CONFIDENCE REPORT: MAINTENANCE

ABSTRACT

This report documents the confidence that North American Class 8 trucking should have in leveraging optimized vehicle maintenance for improved fuel efficiency. The study team engaged the entire industry in the data that is presented here. Thanks to all of those who contributed to this important work.

Trucking Efficiency

Trucking Efficiency is a joint effort between NACFE and the Carbon War Room to double the freight efficiency of North American goods movement through the elimination of market barriers to information, demand and supply.

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1 Executive Summary

The fuel costs faced by the tractor-trailer industry have been swiftly and steadily rising over the past decade. In 2014 diesel fuel costs were $0.58 per mile, costing the industry as much per annum as the costs of drivers' wages and benefits combined. Despite recent fuel cost decreases, all indications are that fuel price volatility will continue, forcing the industry to find solutions that increase its fuel efficiency in order to stay profitable.

Fortunately, myriad technologies that can cost-effectively improve the fuel efficiency of Class 8 trucks are readily available on the market today. Unfortunately, multiple barriers have stymied industry adoption of such technologies, including a lack of data about the true performance gains these technologies offer and a lack of confidence in the data that does publicly exist today. To overcome those barriers and facilitate the industry's trust in and adoption of the most promising fuel efficiency technologies, the North American Council for Freight Efficiency (NACFE) partnered with Carbon War Room (CWR) to form Trucking Efficiency. The work of Trucking Efficiency has begun by producing a series of Confidence Reports, of which this report on maintenance practices is the ninth.

"There is strong evidence that properly maintained trucks will enjoy improved fuel economy."

MIKE ROETH, OPERATION LEAD, TRUCKING EFFICIENCY

The goals of this Confidence Report are: (a) to give the industry a foundational understanding of the impact that maintenance practices can have on fuel economy; (b) to provide a review of key maintenance areas to focus on for fuel efficiency; and (c) to increase investment into improved maintenance practices.

Methodology

This report's conclusions were generated through desk research, conversations at a variety of trucking industry events around the country, and a series of structured interviews with fleets, component manufacturers, and truck and trailer OEMs active in the North American market.

KEY FINDINGS OF THIS REPORT

The study team reached the following conclusions regarding the link between maintenance practices and fuel economy in the trucking industry today:

- Fleets view maintenance as important to their operation, but tend to look at it as a means for reducing downtime rather than improving fuel economy.
- There is strong evidence that properly maintained trucks will enjoy improved fuel economy.
- While reducing downtime is the main pathway to payback from investments in maintenance, adding information about the increased fuel economy enjoyed by well-maintained trucks can make investments in maintenance

technologies, tools, bay space, technicians, or software an easier sell across fleet management.

- There are a variety of sources available, including the Technology & Maintenance Council, where fleets can find information about the maintenance needs of various components.

MAINTENANCE AND FUEL ECONOMY

The maintenance of vehicles is universal to the trucking industry, making this report unlike other Confidence Reports, which look at technologies that either are or are not adopted by a given fleet. All fleets currently maintain their vehicles in order to ensure safe and reliable performance, avoid costly breakdowns or vehicle downtime, and allow their vehicles to reach maximum useful life or obtain higher resale values. The industry-standard best practice for maintaining a fleet of vehicles is through a structured preventive maintenance (PM) program. However, even a vehicle that is running safely and reliably may still enjoy substantial fuel economy savings thanks to additional or more optimized maintenance.

The report finds that while the industry today is aware of the impact of poor maintenance on fuel economy, it is nevertheless uncomfortable quantifying what the link between the two might be, in order to justify investing in improvements. This is understandable, as it is difficult to speak in aggregate about the opportunity available to the industry as a whole from addressing maintenance for fuel economy; each fleet must be individually assessed to determine the gains available to them from making changes to their specific maintenance practices.

The report furthermore identifies the separate components or vehicle systems that are known to impact fuel economy and looks at the role of maintenance in keeping those components/systems operating at peak condition.

The following ten major components or systems were most often mentioned by the fleets and are therefore discussed in depth in the report, but this list is not exhaustive.

1. Lubricants/Engine Oil
2. Intake/Exhaust System and Diesel Particulate Filters
3. Engine Cooling
4. Air Compressors
5. Wheel Alignment
6. Tires
7. Fuel Filter Systems
8. Aerodynamic Devices
9. Electrical Systems
10. Air Conditioning

> "Even a vehicle that is running safely and reliably may still enjoy substantial fuel economy savings thanks to additional or more optimized maintenance."
>
> DENISE RONDINI, NACFE STUDY MANAGER AND COMMUNICATIONS DIRECTOR

BENEFITS OF MAINTENANCE

Discussing the benefits of maintenance may sound odd, as no one in the industry believes maintenance is without a benefit. However, some fleets still view maintenance as a cost, making cuts to the maintenance budget during tough economic times. This Confidence Report recommends that, although still uncommon, fleets should definitely think of maintenance in terms of the *fuel economy* benefits it offers. Adding up all of the potential reductions in fuel economy covered under the 10 components described in the report shows that maintenance can in fact address 30% to 50% of fuel consumption. Certainly no truck will ever have problems with all 10 of these components at once, but the massive size of that figure is indicative of just how significant the opportunity is to use maintenance to improve fuel efficiency. In short, **proper maintenance saves fuel.**

Fleets shared that they have in fact seen fuel consumption improvements of 5–10% after the implementation of rigorous preventive maintenance practices. Such savings indicate that the implementation of more effective maintenance protocols, namely by increasing staff and/or investing in maintenance software, facilities, or other tools, will likely pay for itself in fuel savings in just a few years.

Additional benefits of proper maintenance include:

1. Improved Vehicle Reliability and Reduced Breakdowns
2. Increased Resale Value
3. Enhanced Driver Safety and Satisfaction
4. Reduced CSA Violations and Fines

CHALLENGES OF MAINTENANCE

In spite of these benefits, fleets working to implement more effective maintenance protocols should be aware of the following three challenges:

1. **Scheduling:** It can be difficult to schedule maintenance in a way that does not negatively impact fleet productivity; telematics technologies can help optimize scheduling.
2. **Tracking/Ensuring Compliance:** Fleets using manual methods of tracking PM service are likely not getting all their trucks scheduled for servicing as needed; telematics can also help address this.
3. **Demonstrating Return on Investment:** Getting fleets to factor fuel economy improvements into their maintenance investments is challenging. Moreover, proper maintenance may address multiple

systems at once, so not only is it impossible to attribute any fuel economy gains to a specific maintenance action, it can be difficult to prove that a change in maintenance caused any gains at all.

