could allow for cost savings, per mile, in construction and maintenance of the network (De Palma et al, 2008). The facilities from which trucks would be banned could be maintained to lower, and cheaper, standards, and possibly require maintenance less frequently. The corresponding truck-only facilities along the same corridors would still need to be built to standards that accommodate frequent and heavy loads, but they would likely be fewer lanes than the passenger facilities. Overall, fewer lanes would be built to truck standards. However, the TOT facility’s pavement may deteriorate faster due to the consistently heavy loads (Cambridge Systematics, Inc., and CH2M HILL, 2009c).

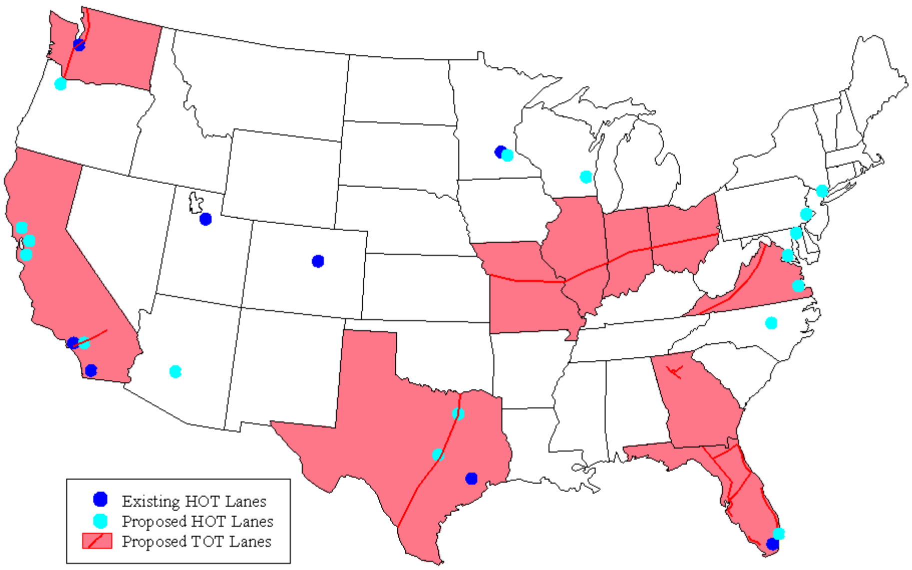

Illustration 3: Existing and Proposed HOT and TOT Lanes in the U.S.

Table 2: Proposed TOT lanes in the United States (Source: Chu, 2007)

State	Proposed Corridors
California	SR-60, I-710 and I-15
	Around 142 miles of 2 lane TOTL
Florida	Six Major Corridors
	I-95 from Miami to Titusville
	I-95 from Daytona to Jacksonville
	I-75 from Naples to Fort Meyers
	I-4 from Tampa to Daytona
	I-75 from Venice to Florida/Georgia Border
	I-10 from Lake City to Jacksonville
Georgia	Study conducted by Meyers, 2006 recommended
	TOT lanes on I-75, I-85 and I-285 in metro Atlanta region
	15 mile TOT lanes also considered in I-75 in Cobb and Cherokee county
Illinois	I-70; Mid-City Freightway in Chicago
Indiana	I-70
Missouri	2 lane TOT lanes considered on I-70
Ohio	I-70
Texas	Trans Texas Corridor (I-35 and I-69)
	600 mile long with 2 TOT lanes
Virginia	TOT lanes in 325 miles of I-81 through the Shenandoah Valley
Washington	Washington Commerce Corridor
	Considering 280 miles of 2 lane TOT lanes

Truck-only lanes and facilities can reduce fuel consumption in two ways: reducing congestion, and increasing trucking efficiency by allowing longer and heavier vehicles. The benefits of truck-only lanes and facilities in a given location can be expected to increase and decrease with truck VMT (De Palma et al, 2008; Rodier and Johnson, 1999). Other factors influencing the success of this strategy include whether or not the facility is tolled (and truckers' willingness to pay that toll) and if its use is mandatory or voluntary.

Currently, there are no truck-only toll facilities in the U.S. (Illustration 3), but there have been many proposals as seen in Illustration 3 and Table 2. Most proposals can be categorized as one of two types: long-haul truckways or urban short-haul truck-only lanes (Cambridge Systematics, Inc., and CH2M HILL, 2009c). Long-haul truckways are typically meant to provide a facility on which longer and heavier trucks could operate. These facilities could be built in such a way that would allow trucks to operate at higher speeds (although speed governors may present an issue here), and they would be separated from the peak period congestion caused by passenger vehicles. In contrast, urban short-haul truck-only lanes span much shorter corridor segments, and, if the corridor is heavily congested, can significantly benefit travel times of both passenger and freight vehicles. In both cases, if use is not mandatory, a toll would need to cost less than the driver's perceived savings gained by using the facility. According to estimates from U.S. studies, the expected construction cost, per lane-mile, is $1.4 million for at-grade rural TOT facilities and $10-30 million for urban facilities[4] (Cambridge Systematics, Inc., and CH2M HILL, 2009c).

In 2002, the Reason Foundation concluded that a long-haul, tolled, barrier-separated network for trucks would be financially feasible, and possibly even profitable (Poole and Samuel, 2004). This proposed network consisted of barrier-separated lanes that would be built in existing rights-of-way, and would allow for heavier, longer, and more productive trucks. Heavier and longer trucks would not be allowed to travel on the passenger lanes, and therefore these lanes would not need to be upgraded. The financial feasibility of this proposal can be largely attributed to the constraint of building within existing rights-of-way. A similar idea (US DOT, 2000) that did not include this constraint was found to be financially infeasible.

Other long-haul truckway proposals in the U.S. include I-15 in California[5]; I-70 in Missouri, Illinois, Indiana, and Ohio[6]; and I-35 and I-69 in Texas[7] (Cambridge Systematics, Inc., and CH2M HILL, 2009c). The California study concluded that the TOT lanes were the least cost effective option for that specific scenario, and projected tolls would not cover the estimated construction, maintenance, and operational costs. The

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[4] Elevated urban facilities are expected to be closer to $30 million, and at-grade urban facilities closer to $10 million.

[5] I-15 TOT lanes would stretch 45 miles from Victorville to SR 60.

[6] 800 miles long.

[7] Both were part of the Trans-Texas Corridor proposal, and were to stretch from a U.S. state border to the Mexico border.

multi-state I-70 project is still being considered, and the feasibility study is currently underway. The proposed truckways in Texas were both part of the Trans-Texas Corridor proposal, which is no longer being considered as it was originally defined. However, future proposals for both I-35 and I-69 could include truck-only lanes to some degree.

Short-haul urban truck-only lanes proposed in the U.S. include California's I-710 and SR 60, Florida's Miami freeways, Georgia's Atlanta freeways, and the Mid-City Freightway (as part of the Mid-City Transitway Corridor project) in Chicago (Cambridge Systematics, Inc., and CH2M HILL, 2009c). The California and Florida studies concluded that tolling would only recover 30-50% of costs and would need additional funding to implement TOT lanes in those locations. In addition, the peak travel times for passenger and truck traffic along the California corridors did not coincide, thus limiting the potential time savings gained from TOT lanes. In Atlanta, TOT lanes were shown to be the most beneficial strategy for reducing congestion, relative to the base case (HOV lanes) and alternative strategy (HOT lanes) (Meyer et al, 2006). The Mid-City Freightway is an alternative being considered to reduce congestion on Chicago-area freeways; it would act as a bypass for freight vehicles. The facility would reduce traffic on competing roadways by as much as 35%, and would raise $409 million in 20 years with tolls at current I-pass[8] levels (Urban et al, 2009). However, no construction, maintenance, and operational cost estimates were available, so it is unclear if additional funding would be needed.

[8] I-pass is the Illinois automated toll system. The average toll plaza charge for a class-8 truck is $4 during the day, and $3 at night (Illinois Tollway, 2010).

There has been very little work in identifying emission benefits of TOT lanes. Chu and Meyer (2009) estimate using MOBILE 6.2 that voluntary and mandatory usage of TOT lanes would reduce total CO_2 emissions on freeway sections by 62% and 60% respectively. These results are similar to those found for strategies involving HOV and HOT lanes.

HOT LANES

A study estimated that emission reductions for HOV lanes in California varied (depending on level of HOV lane utilization) between 10% and 70% for the facility being managed (Boriboonsomsin and Barth, 2007). Of course, savings from managed lane strategies at a regional level are less impressive. Studies conducted by Cambridge Systematics on impacts of HOT lanes in the Minnesota region reveal a potential to reduce fuel consumption by 0.9% in 2010 to 2.5% in 2030. A similar study in the Seattle area reveals a potential reduction in fuel consumption of 0.1% to 1.4%. The study extrapolated the results to urban areas in the nation and estimated that HOT lanes could reduce national fuel consumption from 0.5% to 1.1% (Cambridge Systematics Inc. and CH2M HILL, 2009).

Though these estimates are from HOT lane studies, it is likely that the regional savings from TOT lanes will be of the same magnitude, or even lower. The number of corridor miles in the U.S. where TOT lanes are applicable is probably less than that for HOT lanes. Assuming HOT and TOT lanes are deployed throughout the country, the savings from TOT might be less due to fewer applicable miles. However, it is possible that TOT lane candidate roadways have a much lower average fuel economy due to the high proportion of trucks, which may make TOT lanes more effective than HOT lanes in reducing fuel consumption per mile. Even so, the magnitude of savings will likely be small relative to regional or statewide GHG emissions targets. However, they may be very effective in reducing criteria pollutant emissions at the facility level in an attempt to reach attainment status.

Trucker/Carrier Opinions of User Charging

For successful implementation of pricing strategies, it is important to consider the opinions of the target users. How they value time and money will most definitely impact the success of the new facility. In the trucking industry, these values are different among types of trucking, location, and company structure. The priorities of a long-haul trucker will likely differ from those of a short-haul or just-in-time trucker; companies that regularly do business in the northeast are likely to be more comfortable with tolling than those that typically do business in areas where tolling is not commonplace; owner/operators that pay for tolling out of their own pocket are less likely to consider a tolled road than private or for-hire fleets. Because of these differences, it is very important to cater the plans of a given pricing strategy project to each location and its traffic composition.

Surveys and focus groups administered in various parts of the U.S. have revealed many critical opinions of the trucking industry on pricing strategies, specifically tolling and truck-only toll lanes. In 2007, a survey that focused on truckers' response to proposed optional TOT lanes in Atlanta received responses from 71 diverse Georgia-based trucking companies (Short, 2007). The results revealed that 25% of truckers do not change their route to avoid congestion, while 49% and 42% will change their route to avoid congestion or a typically congested time of day, respectively. While nearly all respondents were willing to use a truck-only lane that was not tolled, only 40% were willing to pay for it at a cost of 5 or more cents per mile. Excluding those that were not willing to pay, the average value of time reported by respondents was 12 cents per mile, or $7.20 per hour (assuming a speed of 60 mph).

A similar survey was administered to long-haul truck drivers in Knoxville, Tennessee and received 500 responses that were evenly distributed between independent and carrier-employed truckers (Adelakun and Cherry, 2008). They found that 42% of drivers will not change their route to avoid congestion, and 31% of all drivers express this behavior while also expressing that they experience severe congestion. Roughly half of drivers are willing to change their schedule to avoid congestion. Though the survey was administered in Tennessee, the participating truckers were based in many U.S. states, and so the authors consider their results to be transferable to other areas of the country. The average amount drivers were willing to pay to avoid 10 minutes of congestion was $1.75 (approximately $10/hour). When excluding those that were not willing to pay, the average value increased to $5.92 per 10 minutes saved (approximately $35/hour). Overall, drivers disliked aggressive, erratic passenger vehicle drivers and were in favor of managed lane configurations that minimized conflict between trucks and other vehicles (e.g. optional truck-only left lane, requiring trucks to use leftmost lanes).

Two studies in Texas were completed by the Texas Transportation Institute to catch a glimpse into trucker attitudes in Texas. One study included focus groups and a self-completion survey (with 30 responses) that focused on how route decisions are made within a trucking company, and who is ultimately affected by pricing schemes (Vadali et al, 2008). They found that, unless the load is time-sensitive, the truck driver is the primary route decision-maker. Even if there is a dispatcher to provide routes, it is a suggestion rather than a requirement. In addition, owner/operators will be paying tolls directly out of their pocket, while for-hire or private fleet drivers will not be paying tolls they choose to encounter. This implies that owner/operators are less likely to consider weighing the benefits of choosing a tolled route over a non-tolled route. A major concern for drivers regarding truck-only lanes/facilities was the potential for getting stuck behind a slower moving truck, and not being given a space in which to pass. The self-completion survey, which consisted mainly of responses from short-medium haul truckers, expressed a willingness to pay between 17 and 23 cents per mile (approximately $10-$14/hour, assuming a speed of 60 mph). The other Texas study focused on trucker opinions of SH-130, a new Austin bypass toll road. Of 2000 respondents, the majority were long-haul owner/operators. This survey explored their willingness to pay for time savings, and to explore incentives that may entice truckers to utilize a tolled facility. The average value of time savings was approximately $10 per 15 minutes, or $44.20 per hour. Incentives that received the most positive response were off-peak toll discounts and receiving a free trip after paying for a certain number. In California, typical values of time are over $30 per hour (Cambridge Systematics, Inc., and CH2M HILL, 2009c).