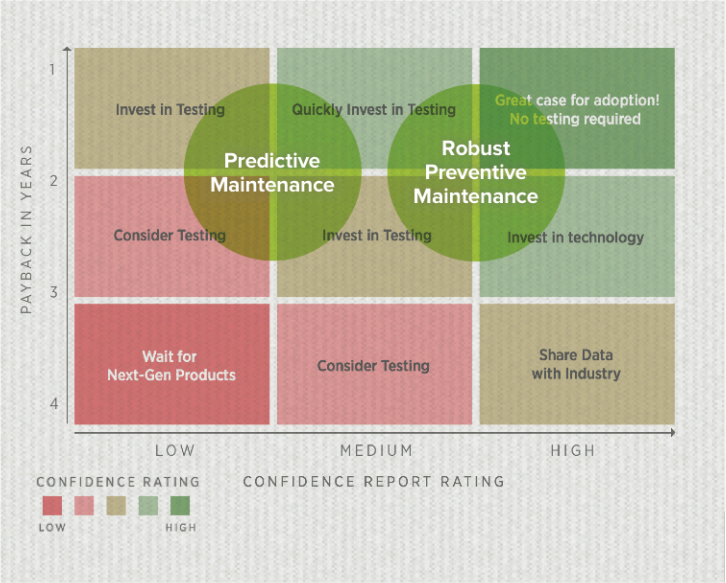
LOOKING FORWARD TO PREDICTIVE MAINTENANCE

Given the increasing sophistication of today's commercial vehicles and the many new technologies, it is likely that the need for maintenance will increase. Fleets have already moved away from reactive maintenance and repair, and are now focusing on preventive maintenance to keep their trucks in top operating condition.

But what fleets really want is to be able to fix a truck before it breaks. The next evolution in maintenance, therefore, will be a new sort of PM: not preventive but *predictive* maintenance. A predictive maintenance system functions using telematics devices and an array of vehicle sensors in order to record and wirelessly relay vehicle performance data, including any issues that may arise, back to the fleet, which in turn can quickly respond.

A one-size-fits-all approach to maintenance is incompatible with predictive maintenance. To be effective it will require each fleet to capture and analyze all of the data being generated by the ECM, sensors, and telematics devices on each of its trucks individually. Proper data analytics will allow fleets to spot wear and breakdown trends, and to schedule preemptive repairs.

FIGURE ES1: CONFIDENCE MATRIX FOR FUEL-ECONOMY-FOCUSED MAINTENANCE



Technology and connectivity are the keys to predictive maintenance, but just as important is the collection and analysis of the data.

CONFIDENCE RATING

It is difficult to quantify the overall fuel savings due to maintenance. There are some areas like tire inflation or the cleaning of diesel particulate filters for which there is plenty of specific evidence as to how much these measures can increase fuel economy. For other components like tires, axle alignment, oil, and aerodynamic devices, there is demonstrable evidence of the fuel economy loss when those components are poorly maintained.

This Confidence Rating indicates that fleets should be willing to invest in technologies and/or staff to optimize their maintenance protocols, and that they should monitor fuel economy savings in order to justify those investments. In particular, fleets should consider investing in telematics technologies, which will allow them to transition from preventive to predictive maintenance practices. The benefits of investments in predictive maintenance are still emerging as there are many solutions, and the capabilities for better decision making with the much larger available data are not yet mature. It is expected that the payback and amount of information available on predictive maintenance will improve over the next 12–18 months.

Trucking Efficiency is always seeking to expand the data or case studies that we can provide to the industry. We invite you to share your own experiences with using maintenance practices to improve fuel economy.

TRUCKING EFFICIENCY

Trucking Efficiency is a joint effort between NACFE and Carbon War Room to double the freight efficiency of North American goods movement by eliminating barriers associated with information, demand, and supply.

Worldwide, heavy-duty freight trucks emit 1.6 gigatons of CO_2 emissions annually—5.5% of society's total greenhouse gas emissions—due to the trucking sector's dependence on petroleum-based fuels. With fuel prices still commanding nearly 40% of the cost of trucking, the adoption of efficiency technologies by all classes of trucks and fleets offers significant cost savings to the sector while reducing emissions. These technologies are relatively cheap to implement and widely available on the market today.

Trucking Efficiency provides detailed information on cost-effective efficiency technologies, including data from across a variety of fleets and best practices for adoption. This Confidence Report series from Trucking Efficiency aims to serve as a credible and independent source of information on fuel efficiency technologies and their applications.

In order to generate confidence on the performance claims of efficiency technologies, Trucking Efficiency, via these reports, gathers and centralizes the multitude of existing sources of data about the performance results of different technology options when employed in a variety of vehicle models and duty cycles, and makes all of that data openly accessible and more easily comparable. Furthermore, we assess the credibility of the available data, and provide an industry-standardized ranking of confidence in performance results, including ROI and efficiency gains.

www.truckingefficiency.org

Trucking Efficiency welcomes outside views and new partners in our efforts to help accelerate the uptake of profitable, emission-reducing trucking technologies.

CARBON WAR ROOM

Carbon War Room (CWR) was founded in 2009 as a global nonprofit by Sir Richard Branson and a group of likeminded entrepreneurs. It intervenes in markets to accelerate the adoption of business solutions that reduce carbon emissions at gigaton scale and advance the low-carbon economy. CWR merged with Rocky Mountain Institute (RMI) in 2014 and now operates as an RMI business unit. The combined organization engages businesses, communities, institutions, and entrepreneurs to transform global energy use to create a clean, prosperous, and secure future. The combined organization has offices in Basalt and Boulder, Colorado; New York City; Washington, D.C.; and Beijing.

www.carbonwarroom.com

NACFE

The North American Council for Freight Efficiency works to drive the development and adoption of efficiency-enhancing, environmentally-beneficial, and cost-effective technologies, services, and methodologies in the North American freight industry by establishing and communicating credible and performance-based benefits. The Council is an effort of fleets, manufacturers, vehicle builders and other government and non-governmental organizations coming together to improve North American goods movement.

www.nacfe.org

2 Introduction

This Confidence Report forms part of the continued work of Trucking Efficiency, a joint initiative from the North American Council for Freight Efficiency (NACFE) and Carbon War Room (CWR) highlighting the potential of fuel efficiency technologies and practices in over-the-road (OTR) goods movement. Prior Confidence Reports and initial findings on nearly 70 available technologies can be found at www.truckingefficiency.org.

The fuel costs faced by the tractor-trailer industry have been swiftly and steadily rising over the past decade (Figure 1). In 2014 diesel fuel costs were $0.58 per mile, costing the industry nearly as much per annum as the costs of drivers' wages and benefits combined (Figure 2). Despite recent fuel cost decreases, all indications are that fuel price volatility will continue, forcing the industry to find solutions that increase its fuel efficiency in order to stay profitable.

Figure 1: US Diesel Fuel Prices

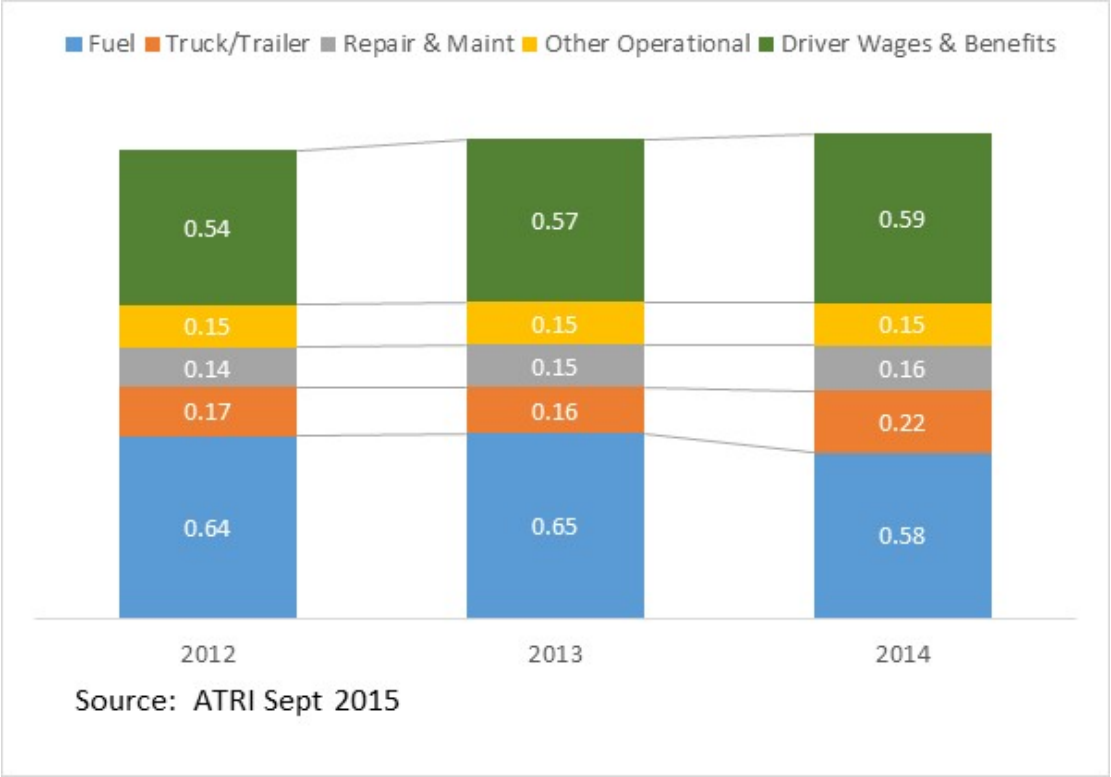


Figure 2: Trucking Operational Cost

Investment into proven technologies and practices that allow a truck or fleet to increase their fuel efficiency – meaning that they can do the same amount of business while spending less on fuel – is a hugely promising option for the industry in light of this trend.

Fuel costs aren't the only factor forcing the industry to consider its fuel economy. The U.S. federal government's "Phase 2 Greenhouse Gas Emissions Standards for Medium- and Heavy-Duty Engines and Vehicles" will come fully into effect in the next few years, and meeting them will require a rapid acceleration in the adoption of fuel efficiency technologies.

To understand, and thereby better facilitate, the uptake of such technologies, NACFE conducts an annual review, the "Fleet Fuel Study," of the industry-wide adoption rates of nearly 70 fuel efficiency technologies currently available for Class 8 tractors and trailers. This work, available on the www.nacfe.org website, has been called "the most comprehensive study of Class 8 fuel efficiency adoption ever conducted." (Truck News, 2012)

Figure 3: Fleet Fuel Study Participants

The overriding take-away from the most recent Fleet Fuel Study, completed in 2015, is that fleets are enjoying dramatic improvements in their fuel efficiency by adopting combinations of the various technologies surveyed — savings of about $9,000 per tractor per year compared to a fleet that has not invested in any efficiency technologies. It found that these fleets have fleet-wide fuel economy of just under 7.0 mpg, while the USA average, for the approximately 1.7 million tractors in over-the-road goods movement, is 5.9 mpg (Figure 4). This finding was drawn from research into the use of fuel efficiency products and practices by 14 of the largest, most data-driven fleets (Figure 3). Those fleets represent both regional and long-haul tractors and trailers, in both dry goods and refrigerated cargo movement, and boast a combined inventory of 53,000 tractors and 160,000 trailers. The 2015 study reviewed twelve years of adoption decisions by these ten fleets, and describes their specific experience with the nearly 70 technologies. Each fleet shared the percentage of their new purchases of tractors and trailers that included any of the technologies; these technologies are the solution set that will also allow the truck builders to comply with GHG regulations Phases 1 and 2. The fleets also shared twelve years' worth of annual fuel economy data for the trucks in their fleet. With these two pieces of information, which will be updated every year, NACFE is able to generate insights into the following aspects of the industry:

- Adoption curves for each of the technologies, indicating which technologies have the steepest adoption rates, which are being adopted steadily but slowly, and which are not being purchased at all. These curves also show how uniformly (or not) fleets are acting in their adoption patterns.
- Identification among the various fleets of the innovators, early-majority, late-majority, and even laggards, in new technology adoption.
- Comparison of technology adoption rates to overall fuel efficiency.
- Identification of three key insights: that the adoption of automated manual transmission has reached high levels, that aerodynamics are now available for natural gas tractors, and

that the optimization of engine parameters is being pursued more widely as a fuel-saving strategy by large, medium, and small fleets.