Overall, the price a truck driver is willing to pay to avoid congestion varies greatly by geographic location, hauling distance, and company structure. The assumed trucker value of time used by FHWA is $25/hour, which falls in the middle of these survey results ($7.20-$44.20 per hour) (Forkenbrock and March, 2005). In addition, a large fraction (25-42%) of truckers were not willing or able to alter their route to avoid congestion. This needs to be taken into consideration when deciding if a corridor is appropriate for TOT lanes. Even if the corridor's total truck volumes warrant TOT lanes, only a fraction may be willing to pay the toll, which will lower the effective truck volume.

Conclusions

First and foremost, the goals of road-user charging strategies are funding transportation infrastructure and improving traffic flow. In some cases, these strategies can also reduce fuel consumption and emissions, though typically not by an amount to make it worth considering implementation with these benefits as a first priority.

Corridor strategies, like HOV, HOT, and TOT lanes can be very effective in reducing fuel consumption and emissions along the corridor they are managing by 10% to 70%, as studies have estimated. The ability of these strategies to have such a drastic impact on emissions in a particular area may make them ideal for areas in non-attainment. However, even this large savings for the corridor does not translate to large state- and country-wide fuel and GHG emissions savings.

Strategies that can govern all roadways within a designated area, such as cordon pricing and VMT fees, have much higher potential for meaningful statewide savings, simply because the strategy impacts a much higher percentage of trips and vehicle miles. Of course, the ability of these fees to reduce fuel consumption and emissions is directly related to VMT reduction. If a VMT fee system is set up as a revenue-neutral replacement for fuel taxes, VMT reduction will likely be minimal. However, if the system is structured in a way that increases the cost of personal vehicle travel, VMT will fall, as will fuel consumption and emissions.

III. FREIGHT LOGISTICS IMPROVEMENTS

Strategies that involve a change in how existing vehicles and infrastructure are used are all logistical improvements. Logistical improvements that reduce fuel consumption are typically also improvements that reduce trucking miles. Expanding vehicle size and weight regulations, as well as packaging strategies, can allow more productive use of a trailer, thus reducing the number of truckloads needed to ship the same amount of goods. Encouraging consumers to purchase products from local sources will reduce the length of travel associated with that product. Reducing empty truck miles will make the trucking industry leaner by eliminating undesirable “overhead” miles. Finally, shifting truck miles to rail or water will allow for a higher average freight fuel economy without reducing the amount being shipped.

Expanding Vehicle Size and Weight Regulations

In the U.S. there are national truck size and weight regulations that apply to the interstate highway system. Prior to 1991, states were allowed to change restrictions on interstates within their boundaries. However, ISTEA allows interstate LCV operation in states where they were in operation before June 1, 1991 (Caltrans, 2009). Under national regulations, the maximum weight of a truck is 80,000 lbs (and maximum axle load is 20,000 lbs); the maximum length limit for a single trailer must be at least 48’, and 28’ for double trailers (US DOT, 2000). States are not allowed to require a lower maximum truck weight, nor are they allowed to require a lower maximum truck length. However, a state can choose to increase these maximum limits. For example, 19 states require maximum weights between 80,000 and 130,000 lbs or require maximum lengths between 75’ and 110’. The miles of roadway open to oversized trucks in each state ranges from 84 to 11,400, as seen in Illustration 4 (CTR, 2009).

Most oversized trucks in the United States are one of four configurations (Figure 4): Tridem, Rocky Mountain Double, Turnpike Double, and Triple. The first configuration is simply a single-unit truck with an additional axle on the trailer allowing for a heavier cargo load. This benefits loads that would otherwise reach the weight limit before utilizing the entire trailer volume (weighing out). The remaining three configurations offer additional volume over the standard single-unit truck, and are beneficial in situations where the trailer volume is completely filled, yet the truck is still significantly underweight (cubing out).

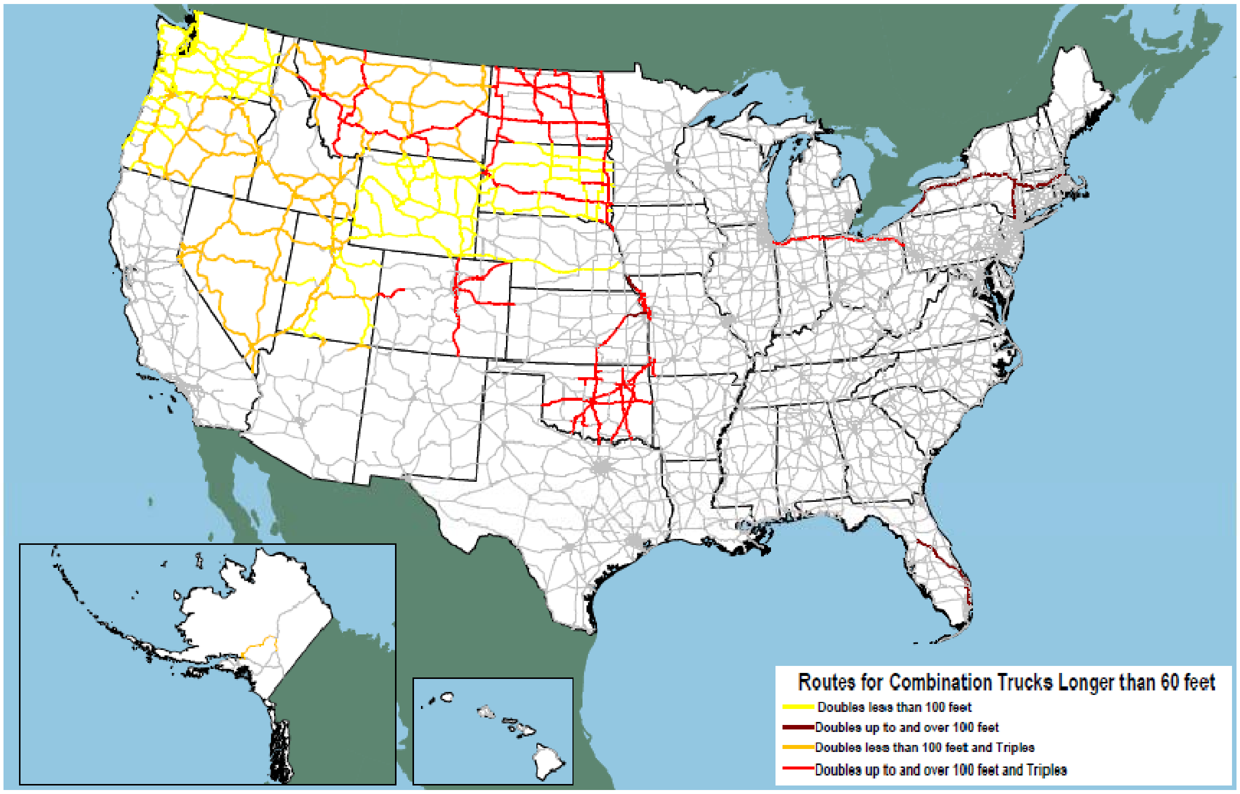

Illustration 4: LCV Configurations Allowed in U.S. States (Source: FHWA, 2008)

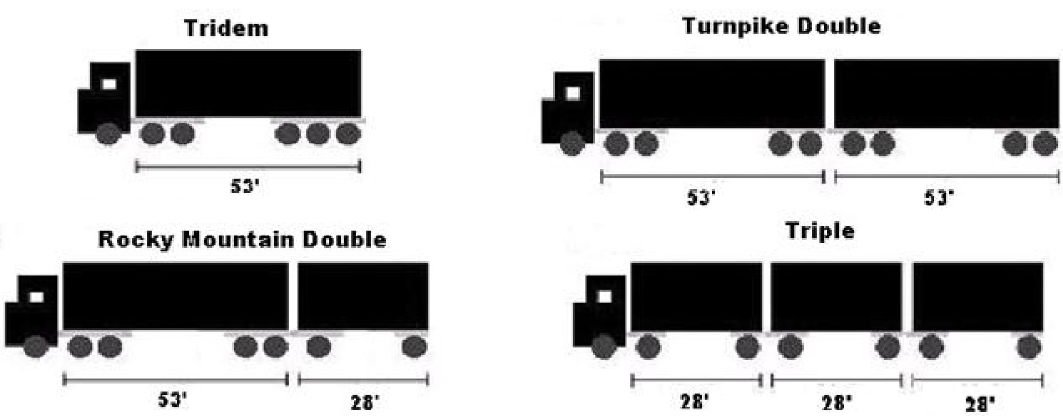

Illustration 5: Typical Oversized Truck Configurations in the U.S. (Source: CTR, 2009)

Table 3 shows the weight and volume capacity of typical LCV configurations as compared to a combination truck with 53' trailer.

Table 3. Weight and Volume Capacity of Common LCV Configurations. (Adapted from Cooper et al., 2009)

VEHICLE CONFIGURATION	MAX VOLUME (ft^3)	**VOLUME INCREASE (%)**	EMPTY WEIGHT (lb)	MAX. WEIGHT (lb)	**WEIGHT INCREASE (%)**
Baseline 53' trailer	4040	n/a	32,000	80,000	n/a
53 Foot Three Axle Trailer	4040	**0%**	35,000	97,000	**29.2%**
28 Foot Doubles	4200	**4%**	35,500	80,000	**-7.3%**
33 Foot Doubles	4950	**22.5%**	37,000	97,000	**25%**
Rocky Mountain Doubles	5750	**42.3%**	43,500	120,000	**59%**
28 Foot Triples	6300	**56%**	47,500	120,000	**51%**
Turnpike Doubles[9]	7300	**81%**	50,000	137,000	**81%**

FUEL SAVINGS

In theory, increasing truck size and weight should lead to a reduction of the number of trucks on the road, thus reducing driver needs, fuel consumption, and potentially the burden of trucks on traffic operations. Of course, reducing labor and fuel consumption would also reduce the cost of trucking. This is based on the assumption that the amount of freight being hauled by trucks remains the same. It is possible that over time, the lowered cost of trucking will encourage loads to be shipped via truck. This would potentially cancel out any fuel savings caused by increasing the size and weight limits for trucks.

9 In the study performed by Cooper et al. (2009), this is defined as two 48' trailers.

Between 60 and 80% of fuel consumed by a fully loaded freight vehicle is used to move the vehicle itself, and the remaining 20 to 40% is used to carry the load (Gilbert, 2004). This means that increasing payload can significantly reduce fuel consumed per ton-mile. Figure 1 demonstrates this relationship in terms of tonne-kilometers. Allowing LCVs and higher weight limits would take full advantage of this relationship by allowing truck engines to haul a heavier load. In Canada, the average load factor is 50% (Gilbert, 2004).

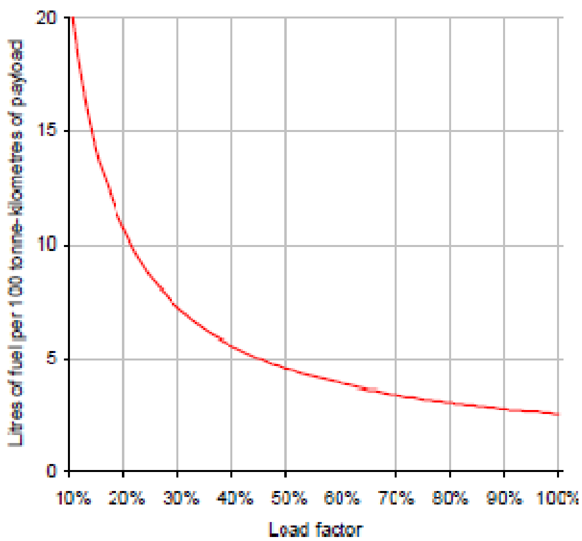

Figure 1: Relationship Between Payload and Fuel Consumption (Source: Gilbert, 2004)

Cooper et al. (2009) used simulation techniques to determine the expected fuel and CO2 emissions savings for each LCV configuration assuming volume and weight limited scenarios, as seen in Table 4. It was assumed that each vehicle configuration was powered by a 500 horsepower (hp) engine. Considering that a more powerful engine may be needed for LCVs to accelerate adequately on the roadway, the fuel and emissions savings was also estimated for the 53’ three-axle and turnpike double configurations assuming a 600 hp and 700 hp engine, respectively. The more powerful engine reduced fuel savings as compared to a standard 500 hp engine, as expected. However, the reduction was estimated to be small enough that an LCV with a more powerful engine is still much more efficient than a standard 53’ trailer. Canadian studies (Nix, 1995) have shown that the expected fuel savings from using Turnpike Doubles instead of single-unit trucks is 30%, which is similar to the fuel savings found by Cooper et al. (2009).