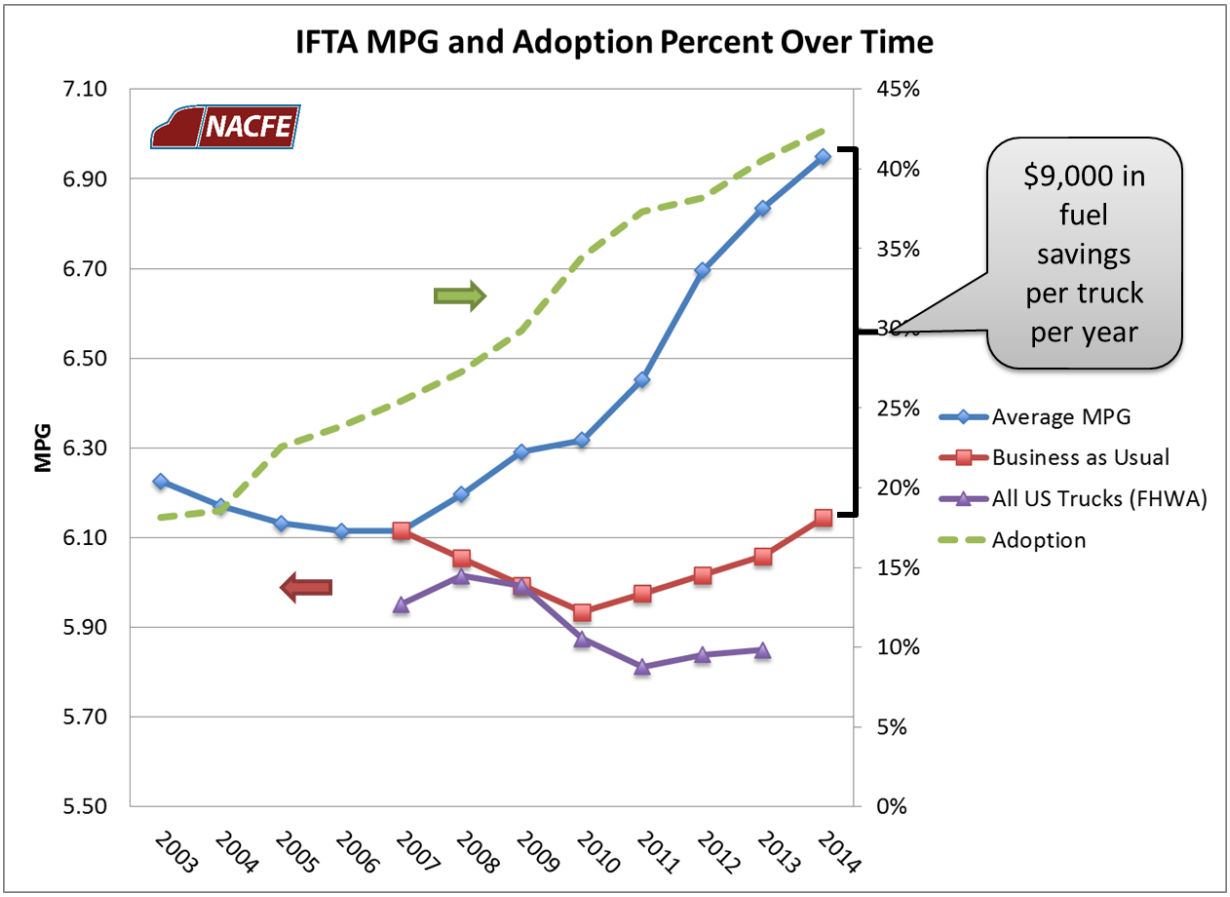


Figure 4: Savings in Fuel per Truck

2.1 Trucking Efficiency's Confidence Reports

NACFE's Fleet Fuel Studies provide useful insights into adoption trends in the industry, as well as into the specific practices of different major fleets. NACFE hopes that this information could alone spur additional investment, particularly by fleets that may be lagging behind the overall industry when it comes to certain widely-adopted technologies. However, in the course of conducting the studies, it became clear that some technologies are still only being adopted by the most progressive or innovative of fleets in spite of their showing strong potential for achieving cost-effective gains in fuel efficiency. In order to facilitate the wider industry's trust in and adoption of such technologies, NACFE and CWR formed Trucking Efficiency and began this series of reports, called "Confidence Reports," which will take an in-depth look at those most-promising but least-adopted technologies one-by-one.

Confidence Reports provide a concise introduction to a promising category of fuel efficiency technologies, covering key details of their applications, benefits, and variables. The reports are produced via a data mining process that both combs public information and collects otherwise-private information (which is shared with Trucking Efficiency for the purpose of the reports), in order to centralize an unparalleled range of testing data and case studies on a given technology set.

The core objective of this Confidence Report is to provide the leadership of fleets with a comprehensive overview of the maintenance practices that affect the fuel economy of Class 8 tractors and trailers.

The full series of Confidence Reports offers a useful roadmap for the industry, and will allow fleets and truck builders to better familiarize themselves with their options for meeting the Phase 2 GHG Regulations, as doing so will require the adoption of some, if not, most, of the fuel efficiency technologies and practices covered in the series. Visit www.truckingefficiency.org to view this and other completed reports on tire pressure systems, 6x2 axles, idle reduction, electronically controlled transmissions, engine parameters, low rolling resistance tires, lightweighting options and downsped powertrains, as well as information on many other freight efficiency technologies.

2.2 Methodology

Trucking Efficiency's Confidence Reports are researched by an unbiased team of trucking industry experts. For this maintenance report the core study team included: Jim Rogers, retired Fleet Manager at McKee Foods, Denise Rondini of Rondini Communications, and Mike Roeth, NACFE Executive Director and CWR Trucking Efficiency Lead.

In March 2015, this study team began assessing the current state of maintenance of Class 8 tractor-trailers. The team used a "360 degree" technique to gather existing data on maintenance in order to uncover any points of industry-wide agreement or areas of confusion. The team met with or used phone interviews to discuss recommended maintenance practices with many component suppliers as well as many large and small fleets.

2.2.1 Sample questions used in interviews

- Does your scheduled maintenance include more than just standard "wet" and "dry" Preventive Maintenance items?
- Does your fleet have a schedule for diesel particulate filter maintenance?
- Do you do alignment checks on your tractors?
- Do you check trailer alignment?
- How do you tire pressure checked?
- If a tractor/trailer fairing or skirt is damaged, is it replaced and if so, how quickly?
- How often is a tractor's fuel mileage checked?
- Are extractions from the tractor's ECM connected to maintenance? Is fuel economy ever downloaded and reviewed?
- How strongly do you feel the link between maintenance practices and fuel economy is understood by your company overall?
- If a maintenance practice was found that saved fuel but had a cost to implement, would it be supported?

3 Overview of Maintenance effect on Fuel Economy

The maintenance of vehicles is universal to the trucking industry, making this report unlike other Confidence Reports, which look at technologies that either are or are not adopted by a given fleet. All fleets currently maintain their vehicles in order to ensure safe and reliable performance, avoid costly break-downs or vehicle downtime, and allow their vehicles to reach maximum useful life or obtain higher resale values. The industry-standard best practice for maintaining a fleet of vehicles is through a structured preventive maintenance (PM) program with qualified technicians and tools. However, even a vehicle which is running safely and reliably may still enjoy substantial fuel economy savings thanks to additional or better-optimized maintenance.

The study team interviewed 12 major fleets for this Confidence Report. When asked how strong they felt the link between maintenance practices and fuel economy to be, 75% of respondents responded that they saw them as being strongly or very strongly linked. The remaining 25% felt that there is a weak connection, while none believed there is no link.

When asked whether the implementation of a new maintenance practice that was found to save fuel but entailed a cost to implement would be supported, 50% of respondents replied that 'yes, probably it would be supported,' 50% replied that 'maybe it would be supported,' and none replied 'no, probably not.'

Taken together the responses to these two questions illustrate that the industry is not unaware of the impact of poor maintenance on fuel economy, but nor is it quite comfortable in quantifying what the link between the two may be, so as to justify investing in improvements. This is understandable, as it is difficult to speak in aggregate about the opportunity available to the industry as a whole from addressing maintenance for fuel economy; each fleet would have to be individually assessed to determine the gains available to them from making changes to their specific maintenance practices.

Maintenance intervals ultimately depend on a fleet's specific equipment and operating parameters, but truck manufacturers and component suppliers offer recommended intervals and suggested operations as a starting place, as well as to ensure warranty compliance. The Technology & Maintenance Council (TMC) has moreover developed a number of Recommended Practices for the maintenance of commercial vehicles, including wheels and rims, air intake systems, water separators, fan drives, diesel particulate filters, coolant, brake, suspensions, axles, etc. (Detailed list available in Appendix A.)

Drivers can be enlisted in a fleet's PM efforts via Driver Vehicle Inspection Reports (DVIRs). Drivers should be encouraged to communicate any problems they find in their pre- and post-trip inspections to the maintenance department. This information can be used to alter existing PM schedules across a specific asset class.

4 Components that Influence Fuel Economy

The study team identified the separate components or vehicle systems that are known to impact fuel economy and looked at the role of maintenance in keeping those components/systems operating at peak condition. This list may not be exhaustive, it merely captures the components most often mentioned by the fleets interviewed for this report.

Ten major components or systems were found and are discussed below:

1. Lubricants/Engine Oil
2. Intake/Exhaust System & Diesel Particulate Filters
3. Engine Cooling
4. Air Compressors
5. Wheel Alignment
6. Tires
7. Fuel Filter Systems
8. Aerodynamic Devices
9. Electrical Systems
10. Air Conditioning

4.1 Lubricants/Engine Oil

Multiple factors in the maintenance of engine oil and drivetrain lubricants can affect mileage, as proper lubrication reduces friction within the engine and therefore improves fuel economy.

Too little or too much engine oil can create more friction and rob the engine of power, decreasing fuel economy. For example, exceeding the recommended oil level can result in oil churning and spin loses; Cummins has found that churn losses can reduce fuel economy by up to 2%.

Oil viscosity also affect fuel economy, as the thicker the oil the more energy it takes to pump around the engine. Chevron conducted research on the impact of viscosity on fuel economy and found that 15W-40 oil performed nearly 0.8% worse than 15W-30 oil on flat roads, which itself performed nearly 0.2% worse than 10W-30 oil. On the other hand, choosing a very thin oil may not be possible for all fleets, as the oil has be thick enough to still protect the engine in low temperature conditions.

Finding the right oil viscosity is going to become even more important under the latest proposed GHG Regulations, as they will make a new oil category available. A technical manager from Shell Global said that the fuel economy aspects of the new PC 11 oils that will be offered will save the industry millions of dollars and reduce carbon dioxide emissions, as a 1% improvement in fuel economy, which can be expected from lighter weight engine oils, will reduce the fuel consumption of the U.S. trucking industry by 1 million gallons per day.

Moreover, Chevron shared that for the first time there will actually be two oils developed under one category. CK-4 will retain its historical limits for high-temperature, high-shear viscosity, while FA-4 will have a high-temperature, high-sheer of between 2.9 and 3.2 mm2/sec. These oils will have an L after their designation to distinguish them from high viscosity oils.