Table 4. Reduction in Fuel Consumption for LCVs, Cubed & Weighed Out. (Adapted from Cooper et al., 2009)

VEHICLE CONFIGURATION	TON-MPG @ 6.93 lb/ft^3 DENSITY	**% REDUX IN FUEL AND CO2**	TON-MPG @ MAX. WEIGHT	**% REDUX IN FUEL AND CO2**
Baseline 53’ trailer	115	n/a	172	n/a
53 Foot Three Axle Trailer (500 hp)	113	**-2**	203	**18**
53 Foot Three Axle Trailer (600 hp)	109	**-5**	195	**13**
28 Foot Doubles	114	**0.8**	158	**-8**
33 Foot Doubles	128	**11**	192	**12**
Rocky Mountain Doubles	138	**20**	218	**27**
28 Foot Triples	145	**26**	207	**20**
Turnpike Doubles (500 hp)	160	**39**	229	**33**
Turnpike Doubles (700 hp)	149	**29**	218	**27**

An L-P Tardif (2006) study measured the real fuel consumption of Turnpike Doubles in comparison to single-trailers. The average fuel consumption rate for a single-trailer was 7 mpg, and 5.4 mpg for a Turnpike Double. Considering that a Turnpike Double can carry twice the cargo of a single-trailer, the average fuel savings is 55%. This savings is quite a bit higher than the expected 30% savings using the simulation presented by Cooper et al. (2009). Of course, the simulation study also assumed a smaller 48' configuration for Turnpike Doubles. Real fuel savings will always be impacted by other factors such as vehicle characteristics, driver characteristics, payload and total vehicle weight, traffic flow and weather (L-P Tardif, 2006).

SAFETY OF LCV OPERATION

LCVs have been used in Canada (Quebec, Manitoba, Saskatchewan, Alberta, British Columbia, and Northwest Territory) and Australia for decades. Most European and U.S. studies conclude that LCVs can operate safely on highways under the assumption that these vehicles will be equipped with modern technology to enhance visibility and braking (CTR, 2009). According to Canadian experience, LCVs are as safe, or safer, than single-unit trucks. The operation of an LCV is usually contingent on adhering to more stringent requirements regarding driver experience and driving record, vehicle safety devices, and road network restrictions. An LCV owner is only issued a permit to operate the vehicle if these criteria are met.

In Saskatchewan, the collision rate for these "special permit vehicles" was only 20% of the overall heavy truck collision rate (L-P Tardif & Associates Inc, with Ray Barton Associates Ltd, 2006). In a study that included 7 fleets, the collision rate was 0.24 incidents per million vehicle-kilometers, which is roughly half that of the tractor-trailer incident rate in Ontario (L-P Tardif & Associates Inc, with Ray Barton Associates Ltd, 2006). These low collision rates are likely due, at least in part, to the strict driver requirements. Increased operation of LCVs should decrease the number of crashes involving trucks because of the lower crash rates of LCVs. In addition, when considering the safety of LCVs, there is evidence that the presence of a truck is more significant than the size of that truck. If this is true, LCVs could actually improve traffic safety by reducing the overall number of trucks in operation.

UPGRADING INFRASTRUCTURE FOR LCVS

Another potential issue related to allowing operation of LCVs is the ability of the existing infrastructure to support the increased size and weight of these vehicles. Roadway geometry, pavements, and bridges are designed to withstand the size and weight of trucks currently allowed. Increasing the allowable size and weight of heavy vehicles is going to accelerate deterioration of these facilities, and will increase infrastructure improvement requirements. Past research has shown that estimated impact on bridges in particular is expected to be the highest infrastructure cost due to new operation of LCVs. A University of Texas at Austin (2009) LCV study discusses these infrastructure upgrade issues in depth.

Reducing Freight Miles

Reducing the number of miles needed to transport the same amount of goods can be accomplished in a variety of ways including trailer loading techniques, compact or innovative packaging, moving production geographically closer to consumption, and improved coordination to reduce empty truck miles. Of course, reducing miles in the supply chain is not always desirable for a variety of reasons, and can have adverse affects.

LOADING STRATEGIES AND COMPACT PACKAGING

Through advances in material and packaging technology, the packaging of goods is becoming increasingly more compact. This reduces the amount of volume required to ship goods and allows for more units of a given item to be loaded onto a trailer, thus reducing overall trips, fuel, and driver hours required to transport the goods. Compact packaging may not be applicable to products that typically ‘weigh out,’ but will probably be very beneficial to those that typically ‘cube out.’ A similar tactic is strategic loading, which is the mixture of items with high and low unit weights to take advantage of a trailer’s weight *and* volume limits.

Examples of Packaging and Loading Techniques in Practice

A well known and recent example of compact packaging is concentrated liquid laundry detergent. Manufacturers are significantly lowering the water content in laundry detergent, resulting in a formula that is two or three times more concentrated than the original. A more concentrated formula allows for a smaller container which reduces the amount of material required for packaging (by 22-43%), and cuts the amount of space required for storage and transportation by 50-66% (McCoy, 2008).

Similarly, a new stackable milk jug design allows the storage and shipment of milk without a need for milk crates. This increases the number of milk jugs that can fit in an area by approximately 50%, and eliminates trips to pick up empty milk crates (Rosenbloom, 2008).

Frito Lay’s Dallas Region utilizes strategic loading by combining lighter chip loads with heavier dip loads. Doing so has allowed them to reduce their number of carrier truckloads by 7.6% in 2009 (and has reduced total truckloads by 2%), which is roughly equal to removing every 14th truckload from the road (Mike Ruscus, personal communication, May 3, 2010). Other strategies include using shipping boxes that double as display boxes, and reducing box height by a minimal amount to allow an extra row on a trailer.

Mazda Motor Corporation has taken advantage of compact shipping techniques and has measurably reduced their container needs and CO2 emissions. For example, better consolidation of parts and simplified packaging has reduced their container needs by 88 and 130 containers, respectively. These and other packaging changes have reduced their overall CO2 emissions by 481 tons (Mazda, 2005).

REDUCING EMPTY MILES

As noted previously in the section titled "Expanding Vehicle Size and Weight Regulations," improving the average load factor can reduce fuel consumption per unit weight of cargo. The majority (60%-80%) of fuel consumed by a freight truck is used to move the vehicle itself, and the small remainder (20%-40%) is used to transport the cargo. Obviously, an empty truck has a load factor of zero, and so reducing the miles that a truck is traveling empty will improve the average load factor. The EPA estimates that 15% or more of a fleet's annual miles will be empty, or deadhead (EPA, 2004).

Assuming 15,000 miles per year are deadhead, this is a waste of approximately 2,400 gallons of diesel and 24 metric tons of CO_2[10] (EPA, 2004).

EPA's SmartWay program recommends the following as potential strategies (those that are starred [*] require no capital investment) for reducing the number of empty miles traveled within a fleet.

- *arranging routes in a triangular pattern,
- *arranging backhauls with other companies,
- consulting a freight broker to arrange backhauls,
- *checking "load boards[11]" at truck stops for backhaul loads,
- *checking appropriate websites for load-matching opportunities,
- using an electronic data interchange system to communicate between dispatchers, drivers, and customers,
- and using route optimization software to achieve higher efficiency than manual dispatching (most beneficial for large fleets of 200 or more trucks).

BUYING LOCALLY TO REDUCE MILES IN SUPPLY CHAIN

Depending on the commodity and modes of travel, reducing miles within the supply chain can reduce emissions and fuel consumption. Of course shifting from rail to truck to reduce miles via a more direct route will likely not reduce fuel consumption and emissions. In addition, changing the location of food origin to shorten the supply chain length can have adverse affects on lifecycle emissions and energy consumption, even though it may reduce fuel consumption and emissions from transport of these goods. For

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[10] On a per mile basis, this translates to 0.16 gallons of diesel per mile, and 0.0016 metric tonnes of CO_2 per mile.

[11] Electronic boards that display updated lists of loads that are in need of a carrier.

example, Pirog and Benjamin (2003) estimated a substantial savings of transport fuel and emissions by obtaining food from regional (within state borders) or local (within 50 miles) sources rather than conventional sources that are 1500 miles away on average. However, Weber and Matthews (2008) found that only 11% of GHG emissions from household food consumption come from the transport of that food, and food consumption is only 13% of the average U.S. household's total GHG emissions. Even if transport of food products was (unrealistically) completely eliminated, this is only a 1.4% reduction of total U.S. household emissions. Furthermore, Capper et al. (2009) considered the complete process of food production and transport and found that it is usually more energy efficient to grow and produce items where it is naturally advantageous while requiring them to travel further, rather than producing things in smaller quantities at a location that is closer to the consumer.

Driver Training

Training drivers to use more fuel efficient shifting techniques, reduce unnecessary idling, reduce cruise speed, and drive with the flow of traffic (to reduce abrupt braking and accelerating) has been shown to improve fuel economy between 5 and 20%. Idling wastes nearly 1 gallon of fuel per hour, a cruising speed of 65 mph can result in 20% more fuel consumption versus 55 mph, and improper shifting and aggressive driving reduces fuel economy (Ang-Olsen and Schroeer, 2002; EPA, 2004). Driver training programs for improving fuel economy include:

- block shifting (e.g. from 2nd to 5th gear),
- progressive shifting (up shift at lowest possible engine speed),

- limiting unnecessary shifting,
- braking and accelerating smoothly/gradually,
- limiting unnecessary truck idling,
- reducing cruise speeds,
- and driving at lowest engine speed possible.

Monitoring drivers for use with incentive programs can encourage drivers to learn and use these techniques. The cost of training and monitoring equipment typically has a payback time of two years. Installation of speed-limiting and idle-control technologies would offer even further fuel economy improvements. If 5% FE improvement is achieved, this would result in an annual $1,200 and 8 tons CO2 savings per truck (EPA, 2004).

Of course, the savings of driver training programs will vary from fleet to fleet and from driver to driver. This variability in fuel savings could be due to the type and extent of training utilized, type of routes driven (urban versus long-haul), and pre-training driver skills. Fuel savings for urban trucking is likely to be higher than long-haul trucking for shifting techniques, and savings from training for drivers with inefficient driving styles will be more than that of drivers with efficient driving styles (EPA, 2004; Strayer and Drews, 2003).

A study in Canada found savings of 10% from driver training and monitoring (EPA, 2004). Two Canadian trucking fleets observed improvements of 18 and 20% from their driver training program (EPA, 2004). A study carried out for the European Commission found that an annual one day driving course resulted in 5% fuel economy savings (EPA, 2004). A study in Utah found that a two hour simulator-based training program resulted in a 3% savings that lasted at least 6 months after training and was transferable to other vehicles (Strayer and Drews, 2004). A study in Australia found that a savings of 27% can be achieved from a training program for long-combination vehicle drivers (Rose and Symmons, 2008). This particular training program consisted of classroom and in-vehicle training. It was determined that the classroom training by itself yielded no fuel economy improvement.

In addition to training drivers of manual transmission vehicles, a study undertaken at the Verkehrs-Sicherheitszentrum Veltheim (VSZV) in Switzerland concluded that shifting automatic transmission buses from drive to neutral while idling will reduce idling fuel consumption by 45% (Muster, 2000). Many trucking companies are moving towards automatic transmissions for trucks, meaning that the driver training techniques listed above will become less and less applicable (Les Findeisen, personal communication, June 14, 2010).

Route Optimization

Many studies have investigated the potential fuel savings from optimizing travel routes for freight truck as well as passenger vehicles. Route optimization, with the goal of reducing fuel economy, is done by assigning values to road segments via Fuel Consumption Factors (FCFs). These are usually estimated using modeling software that considers some combination of vehicle type, speed, roadway, traffic, and driver characteristics. These FCFs are relative to average fuel consumption, meaning that the average road segment would have a FCF of one. For example, a road segment that has characteristics requiring frequent acceleration and deceleration would be assigned a FCF higher than one, and a road segment that allows for constant speed would have a FCF lower than one. The FCFs are then used to assign fuel consumption “costs” to each road segment. Finally, the network can be optimized to identify routes resulting in minimum fuel consumption for a given origin and destination.

Most route optimization packages do not control for all variables affecting fuel consumption, and typically only consider traffic volume, density, and speed (Boriboonsomsin and Barth, 2008). Apaydin and Gonullu (2008) presented a model where FCFs were not calculated, and fuel savings was based solely on distance traveled and average vehicle fuel economy. Tavares et al (2008) developed FCFs based on vehicle type, speed, and road grade. Routes were optimized with respect to fuel consumption and compared with shortest distance routes. Although this analysis was more sophisticated, it neglected to consider traffic conditions and driver behavior. Ericsson et al (2006) appears to have performed the most comprehensive analysis, though the focus was on passenger vehicles. FCFs were calculated based on vehicle type, intersection density, presence of traffic calming measures, speed limit, neighborhood type (i.e. rural, urban, central business district), and traffic volume. In these studies, the optimized routes resulted in significant fuel and GHG emissions savings between 9 and 50%. Palmer (2007) developed a model that optimized routes in real time with the aim of avoiding severe traffic congestion that increases fuel consumption due to idling. The results showed that a CO_2 reduction of 5% is possible. In practice, however, the savings potential will vary from fleet to fleet, and will depend largely on how efficient routing practices are before the use of route optimization software.

Consideration of road grade within route optimization is receiving increased attention. Boriboonsomsin and Barth (2008) found that flat routes achieve 15%-20%

better fuel economy than hilly routes. Route optimization software that does not consider road grade could be recommending suboptimal routes. Of course, a big obstacle to incorporating road grade into commercial route optimization software is the lack of data.