Generally, engine oils and lubricants are simple to maintain, by following the manufacturer's recommended oil change intervals. Regular oil sampling and analysis provide a report on the health of the engine and the oil; monitoring the condition of the oil also helps to determine proper drain intervals and ensures the oil has the proper viscosity and total base number, and is overall preventing unnecessary engine wear. A Trucking Efficiency study team is currently studying low viscosity lubricants and plans to issue a Confidence Report on this technology in the spring of 2016.

4.2 Intake/Exhaust Systems & Diesel Particulate Filters

A combustion engine needs air and fuel to operate. An insufficient amount of either will cause poor performance, including a lack of power and reduced fuel mileage.

First of all, air intake connections and charge air coolers need to be maintained and cleaned periodically. A clean charge air cooler ensures the engine is getting enough air for ideal combustion and prevents the engine from running too hot.

When an issue with the air intake system occurs, such as the air filter becoming clogged, the amount of air that flows into the engine can be reduced, which makes the engine work harder and less efficiently. In some cases, this lack of air will cause accessories such as the turbocharger to work harder in an effort to supply the engine with the air it needs to operate. In the past, an engine suffering from restricted air flow would be obvious as there would be black smoke coming out of the exhaust. But today's electronically controlled engines, equipped with diesel particulate filters and selective catalytic reduction, do not give off any smoke to signal restricted air flow.

Today's electronically controlled engines are able to compensate for a small lack of air with their electronic control modules (ECM); a test recently conducted by the Oak Ridge National Laboratory confirmed that a slightly clogged air filter would not significantly affect fuel economy. There is, however, a limit to this compensation, and clogged filters can cause the ECM to overcompensate by burning additional fuel in an attempt to supply desired power. A lack of air can therefore cause the exhaust to be fuel rich, which could result in an additional regeneration of the diesel particulate filter (DPF). Excessive exhaust regenerations, in turn, further reduce fuel mileage, because they use fuel to raise temperatures as needed. Additional regeneration can also trigger additional intervention of the Selective Catalytic Reduction (SCR) system, causing the excessive use of diesel exhaust fluid (DEF).

Another potential problem which maintenance can monitor is exhaust back pressure – a restriction of the exhaust gas going from a higher pressure to a lower pressure. Exhaust back pressure can be the result of a badly bent exhaust, a "Y" pipe that has closed or restricted the exhaust flow, a muffler with broken baffles, or a clogged DPF. It can easily become an issue in an engine, and will cause both the fuel pump and fuel system to work harder, consuming additional fuel and taking away from engine power. It can also increase operating temperature, reduce intake manifold boost pressure, cause problems with turbochargers, and even cause valve and cylinder damage.

The DPF system, introduced with 2007 EPA regulations, merits particular maintenance attention. It functions to collect ash as a by-product of regeneration. Ash build-up can effect fuel consumption by restricting exhaust gas flow and causing back pressure; it can also decrease the efficiency of the regeneration process causing it to occur more frequently. Fleets questioned by the study team were found to differ in their miles-to-clean-DPF practices. The amount of idling a fleet experiences from its trucks is a determining variable, as trucks that idle more frequently will clog their DPFs more quickly and require more frequent cleaning.

Specifically, the 12 fleets surveyed shared the following regarding their sleeper tractors:

- 4 of the fleets clean their DPFs every 250,000 miles
- 2 of the fleets clean their DPFs every 200,000 miles
- 1 of the fleets cleans their DPF every 300,000 miles
- 1 of the fleets cleans their DPF every 400,000 miles
- 1 of the fleets cleans their DPF every 180,000 miles

The fleet with the procedure for the most frequent cleaning of their DPFs, at every 180,000 miles, stated that they see an improvement in fuel efficiency after cleaning of about 1.5%, which informed their decision to implement such frequent checks.

Overall, the air intake, exhaust, and DPF systems all need to be checked at regular intervals, and any leaks or clogs must be addressed. It is difficult to assign an exact value to the fuel efficiency loss caused by the poor maintenance of these systems, but the study team found that a 5% decrease can be common for vehicles with poorly maintained intake and exhaust systems.

4.3 Engine Cooling

When the engine cooling fan is operating correctly, it will only run as needed to cool the engine. A fan that runs constantly causes a significant reduction in fuel economy, as manufacturers that operating the fan will draw as much as 35+ hp. At 14500 rpm cruise the fan being locked in the on position can cause a massive 8-12% reduction in fuel efficiency.

Coolant temperatures also contribute to fuel efficiency. Regular cooling system operating temperatures are above 180°F; Cummins reports that a 0.4% fuel economy loss is associated with every 30° decrease in temperature below that level.

In sum, an inoperative fan clutch, faulty thermostat switch, low coolant level, and/or anything that makes the fan run longer than it should can all negatively impact fuel economy.

4.4 Air Compressors

The air compressor is necessary for proper operation of the braking system and a few other air accessories. It works to keep the air pressure of the braking system between preset minimum and

maximum levels. . It is powered by the vehicle's engine, cooled by the engine's cooling system, and lubricated by the engine's oil supply.

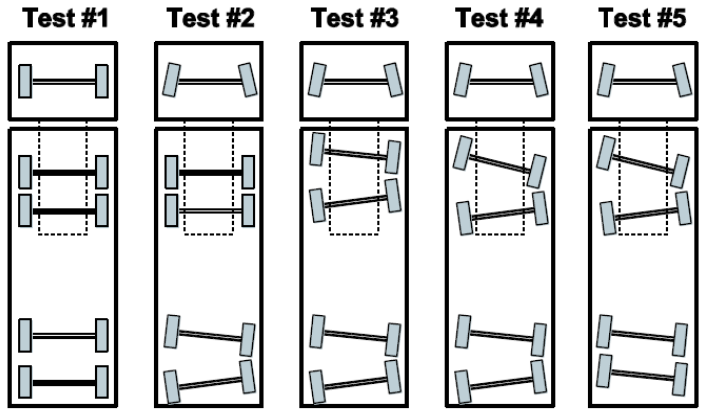
Air compressors are designed need to work to build up air pressure no more than 25% of the time. Higher duty cycles for that piece of equipment can cause conditions that affect the airbrake charging system. It will also decrease fuel economy, but having a system which draw on the resources of the engine running too frequently. Note that poor air compressor performance often is caused by a problem elsewhere in the system, so it is important to find and repair the root cause.

Excessive air compressor operation can result in a loss of 2% of fuel economy, while leaks in the system will have a smaller impact.

4.5 Wheel Alignment

Misalignment of wheels and tires increases rolling resistance, which in turn causes the engine to work harder to overcome the additional drag and negatively impacts fuel economy. A tire that deviates only 1/4 degree from straight will travel 10-15 feet sideways for each mile the vehicle travels forward. Alignment issues may not be visible but still can cause the tires to scrub, greater aerodynamic drag, vibration, reduced stability, poor handling, and a decrease in the vehicle's fuel mileage.

Cummins shared data from tests looking at wheel alignment that resulted in fuel efficiency losses of between 0.6% and 2.2% (Figure 5). Meanwhile fleets that have taken steps to ensure their tractors and trailers are aligned reported to the study team that they have seen fuel savings in the 3% to 11% range.



Alignment	Test #1	Test #2	Test #3	Test #4	Test #5
Steer Tire. Toe-In:	0"	1/4	1/4"	3/8"	3/8"
Drive Axle. Non-Parallel:	0"	0"	1/2"	1"	1"
Trailer Axle. Non-Parallel:	0"	1/2"	1/2"	1"	0"
% Effect on MPG:	0.0%	-0.6%	-0.8%	-1.7%	-2.2%

Figure 5: Alignment and Fuel Economy (Source: Cummins)

Many of the fleets surveyed have scheduled alignment checks for the tractor at steer tire replacement. Some also have an alignment check as one of the steps in their PM inspections, while others have a check was connected to total operating mileage of the vehicle. Few fleets reported they had any

scheduled checks on trailer wheel alignment – it was found that trailer alignment was checked only following driver complaints.

Fleets also discussed improper alignment that can actually cause either well aligned tractors and trailers or those with alignment problems, to be worse yet after an alignment. It is therefore, extremely important to be sure that the alignment process being used is robust.

4.6 Tires

Tire manufacturers agree that the most critical aspect of maintaining a tire is correct air pressure. Extensive research from the U.S. Department of Energy, among others, has found a direct connection between low tire pressure and reduced fuel mileage. Specifically, every 10-psi of under-inflation represents a 1% fuel economy penalty, due to the kinetic energy used to overcome the rolling resistance of the tire.

Mismatched heights between tires is also an issue; studies have shown that a mismatch in the height of tires of as little 5/16" can mean the taller tire will drag the shorter one 13 feet for every mile travelled, or about 246 miles of drag per 100,000 miles driven. Tread on the shorter tire is being scrubbed off by this dragging, which results in increased rolling resistance and therefore a loss of fuel economy. (Any reduction in tire rolling resistance improves fuel mileage.)

Trucking Efficiency has studied tires specifically in two Confidence Reports:

1. Tire Pressure Systems
2. Low Rolling Resistance Tires

4.7 Fuel Filter Systems

Fuel filters must be maintained on combustion engines in order for those engines to operate properly, as clogged diesel fuel filters will affect both engine performance and fuel economy. Any clog in a filter affects the flow of fuel; in extreme cases, if a filter is seriously clogged, the engine may not start. Restricted flow will make the fuel pump and the engine work harder to produce the desired power, which in turn causes a loss of fuel economy.

Clogged filters can also cause excessive heat build-up, and can allow contaminants into the fuel system. Excessive heat build-up can be serious, as it can damage to fuel pump and injector systems. Today's diesel engines have higher fuel system operating pressures that depend on unobstructed fuel flow to help keep the pump and injectors cool, compared to trucks the past, and both of these things can lead to heat build-up in the event of a filter clog. Today's fuel systems also have much stricter tolerances than before, with the orifices in a fuel injector measured in the thousandths of an inch, meaning that the smallest amount of contamination in a fuel system can have a big impact on the fuel injectors and consequently hurt fuel efficiency.

4.8 Aerodynamic Devices

Aerodynamic drag is the number one factor affecting fuel economy at highway speeds over 50 mph. The trucking industry has recently seen widespread adoption of aerodynamic devices on both the

tractor and trailer, with cab extenders, trailer skirts, wheel covers, trailer tail extenders, and more all now common. The correct combination of these devices can increase fuel mileage by at least about 15%. But in order for these aerodynamic devices to works, they must be properly installed and undamaged.

An aggressive repair and replacement policy should be in place for aerodynamic devices, and they need to be repaired or replaced as soon as possible. Unfortunately, damage is likely to happen at some point. Trailer skirts can be damaged going over railroad tracks. Cab extenders are easily damaged if a turn is taken too sharply or when trying to spot a trailer into a tight space. Trailer tail extenders can be damaged backing into the door of a dock if the driver forgets to collapse them.

The majority of the fleets surveyed by the study team indicated that their policy was to repair or replace a damaged aerodynamic device as soon as the damage was reported. The reality though, is that the speed of a repair depends on the availability of necessary parts and technicians, as well as on logistic concerns. Fleets that do their own maintenance indicated they keep replacement panels and extenders in stock to facilitate the repair process.

4.9 Electrical Systems

Parasitic draw is a load against the engine. Some of the loads such as the draw against the engine where it is connected to the drivetrain are necessary to move the vehicle. Additional draw from accessories such as air conditioning systems, charging systems and engine fans (when operating) is also necessary to power for these vehicle sub-systems But poor maintenance of those systems adds additional parasitic draw, thus requiring more fuel and negatively affecting fuel efficiency..

Some fleets have seasonal PMs related to their air conditioning and/or starting systems. While these checks are usually performed to ensure reliability, i.e. that the equipment will start and drivers will be comfortable in hot weather, both can have a positive and negative effect on fuel mileage. If a charging system has weak or incorrect batteries, the alternator will work harder in an attempt to keep the batteries at full charge; this additional parasitic load can negatively affect fuel economy. If the refrigerant level in the air conditioning system is low, the A/C compressor will stay engaged more frequently and for longer periods of time in an attempt to keep up with the demand for lower cab temperatures.