Having this data available would also allow look-ahead gear-shifting optimization as described by Hellstrom et al. (2008), where the upcoming slope of the road is used to choose an appropriate gear, given a desired minimum and maximum cruising speed. This is in contrast to using cruise control that is commonly available in trucks. For example, look-ahead would not use fuel while descending a hill as long as the speed is above the minimum, versus cruise control that would use fuel while descending as long as it is below the set speed (and may require braking later once the vehicle speed surpasses the set speed. During the 75 mile pilot test, this look-ahead gear optimization technology was found to reduce fuel consumption by 3.5%.

Shift Freight from Truck to Rail or Short-Sea Shipping

Shipping freight by rail or water, where feasible, is more fuel efficient than shipping by truck. On average, marine transport is more fuel efficient than both truck and rail, by 3.7 and 1.4 times, respectively (TTI, 2009). In addition, rail and water emit less per unit distance than trucks of most criteria pollutants (NG and Perakis, 2009). Of course, an ICF (2009) study showed that the fuel efficiency gained by shifting from truck to rail can vary greatly depending on the route and equipment characteristics (Figure 2). The majority of variability in the rail-truck ratio is with the rail mode. As seen in the figure, truck fuel economy is rather consistent, ranging from roughly 70 ton-miles per gallon (tmpg) to 120 tmpg. Meanwhile, rail fuel efficiency bottoms out at 120 tmpg and caps at around 500 tmpg. In addition, there are other factors that shippers consider before fuel efficiency when selecting a mode, such as cost, transit time, and reliability.

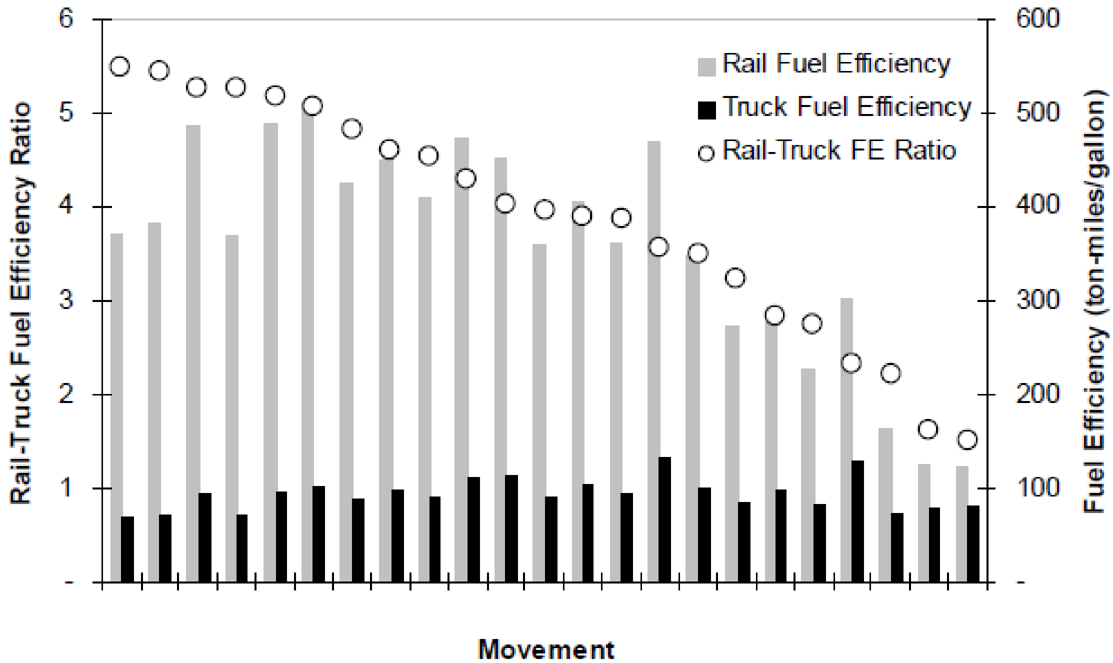

Figure 2: Variance in the Rail-Truck Fuel Efficiency Ratio. (Source: ICF, 2009)

A study showed that short-sea shipping (SSS) was the most cost-effective mode of freight transportation on four major U.S. trade corridors versus truck and rail, while also having the longest transit time (NG and Perakis, 2009). A survey of shippers showed that only 15% consider transit time to be highest priority when making transportation choices, while 48% and 37% value reliability and cost first, respectively (NG and Perakis, 2009).

For situations where SSS is not available, it may be beneficial to consider diverting truck trips to rail. The results of an NCHRP study included several actions that could encourage such diversions (Bryan et al., 2008). Among these, improving the rail network in a city center is likely the most expensive and most complex improvement action. This would involve resolving low capacity track segments, improving integration with other modes, and addressing the adequacy of urban rail terminals. Another strategy is to improve rail service to industry. This can be done by providing incentives for new industries to build on existing rail lines, and by catering rail service to existing industry sites. Providing public support for improving facilities to handle heavier and/or double-stacked trains could encourage shipments from markets that the current facilities don't allow. For example, some lower-density short-line routes haven't upgraded their tracks to accommodate the increased axle weight allowed after 1990. Reducing conflicts with other traffic flows by increasing congested line capacity and eliminating at-grade crossings will also encourage diversions.

Of course, the U.S. economy is shipping higher-value goods, like electronics, pharmaceuticals, and food, and shifting to just-in-time delivery, which requires smaller and more frequent shipments (EPA 2006). This trend may prevent a large share of truck traffic from being eligible for shifting to rail or water, since those shippers will place very high value on trip time. In addition, overall trip length is an important factor they may determine whether or not it makes sense to consider shipping by rail.

Conclusions

Simulations and experiences in other nations have shown that LCVs are much more energy efficient per ton-mile than the 53 foot long, 80,000 pound trailer that is allowed in the U.S. today, even when considering the larger engine that may be necessary. A turnpike double can result in fuel savings of 30%-50%, relative to the standard combination truck. The major concerns regarding the allowance of LCVs are decreased safety and increased infrastructure damage. As studies have shown, LCVs may actually improve highway safety, contrary to the common perception. The number of trucks on the road has a much higher impact on truck crash rates than does the size of the truck. Some reasons for this might be the fact that LCV drivers are held to much higher standards, and the vehicles are equipped with advanced technology to enhance vehicle braking and driver visibility. The impact of LCVs on pavements and bridges will be different for every state, because each state follows its own standards. In general, it is expected that bridge impacts will be more costly than pavement impacts. Perhaps the most interesting thing about expanding vehicle size and weight limits, relative to other strategies discussed in this report, is that the beneficiary is not responsible for maintaining pavements and bridges. In this respect, it especially important that any fees associated with operating LCVs need to accurately reflect the impact of these vehicles on the roadway infrastructure.

Where feasible, compact or innovative packaging is one way to increase the load factor on trailers, thus reducing the number of truck loads and fuel consumed. This is a strategy to be implemented by the manufacturer, and the manufacturer must also consider the primary purpose of packaging: marketing. If the consumer doesn’t like the new packaging, it may negatively impact sales. It is unlikely that a manufacturer will try innovative packaging at the risk of losing customers; any fuel savings would be negated by the drop in sales. Square milk jugs eliminated half the trips associated with milk delivery at a big box supermarket. However, the new milk carton style is not popular among users, and may be a key reason that other milk suppliers have not switched to square containers. On the other hand, compact packaging can also increase sales, if one is creative. For example, the recent focus on American obesity may be just the right time for smaller individual bags of chips that are marketed as being less than 100 calories.

Buying locally is another strategy that is tied heavily to marketing and consumer preference. Moreover, the consumer can be viewed as the primary decision maker, in this case. It is an individual's choice whether or not to shop for goods that are produced locally. Of course, producers can respond to this behavior by modifying their supply chain such that more of their products can be considered "local". While "buying local" is typically thought of as being a good deed, and it is not necessarily good for the environment. The transport of food products is only a small portion of the total energy required for the production of that food item. Opting to produce the food in a location that is closer to the consumer may be trading transport fuel consumption for a production site that requires more energy to make the same product. That is, growing food where it is naturally advantageous is usually the best option, even if that means a longer transportation haul.

Another strategy aimed at increasing the average trailer load factor is reducing empty truck miles. The approach to this strategy will differ based on fleet structure. An owner-operator is not likely to benefit from scheduling and dispatching software or routing techniques, but may find it very beneficial to check load postings at truck stops or on the internet.

Routing and scheduling technology has been used by fleets for several years, but typically not with the goal of optimizing fuel consumption or GHG emissions. Common optimization goals are maximizing profit and minimizing time. Relative to minimizing fuel consumption, these goals are simple. There are dozens of factors that impact fuel consumption, including distance, vehicle type, vehicle speed, frequency and duration of accelerations and decelerations, driver behavior, traffic conditions, roadway class, and roadway geometric characteristics. In the last few years, models have been developed for optimizing routes for lowest fuel consumption, and none of them consider all of these factors. First, inclusion of all of these factors would result in an overly-complicated model. Second, the data for some of these is not available, and has only recently become available for others. For example, real time traffic data is fairly new, and roadway grade databases are nonexistent for the entire U.S. network. Primitive models for reducing route fuel consumption only consider average vehicle speed and distance, which is essentially identical to a model that optimizes travel distance. Other models have included an extensive list of factors. It will likely be most effective to include only those factors that are most important to predicting fuel economy such as instantaneous vehicle speed, real-time traffic conditions, distance, and road grade. To include road grade in routing optimization, a serious effort for database development will be necessary. Another potential benefit of developing a road grade database would be to allow look-ahead gear shifting, which has also been shown to reduce fuel consumption.

IV. IDLE REDUCTION

An idling heavy-duty vehicle wastes approximately 1 gallon of diesel fuel per hour. In the U.S., a typical truck idles while at rest 1500-3000 hours per year, resulting in 500 tons of NOx emitted per day and 2 million gallons of diesel[12] wasted daily, costing approximately $1,790 per year per truck (Lee et al 2008, Muster 2000).

Using idle reducing technology reduces fuel consumption and emissions, and saves money. In addition, many states (25, as of July 2008) are regulating or banning truck idling (ATRI 2008). These idle reduction devices include auxiliary power units (APU), direct-fire heaters, truck stop electrification (TSE) and automated engine idle systems. Approximately 0.68 million trucks in the U.S. have sleeper cabs, and are prime candidates for these technologies (Frey & Kuo, 2007). Because these strategies are primarily vehicular, these will be discussed in detail in chapter VI.

In addition to the estimated 2 million gallons wasted during overnight idling, additional truck fuel is being wasted during queue idling. Strategies for reducing this type of idling rely mainly on logistics rather than technology, and these strategies are discussed below.

Queue Idling

Queue idling occurs when a truck is stopped, but must be running to maintain its place in line. The line may be traffic on the freeway or a queue at a weigh station, port terminal, border crossing, et cetera. Various strategies for reducing these queues, and thus

[12] The trucking industry consumes 38.5 billion gallons of diesel and gasoline per year (FHWA, 2008).

the associated fuel consumption and emissions, include electronic screening, virtual container yards (VCY), extended port gate hours, terminal appointment systems, and freeway traffic management strategies.

ELECTRONIC SCREENING

Electronic screening is the use of technology to automate procedures associated with the validation of information, broadly speaking. Within freight transportation, electronic screening is commonly used at weigh stations, border crossings, inland and marine ports, and tolling facilities.

In 1998, Iowa State University's Center for Transportation Research and Education conducted a study to determine the extent of fuel and time savings provided by electronic screening bypasses. The study concluded that bypassing of any scale type (static, weigh-in-motion [WIM], and high-speed WIM) results in measurable fuel savings. As expected, bypassing a static scale provides more fuel savings than bypassing a WIM scale. The measured fuel savings of bypassing a static, WIM, and high-speed WIM scale ranged from 0.16-0.18 gallons, 0.06-0.11 gallons, and 0.05 gallons, respectively (McCall et al, 1998). These savings assume there is no queue at the weigh station. Such queues typically have stop-and-go traffic averaging 2-4 mph, and can consume an additional 0.26-0.37 gallons per station. Therefore, the fuel savings of bypassing a weigh station, as estimated by McCall et al, can range from 0.06-0.55 gallons, and depends on the type of weigh station being bypassed and the queue length experienced by the truck.

PrePass[13], NORPASS, and NCPass are the major bypass service providers in North America. PrePass is a private company that offers its service in 29 U.S. states, and has nearly 370,000 trucks enrolled as of May 2010 (PrePass.com). This is approximately half of the 680,000 trucks with sleeper cabs in the U.S. On average, their enrolled trucks successfully bypass 12 stations per month. The cost of the service is $16 per month per truck.

Based on an Iowa State University (1998) study, they assume that each bypass saves 0.4 gallons of fuel and 5 minutes of time. According to a U.S. DOT (2007) study, this time savings translates to an operating savings of $8.68 per bypass, and includes vehicle maintenance, driver wages, administration costs, insurance and more. For the average truck, the fuel savings is not enough to make the system cost-effective unless diesel prices are $3.34 per gallon or higher. Of course, when considering the additional operating cost savings, the system is cost effective for any truck that bypasses two or more weigh stations per month.

NORPASS is a non-profit agreement between 9 U.S. states and Canadian provinces (Alaska, British Columbia, Connecticut, Idaho, Kentucky, New York, Quebec, South Dakota, and Washington), and two partner states (Oregon and North Carolina). There are no recurring fees for this service, and enrolled carriers only pay a one-time fee of $45 for the transponder, which is also compatible with other bypass service providers such as NCPass[14] and PrePass (NORPASS, 2010).

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[13] PrePass Plus is an extension of the PrePass service to include passage under E-Z Pass toll gantries.

[14] North Carolina’s bypass service.

Port Access Improvements

In 2001, an LA/Longbeach port study showed that 40% of all import, export, and empty truck trips have a wait time of at least 2 hours (Barber and Grobar, 2001). There are many port-specific operational strategies that aim to reduce truck congestion as well as the associated fuel consumption and emissions. This includes extended gate hours, virtual container yards, terminal appointment systems, variable pricing schemes, and upgrading rail service at the port.

In 2003, the California Assembly Bill (AB) 2650 required large ports to develop a strategy to reduce truck queueing at port terminals, or be subject to a $250 fee for each truck idling more than 30 minutes. The strategies recommended were extended gate hours (i.e., being open 70 or more hours per week) and an **appointment system**. There are a total of 13 terminals at the Los Angeles, Long Beach, and Oakland ports that are required to adhere to this bill. Of these, 7 chose to add an appointment system, 2 added an appointment system to extended hours of less than 70 hours per week, and 1 terminal chose to do nothing and was subject to the fine. No terminals chose to extend their hours, because an appointment system proved to be less costly (Giuliano and O'Brien, 2007).

While the bill aimed to reduce emissions, it lacked the structure to ensure accountability. If a terminal chose to use an appointment system, it did not have to require trucks to use this appointment system, and appointments did not have to receive priority over trucks that did not make an appointment. In addition, terminals didn't view this as an effective strategy, and made minimal effort to encourage use of the appointment system. As a result, a small percentage of trucks used the appointment systems (Figure 3)[15], and those appointments were not given a priority, so queues were not reduced (Giuliano and O'Brien, 2007). It was recommended that such a system could potentially be successful in reducing queues if appointments were given priority, and if a large proportion of total gate movements utilized the appointment system.

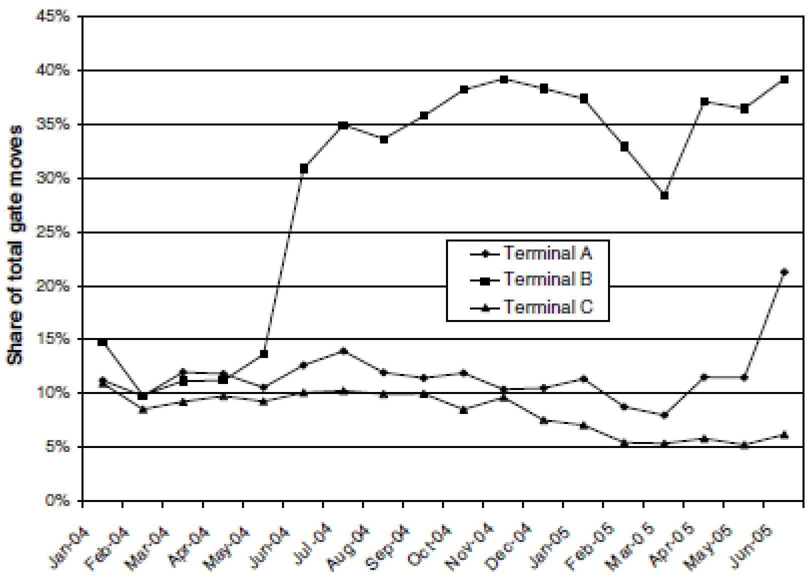

Fig. 2. Appointments as share of gate moves.

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Figure 3: Share of Gate Moves Using the Appointment System (Source: Giuliano and O'Brien, 2007)

A **virtual container yard** (VCY) is an internet-based system that allows for a truck delivering an import load to return to the port with an export load, rather than

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[15] The jump seen in terminal B's share of movements using the appointment system was due to a marketing strategy that wasn't used by the other terminals.

returning empty. Returning with a load is called a street turn. At southern California ports, it was estimated that only 2% of import trips return with an export load in the absence of a VCY system (The Tioga Group, 2002). Even with a VCY, it is estimated that the street turn rate can only be increased to 5%-10% due to a mismatch of location, timing, ownership, and commodity type. Facanha and Olsen (2008) found that an increase to 10% could result in a savings of 95 and 4 tons per year of NOx and PM at a cost of $1,922 and $46,555 per ton, respectively. The VCY is very cost effective in comparison to vehicular strategies like vehicle and engine replacement, but the potential for reducing emissions is much less. In addition, Fischer et al. (2006) found that a VCY has a low impact on reducing total truck traffic at ports and emissions relative to other port operational strategies such as extended gate hours (i.e. PierPASS) and port rail service improvements. This relatively low impact is due to the fact that VCY strategies only target empty truck trips and are limited to 10% penetration within that market, while other strategies have a much higher market penetration potential.

Cambridge Systematics (2009) studied the southern California PierPASS system to determine its impact on peak period truck traffic. The PierPASS program provides truckers with an incentive to move cargo during off-peak periods, such as weeknights and weekends. Such a program encourages peak-period traffic congestion reductions, and allows for better utilization of terminals' extended hours. Overall, the system was very effective in diverting truck trips from the day time period (6a-5p) to off-peak periods. Prior to PierPASS, 90% of trips were during the day time period, versus just 66% after the program had been in operation for a few months. In addition, the program has had a large impact on reducing I-710 weekday traffic over the course of two years (Table 5).

Table 5: Truck Traffic Distribution on I-710 (both directions) Before and After PierPASS.

	May 2005	**Sep 2007**
8a-6p	72.5%	59.4%
6p-8a	27.5%	40.7%

Even though the overall diversion trend was positive, there was an increase in truck congestion between the hours of 5p and 6p as trucks anticipated the beginning of the night time period. This could be avoided in the future with the use of variable pricing.

Conclusions

Electronic screening is technology used to transfer information between a vehicle and a transportation authority. This is applicable to trucking at weigh stations, on toll roads, and any other entrance queue that requires vehicle clearance for security purposes. Allowing a truck to bypass a static weigh station can save 0.2 gallon of fuel, plus an additional 0.25 gallon when accounting for the queue that would have been experienced at the weigh station. PrePASS, a major electronic screening provider in the U.S., charges approximately $16 per truck per month for this service. Considering that the average truck bypasses 12 weigh stations per month, the cost of diesel would need to be greater than $3.30 per gallon to offset the cost of the pass. When considering other savings the truck owner may experience, such as driver time and reduced maintenance needs, the monetary savings for the truck owner is much more. However, these additional benefits may be things that an owner-operator is not likely to focus on; they may be more focused on the immediate fuel savings, which is not likely to surpass the amount of the monthly fee by a significant amount. Of course, another benefit to bypassing weigh stations is the increased safety due to eliminating merge points on the freeway.

Idle reducing strategies specific to ports are appointment systems, extended terminal hours, and virtual container yard systems. An appointment system for a port terminal is typically meant to be voluntary, and the trucks that choose to schedule an appointment will receive some type of preferential treatment over those that do not schedule an appointment. The goal is to reduce queues at port terminals. In 2003, California passed a bill that required 13 terminals at the ports of Oakland, Los Angeles, and Long Beach to create an appointment system or face a charge of $250 for each truck caught idling more than 30 minutes. Terminal operators were not in favor of the appointment system and made little effort to allow it to be successful. The system was typically not advertised (with the exception of one terminal), and trucks received no priority if they made an appointment. Not surprisingly, the system had little effect on reducing queues, and thus fuel consumption and emissions. An assessment of the systems concluded that allowing schedule trucks to receive priority, and advertisement of the system would allow it to be more successful in achieving those goals.

A virtual container yard system is a web-based approach to matching tractors with trailers as they head back to the port. This is referred to as a street turn, and the typical rate of street turns is just 2%, meaning that 98% of tractors return to the port without a load. It is expected that a VCY system could increase street turns to 5-10%. Any increase in street turns will increase the average load factor, thus reducing fuel consumption. This strategy is found to be very cost effective as a tool to reduce emissions at ports. However, the maximum penetration of this strategy is quite low because it only targets a small niche of all truck trips.

Extended gate hours attempt to redistribute the arrival times of trucks to port terminals throughout a 24-hour day. Offering later hours as well as incentives to use the off-peak hours will reduce congestion at port terminals, as well as nearby roadways. In California, the PierPASS program was successful in reducing daytime truck arrivals from 90% to 66%, and reduced daytime truck traffic on a nearby freeway by 13%. However, due to the static pricing scheme, the ports experienced heavy queues just before the opening of the off-peak hours. A variable pricing scheme would alleviate this side effect.

VI. VEHICULAR STRATEGIES

This chapter is quite different from previous chapters, because the focus is on vehicular strategies, rather than operational strategies. The most obvious difference between these two strategies is the fact that vehicular strategies require modification to the truck itself, or perhaps even the purchase of a new truck. In contrast, Operational strategies attempt to reduce fuel consumption and emissions by changing the way owners use the vehicles they already have.

Engine and Fuel Types

Alternative engines and fuel types range from being the most expensive vehicular strategy available to having negligible or no cost. Purchasing a new truck that runs on alternative fuels is very expensive and can be up to twice the cost of purchasing a truck with a conventional engine. The cost may even be prohibitive for smaller fleets or owner-operators. On the other hand, using biofuels instead of oil-based fuels is an extremely inexpensive option. Depending on the current price of diesel and gasoline, the price of biofuels may be on par with, or even lower than, the price of oil-based fuels.

PETROLEUM-BASED DIESEL AND GASOLINE

In 2006, heavy-duty vehicles in the U.S. consumed 19.4% of energy and emitted 23% of greenhouse gases within the transportation sector (Davis & Diegel 2008). Of that, 89.6% of BTUs consumed by heavy-duty trucks were diesel, 10.1% gasoline, and 0.3% liquefied petroleum gas (Davis & Diegel 2008). Other heavy-duty vehicle types currently in use include natural gas and hybrid vehicles. Diesel vehicles dominate the heavy vehicle fleet because they are more powerful and more efficient (relative to gasoline engines). On average, single unit HDVs achieve 8.2 miles per gallon (mpg) and combination trucks get 5.1 mpg.

Nearly all of CO and HC, 58% of NOx, and 28% of PM mobile source emissions are from gasoline vehicles (EPA 2007). Of course, more gallons of gasoline are consumed per year, and when this is accounted for, a gallon of gasoline emits roughly 7 times more CO and 5 times more HC than a gallon of diesel. A gallon of diesel emits 2 times more NOx and 8 times more PM than a gallon of gasoline. Diesel fuel is more carbon intensive per gallon[16] and slightly more per unit energy. Of course, diesel vehicles are more efficient and emit fewer GHGs per mile than their gasoline counterparts. While petroleum diesel is the dominant fuel used to power heavy-duty vehicles, other fuels such as natural gas, biodiesel and emulsified diesel are also commercially available.

Emulsified diesel is a mixture of petroleum diesel and water that can be used in any compression-ignition engine. This mixture can separate if a vehicle is unused for more than 2 months and become harmful to the vehicle. Relative to pure diesel, emulsified diesel can reduce PM by 20-50% and NOx by 5-30% (EPA 2003). While it is effective in reducing emissions, the added water reduces the energy content of the fuel, and thus reduces power and fuel economy. In addition, the fuel is about $0.20 more per gallon than pure diesel.

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[16] The average gallon of gasoline contains 19.4 lbs CO2/gallon and diesel contains 22.2 lbs CO2/gallon (EPA 2009)

BIOFUELS

Production of biofuels has increased in recent years due to interests in reducing oil consumption and GHG emissions. From 2005 to 2007, biofuel production increased 40% and is expected to increase an additional 100% by 2015 (McDonnel and Lin 2008). Many state and federal initiatives are encouraging this trend, including former President Bush's Twenty in Ten plan, which aims to increase production of biofuels to five times that mandated for 2012 by 2017, resulting in 15% of gasoline and diesel demand in 2017 to be displaced with biofuels (White House 2007).

Biodiesel, a fuel made from vegetable oil and animal fat, is an alternative to diesel fuel and can be used interchangeably with petroleum-based diesel to power compression-ignition engines. Currently, biodiesel is approximately 10% of the biofuels market, with the majority being produced from soybeans (McDonnel and Lin 2008). Because crude oil is not required for production, increased use of biodiesel could decrease U.S. reliance on foreign sources of energy.

Biodiesel is available in pure form, known as B100, and in blends with petroleum diesel (e.g. 20% biodiesel and 80% petroleum diesel, known as B20). B20 reduces HC emissions by 13-21%, CO by 7-11%, PM by 10-20%, and increases NOx slightly by 1-2% (Van Gerpen et al 2007). Graham et al (2008) show that B20 is not effective in reducing tailpipe GHG, relative to petroleum diesel. However, Van Gerpen et al (2007) have found that biodiesel reduces GHG by 78% when considering the fuel's lifecycle, not just tailpipe emissions. Of course, as the proportion of biodiesel in the mixture increases, emissions of HC, CO, PM, and GHG decrease, while NOx emissions increase.

While B100 is more effective than B20 in reducing emissions (of PM, CO and HC), it may cause undesirable issues . B100 is a good solvent, causing paint to deteriorate if the fuel is spilled. This property also loosens deposits in used vehicles that will plug filters. To fix this, the tank, fuel lines and filters need to be cleaned. Storing a vehicle for long time periods leaves the fuel susceptible to chemical changes. Excess oxygen or water in the tank can react with the fuel and cause it to transform (Van Gerpen et al 2007, EPA 2003). Attempting to power a vehicle with this transformed fuel can be damaging. Lastly, the energy content of biodiesel is lower than petroleum diesel, lowering the relative power and fuel economy of biodiesel. To use pure biodiesel without experiencing the maintenance side effects, engine modifications would be necessary, deterring many fleets from using B100. In addition, biodiesel is more expensive than petroleum diesel, with B20 approximately $0.15-0.30 more per gallon, and B100 $0.75-1.50 more per gallon (EPA 2003). However, incentives at the state and federal level are making biodiesel increasingly competitive with petroleum diesel (Van Gerpen et al 2007).

Another downfall of biodiesel is the massive amount of land required to produce it in quantities large enough to satisfy U.S. yearly diesel consumption. In 1995, it was estimated that 65% of total U.S. agricultural land is needed to completely replace petroleum diesel with land-based biodiesel (Van Gerpen et al 2007). If all current U.S. soybean production was used to make biodiesel, only 6% of demand for diesel would be met (Hill et al 2006). In addition, recent studies have shown that converting non-agricultural land to grow feedstocks of biofuels can actually increase emissions (Searchinger et al 2008, Fargione et al 2008). To achieve GHG savings from biofuels, they must be produced without necessitating (direct or indirect[17]) land conversion. Yellow grease[18] is a biodiesel feedstock that doesn't require land conversion, but this method of production requires 1.7 times the energy required for soybean biodiesel (EPA 2007b). A study by the National Renewable Energy Laboratory (2009) found that there are sources in the U.S. that can produce the equivalent of 495 million gallons of biodiesel, with good yields.

Ethanol is a biofuel that is blended at various levels with gasoline. E10, also known as gasohol, is a blend of 10% ethanol and 90% gasoline. This blend is commonly found at fueling stations and can be used in most spark-ignition vehicles without negative consequences. Blends with higher ethanol content, such as E85, can only be used in spark-ignition vehicles equipped to handle this fuel (e.g. flexible fuel vehicles).

Using ethanol in place of gasoline reduces oil consumption and reliance on foreign sources of energy, and can also reduce GHG emissions depending on the method of production. The EPA estimates that relative to gasoline, on average, corn ethanol reduces GHG emissions by 22%, sugarcane ethanol reduces GHG by 56%, and cellulosic ethanol reduces GHG by 91% (EPA 2007). Facanha and Simiu (2008) compared the results of studies reporting the GHG emissions associated with ethanol production from various feedstocks in an attempt to deduce which type of ethanol (sugarcane, corn or

[17] Direct land conversion would be converting land solely to produce biofuel feedstocks. Indirect land conversion would be using existing supplies of biofuel feedstocks (e.g. corn, soybeans), thus causing land conversion to meet the demand of the feedstocks' previous use (food production, in most cases).

[18] Used cooking oil, typically from restaurants.

cellulosic) will provide the greatest GHG benefit. Even after considering the additional transportation required for sugarcane ethanol (from Brazil to the U.S.), it offers a greater GHG benefit than corn-based ethanol. Of course, cellulosic ethanol, which is made from grasses and unused portions of plants, can also reduce GHGs substantially, relative to gasoline and ethanol produced from other feedstocks. However, this type of ethanol is in early stages of development, and estimates of GHG benefit and maximum production volume are uncertain. Figure 4 shows the GHG emissions associated with gasoline and ethanol. Like biodiesel, any production of ethanol causing agricultural land-use changes could result in a net GHG increase.

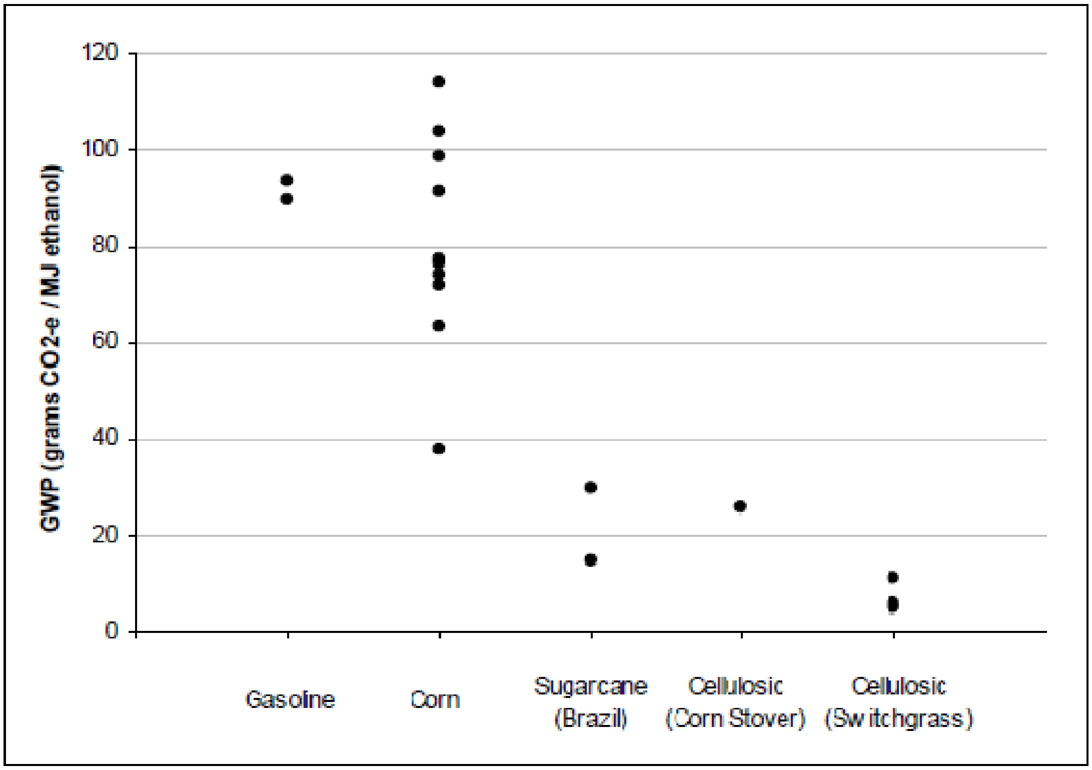

Figure 4: Comparison of Global Warming Potential Across Gasoline and Ethanol Feedstocks (Source: Facanha and Simiu (2008), Figure 1).

UNCONVENTIONAL FUELS

Liquefied Petroleum Gas (LPG) is the third most common fuel used to power heavy-duty vehicles. It is cleaner burning than gasoline (20% NOx reduction, 60% CO reduction). Eighty-five percent of LPG consumed in the U.S. is domestic, and it is cheaper than gasoline (DOE 2003, EPA 2009). However, the fuel is not typically available at fueling stations and most production vehicles cannot use the fuel without being properly converted.

Natural gas is another fuel used to power heavy duty vehicles, and the majority consumed in the U.S. is produced in North America (EPA 2003). Bus fleets are attracted to natural gas because of its substantial reduction in PM emissions. Buses are often running idle waiting for passengers to load or unload in densely populated areas, making it especially important to reduce PM and its adverse health effects.

Natural gas is available in two forms: compressed natural gas (CNG; 85-95% methane), and liquefied natural gas (LNG; nearly 100% methane). LNG is produced by liquefaction of CNG, which consists of cooling CNG to -259° F. CNG must be stored in high pressure tanks, while LNG must be stored in insulated containers to maintain its cold temperature (DoE 2008). Converting from CNG to LNG condenses the fuel, allowing for cost-effective transport. Typically, natural gas vehicles are just as efficient as gasoline vehicles on an energy basis. However, LNG has lower heat content than gasoline, meaning that 1 gallon of gasoline contains the same amount of energy as 1.5 gallons of LNG (DoE 2008). In addition, fuel costs are comparable with diesel on a per-mile basis (EPA 2002).

The advantages of natural gas, relative to petroleum diesel, are its 50% reduction of PM, NOx, and HC, and 25% reduction of CO2. Compression is less energy intensive than liquefaction, so the savings resulting from CNG is slightly higher than LNG. Of course, since natural gas contains so much methane (which has a higher global warming potential than CO2), a spill or leak would contribute substantially to GHG emissions. CNG vehicles are quieter than diesel vehicles, making them an attractive option where noise pollution is a concern (Kiel 2008), while LNG is cleaner burning, reducing engine maintenance costs and prolonging engine life (EPA 2002).

The cost of a LNG heavy-duty vehicle can be twice that of its diesel equivalent ($207,000 versus $110,000), but these premiums are expected to decrease over time, assuming the market matures and vehicles are produced in larger quantities (Kiel 2008, EPA 2002). Many subsidies are also available. For example, Los Angeles and Long Beach ports offer $105,000 for each LNG vehicle purchased as a means of improving regional air quality (Kiel 2008). The private fuel distribution and storage systems add $15,000-20,000 per vehicle. Of course, as LNG vehicles become a larger share of the market, the number of public refueling facilities will probably increase.

As of 2008, only one manufacturer, Cummins Westport, produces heavy-duty LNG engines, and only two truck manufacturers, Kenworth and Sterling, are producing trucks with these engines (Kiel 2008). Two engine sizes are available (8.9L and 15L), and the 8.9L engine already meets EPA's 2010 NOx emission requirements (Kiel 2008). During summer 2009, Clean Energy opened the largest natural gas fueling station in the world at southern California ports (Transport Topics 2009a).

Widespread use of natural gas faces challenges similar to hydrogen fuel: fuel storage, transport, lack of distribution infrastructure, and educating users. However, new dual-fuel (i.e., natural gas *and* diesel) vehicles may encourage use of natural gas vehicles without the need for widespread natural gas refueling infrastructure. LNG's extremely cold temperature could cause frostbite while refueling a vehicle. LNG vehicles being stored indoors for a week or longer could be a fire hazard because of the flammable gas vented by the vehicle. Training would be necessary to prevent both of these incidents.

Another transport fuel derived from natural gas is called Fischer-Tropsch (F-T), or **gas-to-liquid** (GTL) **diesel**, and can also be made from coal or biomass. This fuel can be used alone, or blended with conventional diesel. California has been using GTL as an additive to conventional diesel as means of reducing PM emissions (DOE 2006). Depending on the production process, GHG emissions from GTL diesel can be equal to or greater than that of conventional diesel (Jaramillo et al, 2008). The fuel is, however, successful in reducing emissions of HC, PM, CO and NOx by 30%, 30%, 35%, and 8% respectively (CEC 2006).

HYBRID ENGINES

In recent times, increasing attention has been paid to using hybrid heavy-duty vehicles, which are vehicles driven by power from multiple sources. Two types of hybrids are most common for heavy-duty vehicular usage: diesel-electric hybrid engines and diesel-hydraulic hybrid engines.

Diesel-electric hybrid vehicles contain an internal combustion engine, an electric motor powered by an alternator or generator, and an energy storage device. Note that the electric hybrid system for a light-duty vehicle is significantly different from the hybrid system for a heavy-duty vehicle. Many lightweight passenger vehicles employ a series hybrid system in which the engine energy is used to drive an electric motor which provides torque for the wheels. Heavier vehicles employ parallel hybrids where both the electric motor and diesel engines can be used to drive the vehicles through separate independent connections. For optimal performance, diesel engine power is used to drive the vehicle during high speeds while the electric motor is used to power the vehicle during low speeds, and both sources power the vehicle during acceleration. Benefits of diesel-electric hybrid engines include smaller conventional engine size, regenerative braking (converting heat energy from braking to electrical energy), power-on-demand (not using the combustion engine while the vehicle is idling or coasting), constant engine speeds and power output. Presence of an electrical power source enables the diesel engine to operate at an optimal speed thus increasing fuel efficiency and reducing emissions.

Despite its obvious environmental benefits, diesel-electric trucks are not heavily used because they are much more expensive than conventional diesel trucks. In addition, there are concerns that the battery will need replacement after the warranty has expired. While economies of scale bring the price down for hybrid passenger vehicles, only a fraction of vehicles produced per year are heavy vehicles. Moreover, heavy vehicles are available in dozens of configurations, and each is not produced in bulk (DOE 2006). Table 6 shows the estimated incremental cost of a variety of heavy-duty diesel-electric hybrid systems. In general, a series system is more expensive than a parallel system, and utilizing lead-acid (PbA) batteries is less expensive than Nickel Metal Hydride (NiMH) batteries. In addition, as a vehicle becomes less reliant on the conventional engine (CV-like) and more reliant on the electric engine (EV-like), expense increases. An et al (2000) estimate that the average payback time for a heavy-duty diesel-electric vehicle is 6 years.

Table 6: Incremental Cost of HDV Hybridization (Source: An et al, 2000).

$	CV-like parallel, PbA	CV-like series, PbA	CV-like parallel, NiMH	CV-like series, NiMH	EV-like series, PbA
Class 3-4	5,750	11,458	9,720	15,613	26,333
Class 6-7	7,149	12,211	12,843	18,092	44,789

Lead-acid batteries, though cheaper, are more toxic and have lower energy density than Nickel Metal Hydride and Lithium Ion (Li-ION) batteries. NiMH batteries are the most common type used in hybrid-electric vehicles because of higher energy density, proven longevity and safety. Li-ION have even higher energy density and are more suitable for plug-in hybrid-electric vehicles, but are not yet as safe or long-lasting as NiMH[19] (Axsen et al 2008). With further development, Li-ION batteries will likely last as long (or longer) than NiMH and cost less per kWh.

Within the heavy-vehicle fleet, diesel-electric hybrid vehicles have been used for transit buses and in medium sized trucks used for urban delivery. These vehicles are more efficient in congested urban environments with lots of stop-and-go traffic. New York City Transit purchased an initial fleet of 10 diesel electric-hybrid vehicles in 1997. The initial purchase cost of diesel-electric hybrid buses was found to be 60% higher, and maintenance cost around 75-150% higher than conventional diesel vehicles. Even though the initial purchase cost has reduced in recent years, diesel electric hybrid buses cost approximately 30% more. The hybrid-electric buses that were purchased in 2006 by the Toronto Transit Commission were originally equipped with lead-acid batteries that failed after just two years and are being replaced with Li-ION batteries (Gray 2008).

Fedex has experimented with using diesel electric hybrid vehicles for medium duty urban delivery trucks and is considering replacing a significant portion of their fleet

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[19] In mid-2008, production of NiMH batteries couldn't keep up with the demand for hybrid-electric vehicles. Customers waited for months to purchase a Toyota Prius, and new plants are not expected to be operational until 2010 (Szczesny 2008).

with hybrid vehicles. They have experienced 42% fuel economy gains, and reduction of greenhouse gases and PM by 30% and 96%, respectively, from their diesel-electric hybrid fleet (FedEx 2008). To date, diesel electric hybrid engines have not been used for long haul freight.

A new and more promising technology for heavy-duty trucks is the hydraulic hybrid. These engines have a radically different mechanical system for powering a vehicle and contain two pump motors. The energy from the diesel engine is used to drive a hydraulic pump motor. The hydraulic pump motor charges a high pressure accumulator which propels the vehicle through a bent-axis pump on the rear wheels. A reservoir circulates fluid between the two pump motors. Even though most hydraulic hybrid technologies are still in developmental stages, hydraulic hybrids are low cost and are potentially the most effective type of engine for heavier vehicle classes such as heavy-duty trucks. Hydraulic hybrids potentially have the same advantages of diesel electric hybrids including regenerative braking.

While electric hybrids and plug-ins seem to be the best hybrid technology for passenger vehicles, hydraulic hybrids are better suited for heavy-duty vehicles. Hydraulic hybrid vehicles can achieve 50-70% fuel economy improvement, 30-40% GHG reduction, 50% HC reduction, and 60% PM reduction (EPA 2006, Galligan 2008). These vehicles only cost approximately 15% more than a comparable conventional vehicle. When factoring in gas savings, the technology pays for itself within 1 to 3 years, and a savings of $50,000 is estimated for a 20 year vehicle lifetime (EPA 2006). Current models exhibit negligible NOx reductions. However, the technology is currently utilizing off-the-shelf parts and substantial NOx reductions are expected from future optimized hydraulic hybrids (EPA 2006, Kutz 2000). The first operational hydraulic hybrids are part of the UPS fleet. Two were purchased for use in Minneapolis and will be deployed in 2009, and five additional vehicles will be deployed by 2010 (Galligan 2008). In addition, Eaton Corporation is now retrofitting existing trucks with hydraulic hybrid technology, and these vehicles are expected to experience a 20-30% increase in fuel economy.

Vehicle Retrofit Technologies

ENGINE IDLE REDUCTION

APUs are diesel-powered units that can be used to power climate control and other in-cabin devices. Direct-fire heaters are also diesel-powered units, but only provide heat and cannot power other devices. Automated engine idle systems monitor the cabin temperature and shut the idling engine off when power is not needed for climate control. TSE systems electrify climate control and other in-cabin devices by either allowing the vehicle to plug into an electrical outlet or placing a device in the cabin that delivers climate controlled air (for an hourly fee). Ang-Olsen and Schroeer (2002) found that APUs, direct-fire heaters and automated engine idle systems can reduce annual fuel use by 8.1%, 4.3%, and 5.6% per truck, respectively. Automated engine idle systems and direct-fire heaters cost approximately $1,500 per unit and APUs cost $7,000 (DOE 2009). Despite the higher capital cost of APUs, the payback time is only two years.

The initial cost of installing TSE infrastructure is approximately $2,500 per space (and $10 per space for advanced TSE) (WSU, 2004). The majority of TSE service was provided by IdleAire, Shorepower, or CabAire (DOE 2009). However, IdleAire announced closure of its operations in January 2010. Service ended at its 131 locations in

34 states, though service is expected to reopen at a limited number of those locations (Transport Topics, 2010). IdleAire offered basic service for $2.45-2.89 per hour[20], depending on membership type (IdleAire 2008). Only considering the cost of fuel, and assuming that a truck consumes 1 gallon of diesel per hour, this is only a cost effective idle reduction strategy if per-gallon diesel prices exceed this hourly fee.

The Texas Transportation Institute, in partnership with IdleAire, monitored the success of three truck stops in the Midwest with newly installed TSE in roughly half of truck parking spots. After one year, the average idling rate of these stops decreased 6%, and average TSE utilization was 25.7% (Zietsman et al, 2009). This resulted in improvement of fuel consumption and emissions of 5%, 16%, and 44% at each of the three truck stops. The differential improvement is due to the varying idle rates of each location (i.e., stations with higher average idle rates will benefit more from TSE than will stations with lower idle rates).

In addition to fuel consumption and GHGs, pollutant emissions are important to consider when comparing idle reduction strategies. Gaines et al (2008) utilized the GREET model to estimate total upstream (fuel production/power generation) and downstream (vehicle) emissions associated with idle reduction options including APUs, direct-fire heaters, and TSE. They found that, during periods of cab air conditioning (A/C), the APU has the highest NOx and CO2 emissions and the TSE emits the most PM. However, the PM emitted due to TSE occurs upstream at the electricity generation site,

[20] WSU (2004) notes that TSE operating charges consist of a $3,000 annual fee, and $1.25 per hour. This is more expensive than IdleAire's hourly cost, assuming 1500 idling hours per truck per year.

which is potentially an area of lower population relative to a truck stop[21]. During heating days, APUs are more emitting of NOx, CO2, and PM than direct-fire heaters and TSE. The emissions of all idle reducing options proved lower than that of an idling truck.

It should be noted that these results assume the average U.S. electricity generation mix. Results differ in each region of the U.S. since methods of electricity generation differ in efficiency and emissions rates. This study assumed 500 sulfur-ppm (low sulfur) diesel rather than ultra-low sulfur diesel (ULSD) fuel due to data availability. Estimating emissions using ULSD would likely reduce PM emissions from the idling truck, APU and direct-fire heater. In addition, the truck modeled in this study follows 2001 emissions regulations, rather than the stricter NOx and PM rates of the 2007 and 2010 regulations.

Finally, Lee et al (2008) investigated the effect of idle-reducing devices on in-cab air quality delivered by air conditioning systems at a truck stop in El Paso, TX. The alternatives included using the truck to power its A/C, using the truck to power its A/C recirculation, using APU to power the truck's A/C, and using TSE to power the truck's A/C. Overall, using the TSE to power the A/C resulted in the best in-cab air quality, which is not surprising since the associated emissions occur off site.

REDUCING AERODYNAMIC DRAG

Over the last 30 years, aerodynamic drag has decreased by 40%, and the drag coefficient (c_d) is currently about 0.625 (Muster 2000, DOE 2006). Aerodynamic drag

[21] Percentage of truck stops in urban areas in U.S. states: 45% in CA, 47% in FL, 59% in IL, 41% in NY, 51% in TX, 25% in VA, and 9% in WV (Gaines et al, 2008).

consumes 21% of the energy used by class 8 trucks traveling at 65 mph. The DOE’s 21st Century Truck Partnership recommends a 20% reduction in aerodynamic drag (c_d=0.5) which would result in a 6.5-15% fuel economy improvement (DOE 2006, Vyas et al 2002). Add-on aerodynamic drag reduction devices currently available can reduce drag by up to 25%. However, many add-ons hinder operational performance of the vehicle, discouraging many truck owners from utilizing them (DOE 2006). In addition, technologies that are intended for use by the tractor, rather than the trailer, will be more cost effective since there are approximately three trailers for every tractor. Future research and development will aim to reduce aerodynamic drag using less obtrusive devices that are effective without affecting vehicle performance.

Drag-reducing technologies include cab top deflectors, sloping hood, cab side flares, aerodynamic bumpers, increased curvature in tractor and trailer design, underside air baffles, wheel well covers, gap closure (between tractor and trailer), and pneumatic blowing. All of these methods are currently used on trucks to varying degrees with the exception of pneumatic blowing, which has a history of use on aircrafts.

LOW-RESISTANCE TIRES

Rolling resistance is the energy consumed due to the friction between the tires and road surface, and increases with vehicle weight and speed. Because of this weight-speed relationship, class 8 trucks are likely to benefit the most from technologies combating rolling resistance. It is estimated that rolling resistance accounts for nearly 13% of the energy consumed by a truck (Vyas et al 2002). Currently, the rolling resistance coefficient (RRC) is typically 0.007, but 0.0054 is possible using currently available methods.

Two types of tires, low-resistance tires and super singles, are effective in improving vehicle fuel economy by 3% (Vyas et al 2002). Of course, these are mutually exclusive technologies. Low resistance tires can be used on any truck, but require high pressure and frequent monitoring which has deterred truck owners from using them. Super singles eliminate the maintenance burden of low-resistance tires, but can only be used in newer MY trucks.

Pneumatic blowing can also provide benefit for rolling resistance by reducing the load on the tires. However, this technology's research and development is in the early stages and the full effects on fuel economy are not yet known. Vyas et al (2002) assume that this will improve truck fuel economy by 1.2%.

Conclusions

The majority of fuel used to power heavy-duty vehicles is diesel, while gasoline and liquefied petroleum gas also provide fuel for a significant portion (10% and 0.3%, respectively). Gasoline vehicles are responsible for the majority of CO and HC emissions, while diesel vehicles are known for emitting large amounts of NOx and PM. Diesel is more common for use in heavy-duty vehicles because the engines are more powerful and efficient.

Biodiesel can reduce oil consumption and emissions of GHG (lifecycle, not tailpipe), PM, HC and CO. Most fleets prefer not to use 100% biodiesel because it would require altering the vehicle to avoid maintenance issues. B20, a mixture of 20% biodiesel and 80% petroleum diesel, still reduces oil consumption and emissions without the need to alter vehicles. Ethanol is another commonly used biofuel that is used in place of, or blended with, gasoline. The way that ethanol is produced, and the choice of feedstock used to produce it, has a large impact on its ability to reduce emissions. Ethanol made from corn offers the least emissions benefits, while sugarcane and cellulosic ethanol offer 2-3 times the benefit of corn ethanol. However, cellulosic ethanol is still in developmental stages and is not being commercially produced. It should be noted that biofuels only offer GHG emissions benefits if it doesn't require the conversion of non-agricultural land.

Relative to diesel fuel, natural gas reduces emissions of CO2 by 25% and PM, NOx, and HC by 50%. However, to use the fuel it is necessary to invest in a private fueling storage and distribution system. It is a good alternative fuel for fleets that return to their point of origin on a daily basis (e.g. intracity buses and delivery trucks). Of course, dual-fuel natural gas and diesel vehicles will allow more flexibility in using these vehicles out of range of a private natural gas refueling station. Natural gas vehicles can cost twice as much as their diesel equivalent, but there are an increasing number of subsidies available to help offset this cost.

Electric hybrid engines have not yet been used in combination trucks, but have been used in many bus and package delivery truck fleets (e.g. UPS and FedEx). Despite the increased fuel efficiency and air quality benefit, electric hybrid engines are not a popular choice for heavy-duty vehicles because they are much more expensive than conventional engines. Lead-acid batteries are no longer used in hybrid vehicles and were replaced with Nickel Metal Hydride (NiMH) batteries that have higher energy density and are safer (though more expensive). It is expected that Lithium-ION batteries will replace NiMH batteries in the future due to greater longevity and lower cost.

Hydraulic hybrids, vehicles powered by a diesel motor and hydraulically stored energy, are an inexpensive alternative to electric hybrids for large vehicles. Though still in the development stage, these vehicles improve fuel economy 50-70% and reduce GHG, HC, and PM emissions by roughly 50%. Costing only 15% more than a comparable conventional vehicle, it is estimated that the payback period is between 1 and 3 years.

Truck idling wastes approximately 1 gallon of fuel per hour and can cost approximately $2000 per truck depending on fuel prices. In addition to the fuel waste, excess emissions are being released into the atmosphere. Auxiliary power units, automated engine idle systems, and direct-fire heaters are all on-board devices aimed at eliminating the need for a truck to idle during extended rest periods. These can reduce fuel use by 3-10% and cost between 2 and 8 thousand dollars. Auxiliary power units cost more, but also save more fuel and have a shorter payback time. Electrified truck stops are a method of reducing engine idling without an on-board device. These stops either provide climate control for the cabin or provide the truck with electricity from which to run its own climate control system and other accessories. For this to be cost effective, it is necessary for the per-gallon price of fuel to be more than the hourly rate of the stop.

Aerodynamic drag has decreased by 40% in the last 30 years, and the add-on devices available today can offer further reduction of 25%. Unfortunately, many of these devices infringe on the operational performance of the vehicle, making them undesirable. Low-resistance tires and super single tires are designed to reduce the rolling resistance between vehicle tires and the road surface, and can improve fuel economy by 3%. Low rolling resistance tires can be used on any truck, but require high pressure and frequent monitoring. Super singles are lower maintenance, but can only be used on newer model trucks.

VII. CONCLUSIONS

In general, user-charging strategies are not likely to be useful as strategies to reduce fuel consumption and emissions at the state and national level. Most user-charging strategies only target a small portion of trips, and thus their maximum savings potential is low. There are two exceptions to this. First, because these strategies have been shown to result in large savings at the facility and county level, they are prime candidates for reducing criteria pollutants in non-attainment areas. Second, VMT fees are capable of affecting all travel within the boundaries it governs.

If VMT fees are structured in such a way that reduces overall travel, they could be very beneficial in reducing fuel consumption and emissions. Of course, the reduction in travel is more likely to be from passenger vehicles rather than freight, unless the pricing is so extreme that trucking becomes too expensive to make a profit. At that point, shippers would be forced to choose another mode, or to charge their customers a higher fee to pay for the additional transportation, which may affect overall sales and thus have a negative impact on the economy. Because of this, as well as the trucking industry's (and the general public's) opposition to VMT fees, it is more likely that if they are implemented, they will be a revenue-neutral replacement for fuel and other transportation taxes.

Freight logistics improvements essentially involve the reorganization of routing, scheduling, and loading. In most cases, these strategies are implemented by the party which manages the truck fleet. The incentives to engage in such strategies are typically time and fuel savings with the goal of maximizing trucking profit margins. Strategies of this type include compact and innovative packaging, strategic loading, eliminating deadhead trips, and reducing miles in the supply chain. The fuel and emissions benefits of these strategies are rather obvious because they allow reduction in truck miles while hauling the same amount of goods, though there are drawbacks associated with each. Packaging techniques can only be implemented by the manufacturer, and their primary goal in packaging is to create a package that is appealing to the consumer. Allowing that package to optimize loading is a secondary goal. Loading strategies will be most beneficial to private carriers that haul a similar mix of products on a regular basis; developing a complex loading strategy for each trip is not a good use of time. Reducing the overall number of miles in a supply chain is not always beneficial, from an energy use perspective. Most often, it is most energy efficient to produce things where it is naturally advantageous, even if it requires hauling a significant distance to the location where it is consumed. Of course, this will differ on a case by case basis. The point is that transportation fuel use is not the only phase of a product's life where energy is consumed, and in many cases, transportation energy consumption is a rather small portion of the total energy consumed during the products lifecycle. The impact of reducing supply chain miles on other parts of the product's lifecycle must be considered before it is determined that it would benefit overall energy consumption.

Unlike other logistics improvements, the expansion of vehicle size and weight regulations will have the most benefit to the trucking industry, yet they do not have the authority to implement it. The allowance must be implemented by those that own and manage the roadway infrastructure. Furthermore, it is not the beneficiaries who will suffer the consequences (i.e., damage to infrastructure) of heavier and longer vehicles. To compensate for this, such vehicle allowances will likely come with a price for the trucking industry. Fortunately, the benefits of these larger and heavier vehicles are so great that it would likely be worth any additional cost. LCVs increase fuel economy per ton-mile by roughly 30%, and their use has other benefits like reducing the number of drivers needed to carry the same load.

Training drivers to drive in a more energy efficient manner is a strategy where you really get what you pay for. It has been shown that more extensive training programs result in bigger fuel savings. Specifically, training programs that only involve classroom training are much less effective than programs that supplement classroom learning with in-truck practice. One caveat is that training is an ongoing process. New drivers will need initial training, and seasoned drivers may need refreshers. Furthermore, drivers that have been trained may not have an incentive to utilize the skills they have learned without additional incentives. It may be necessary to monitor drivers' fuel consumption to offer these incentives, and to ensure that the training program is effective. Of course, these are issues that will affect large fleets more so than owner-operators, who have the incentive of saving fuel that they pay for.

Reducing truck idling is both an operational and a vehicular strategy. Truck idling is most often thought of as overnight idling when a trucker is resting, and the truck engine is left idling to control the in-cab temperature as well as control other amenities. The best strategies for reducing fuel consumption and emissions due to this type of idling are vehicular improvements. There are a variety of devices that can be purchased for trucks that allow for the driver to be comfortable while resting without requiring the large truck engine to continuously run. Of these, perhaps the best strategy, in terms of total energy use and emissions reduction, is truck stop electrification. These systems supply temperature controlled air to the truck cabin, as well as electricity for any other devices that may need energy. However, the largest provider of this service, Shorepower, has recently shut down their service, and has filed for bankruptcy more than once. While, TSE may be the best for reducing energy consumption, it is not currently the most reliable strategy. Perhaps one reason for this is the fact that drivers have no incentive to use it if the cost of service is not significantly cheaper than the cost of diesel fuel. When fuel prices decrease, the TSE providers lose customers. In the future, these systems may do better with a business model that allows for a profitable service fee that can always beat the cost of fuel. A more reliable technology for combating the environmental effects of overnight idling is an auxiliary power unit. Though this is the most expensive truck add-on idle-reduction device, it is also the most effective, and still has a reasonably short payback period of approximately 2 years.

A less obvious form of truck idling occurs when trucks must remain running to preserve their place in a line. The line can be general traffic, a port terminal entry, a weigh station, a border crossing, a toll collection booth, and more. Strategies to reduce this type of idling must change the way truck traffic operates to reduce the queues that cause idling. Electronic screening has proven to be effective in eliminating queues at weigh stations and tolling locations. Rather than requiring vehicles to stop, the necessary information is transmitted electronically while the vehicle continues moving at full speed. Similar to TSE, the fuel savings from electronic screening is typically not greater than the monthly cost to utilize the service. However, unlike TSE, drivers also experience a time savings, which adds to the value of the service. Other operational idle reducing strategies are focused on port access. In the U.S., there has been success with strategies like extending terminal gate hours, virtual container yards, and terminal appointment systems. While virtual container yards can increase street turns substantially from 2% to 5-10%, and can be a very cost effective strategy for reducing fuel consumption and emissions, it is very limited in its maximum potential. VCYs only target a small fraction of all port truck trips, which is an even smaller fraction of total truck miles. Experiences with extending gate hours and using appointment systems have shown that the details of the system are crucial to its success. Various terminals in California had appointment systems, but only one advertised the system and it had the highest use. Encouraging use even further could be done by allowing these vehicles some type of incentive over vehicles that don't have appointments. Also in California, extending gate hours was very successful in diverting port truck trips from day hours to off-peak hours. However, a variable pricing scheme would prevent trucks from queuing just before the opening of off-peak hours.

Aside from idle reduction, other vehicular strategies for trucks include using alternative fuels with conventional engines, using alternative engines, installing add-on devices to improve aerodynamics and using tires that reduce rolling resistance. Biodiesel can reduce emissions of GHG (lifecycle, not tailpipe), PM, HC and CO. Most fleets prefer not to use 100% biodiesel because it would require altering the vehicle to avoid maintenance issues. B20, a mixture of 20% biodiesel and 80% petroleum diesel, still reduces emissions without the need to alter vehicles. Ethanol is another biofuel that is commonly used in place of, or blended with, gasoline. The way that ethanol is produced has a large impact on its ability to reduce emissions. Ethanol made from corn offers the least emissions benefits, while sugarcane and cellulosic ethanol offer 2-3 times the benefit of corn ethanol. However, cellulosic ethanol is still in developmental stages and is not being commercially produced. It should be noted that biofuels only offer GHG emissions benefits if no agricultural land conversion is required to produce the fuel.

Relative to diesel fuel, natural gas reduces emissions of PM, NOx, and HC by 50%, and CO2 by 25%. However, it is necessary to invest in a private fueling storage and distribution system. It is a good alternative fuel for fleets that return to their point of origin on a daily basis (e.g. intracity buses and delivery trucks). Natural gas vehicles can cost twice as much as their diesel equivalent, but there are an increasing number of subsidies available to help offset this cost. Dual fuel vehicles may be an answer to increasing the use of natural gas vehicles without worry about running out of fuel with no place to refill.

Despite the increased fuel efficiency and air quality benefit, electric hybrid engines are not a popular choice for heavy-duty vehicles because they are more expensive than conventional engines. It is expected that Lithium-ION batteries will replace NiMH batteries in the future due to greater longevity and lower cost. Hydraulic hybrids, vehicles powered by a diesel motor and hydraulically stored energy, are an inexpensive alternative to electric hybrids for large vehicles. Though still in the development stage, these vehicles improve fuel economy 50-70% and reduce GHG, HC, and PM emissions by roughly 50%. Costing only 15% more than a comparable conventional vehicle, it is estimated that the payback period is between 1 and 3 years.

Aerodynamic drag has decreased by 40% in the last 30 years, and the add-on devices available today can offer further reduction of 25%. Unfortunately, many of these devices infringe on the operational performance of the vehicle, making them undesirable.

Low-resistance tires and super single tires are designed to reduce the rolling resistance between vehicle tires and the road surface, and can improve fuel economy by 3%. Low rolling resistance tires can be used on any truck, but require high pressure and frequent monitoring. Super singles are lower maintenance, but can only be used on newer model trucks.

All of the operational and vehicular strategies discussed in this report are successful in achieving reductions in truck fuel consumption and greenhouse gas emissions to some degree. The major differences between them are who pays for, implements, and benefits from them, maximum market penetration, and cost. Road-user charging, expanding vehicle size and weight limits, and many port logistics strategies must be implemented by the entity owning and managing the infrastructure, and they would also be charged with any capital cost required. Of course, in most cases, truck owners would still have the authority to decide if they want to partake in any new logistics system that is set up. In this sense, they also have the power to implement the strategy. While many of these traffic management strategies have relatively limited impact on fuel consumption and emissions, the primary goal is usually to have a positive impact on traffic flow. In this case, any impact on fuel consumption is a bonus.

Loading, packaging, and supply chain strategies are typically implemented and paid for by the product manufacturer. In the case that these good are distributed by their private fleet, they are also the primary beneficiary of any fuel savings. However, when products are distributed by for-hire trucks, the beneficiary is no longer the entity paying for the improvement. In this case, it may be more difficult to justify implementing these strategies. In addition, in the case of packaging and “buying local”, the product consumer is the ultimate decision maker. A manufacturer can decide to alter the packaging of its product, but the consumer can decide that the packaging is unappealing and discontinue purchase of that product. In this case, the primary goal of packaging is not to improve trailer loading.

Vehicular strategies are a bit tricky, because the person who owns the equipment is the one with the power to implement fuel saving strategies. However, trucking equipment isn't always owned and maintained by the same party. For example, an owner-operator may own a tractor, and will haul trailers that are all owned by different companies. The driver, and the primary beneficiary of fuel savings, does not have the power to implement fuel savings strategies that include trailers, such as aerodynamic add-ons, low-resistance tires, and more efficient energy source for climate-controlled trailers. In addition, large fleets are typically those that are willing and able to experiment with new fuel savings technologies and strategies. Interestingly, 90% of trucking companies in Texas own 10 trucks or less.

However, the market penetration of each strategy is what will ultimately determine each strategy's potential to improve the fuel efficiency of trucking. In general, many user charging strategies are limited severely by their natural restriction to impact travel only within a small designated area. Similarly, user-charging strategies that impact a larger proportion of travel are capable of having more meaningful impacts on fuel consumption. Port related strategies are restricted to impacting truck trips to and from ports, and some only impact a fraction of those trips. Diverting truck trips to rail or maritime transport is only an option for loads with longer traveling distances, and less stringent delivery times. Furthermore, many of these strategies are not brand new; they have already been implemented to some degree, and some may have already reached their maximum market penetration. The largest electronic screening provider in the U.S. for bypassing truck weigh stations has 370,000 trucks enrolled. This is roughly half of all long-haul trucks in the U.S. When considering other providers, this strategy may be near its maximum market penetration. To truly understand the relative importance of these strategies, further work needs to be done to determine the maximum and current market penetration of each strategy. Pairing that information with cost and fuel savings ability will create a clearer comparison of these strategies.

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