4.10 Air Conditioning Systems

A poorly maintained A/C system can cause the need for the fan to run much more frequently, wasting fuel, as an air conditioning system that is not operating at its optimum efficiency requires more power to function. Specifically, the condenser and evaporator coils must be clean and free from obstructions, the drive belt must be in good condition, and the refrigerant must be kept at the proper level.

5 Benefits

Discussing the “benefits of maintenance” may sound odd, as no one in the industry believes maintenance is without a benefit. However, some fleets still view maintenance as a cost and make cuts to the maintenance budget during tough economic times. It is not common for fleets to think of

maintenance in terms of the *fuel economy* benefits it offers – the study team recommends that in fact they absolutely should. Adding up all of the potential reductions in fuel economy covered under the 10 components described in section 3 shows that maintenance can in fact address 30% to 50% of fuel consumption. Certainly no truck will ever have problems with all 10 of these components at once, but the massive size of that figure is indicative of just how significant the opportunity is to use maintenance to improve fuel efficiency. In short – **proper maintenance saves fuel**.

Fleets shared with the study team that they have seen fuel consumption improvements of 5% to 10% after the implementation of rigorous preventive maintenance practices. The average cost per mile of diesel fuel in 2014 was $0.58, while the average truck ran 120,000 miles per year, meaning that a 5% gain in fuel economy equates to a reduction in fuel cost of $3,800 per year per truck. Even at current 2015 price of around $2.50 per gallon, this still represents about $2,150 in savings. Such savings mean that implementing more effective maintenance protocols, by increasing staff and/or investing in maintenance practice software, facilities, or other tools, will likely pay for itself in fuel savings in just few years.

Additional benefits of proper maintenance include:

1. Improve Vehicle Reliability and Reduced Breakdowns
    - Well-maintained trucks are less likely to have on-road breakdowns; unscheduled repairs are the most costly and result in more downtime.
2. Increased Resale Value
    - Anecdotal evidence shows that buyers of used equipment are willing to pay more for a vehicle when the seller has records that prove maintenance was done on an ongoing basis. There is evidence that a well-maintained truck, for which maintenance records are available, will bring more money at resale.
3. Enhanced Driver Safety and Satisfaction
    - Well-maintained trucks are safer to operate. Given the worsening driver shortage, anything that can be done to improve driver satisfaction is a bonus for fleets, and drivers vastly prefer to drive trucks that don't break down or otherwise suffer from performance issues.
4. Reduced CSA Violations and Fines
    - The overwhelming majority of CSA violations are in the Maintenance BASIC. According to Athena/Vigillo as reported by Fleet Owner, violations for one inspection period were as follows:

Vehicle Maintenance	17,140,126
Hours of Service	2,167,006
Driver Fitness	1,162,682
Unsafe Driving	1,118,491
Hazmat	172,201
Controlled Substances	17,893

6 Challenges

In spite of these benefits, fleets working to implement more effective maintenance protocols should also be aware of the following three challenges that they may face while doing so:

1. Scheduling
    - Given the demands placed on trucking companies, including capacity constraints, Hours of Service regulations, and limited bay space availability, it can be difficult to schedule PM service in a way that does not negatively impact fleet productivity.
2. Tracking/Ensuring Compliance
    - Fleets using manual methods of tracking PM servicing are likely not getting all their trucks scheduled for PM servicing as needed. Luckily, programs are available that electronically track compliance with scheduled PMs using telematics devices that are tied to software programs and alert the fleet manager when a PM service is upcoming.
3. Demonstrating Return on Investment
    - Maintenance is typically viewed as something that is done to keep trucks on the road, and not as a way to improve fuel economy. Getting fleets to factor fuel economy improvements into their maintenance investments is challenging. Moreover, proper maintenance may address multiple systems at once, and not only is it impossible to attribute any fuel economy gains to this or that maintenance action, it can be difficult to prove that a change in maintenance caused any gains at all, especially depending on how a fleet was monitoring their fuel economy previously.

7 Insights from Fleets

Overall there is a growing interest in and reliance on electronic prognostics, especially as they relate to engine maintenance. Fleets that are dedicated to improving their preventive maintenance practices are investing in software products that track, monitor, and measure maintenance for all their assets. These software platforms allow PM schedules to be set for either individually for each asset or for groups of similar assets, and automatic notifications are sent to remind the fleet manager that maintenance is due for a specific asset. Rather than scheduling preventive maintenance inspections based on mileage or months, fleets can use these tools to rely on dashboards sensors that keep them updated on the condition of something like the oil, and send an alert when oil needs to be changed.

One fleet manager told the study team, “We do consider the fuel economy benefits of maintenance when making decisions to invest in a more aggressive maintenance program, whether software, personnel, or tools and equipment.”

Another fleet manger said, “I believe there is a close correlation between maintenance and fuel economy, but my opinion may not be widely shared among my management peers. I would definitely review any product or maintenance practice that would yield improved fuel economy for the fleet, but adoption would wholly depend on a solid cost-benefit analysis and rate of return on investment.”

However the viewpoint of many other fleets today, who are less certain about the relationship between maintenance and fuel economy, is best summed up by this comment from a fleet manager: "It would need to be sold to me with a valid ROI and test results."

Finally, one large fleet reported having instituted a truck maintenance program that allows a truck to be diverted to a maintenance facility by a fleet manager if the vehicle's mpg decreases. Any driver or technician was also allowed to intervene and request that the truck be brought in for service because of fuel economy problems. This process impressed the study team and is detailed as a best practice in the next section of this report.

8 Best Practices

Since their inception, commercial vehicles have needed to be maintained. That is something that is not likely to change anytime soon. The place to start with developing a maintenance plan is to review OEM and component supplier recommendations. In addition, the Technology & Maintenance Council has developed Recommended Practices that provide recommended maintenance practices for many components (Appendix A contains key examples).

Maintenance needs to be performed on an on-going and consistent basis. An excellent option for facilitating this today is to invest in technology that allows your fleet to schedule and track maintenance compliance. The fleet can also then rely on that telematics data to send an alert when a vehicle is reaching its next maintenance milestone, whether that is miles driven, fuel used, hours of operation, or engine hours, or simply a scheduled PM Service.

Other general best practices which will allow fleets to obtain optimal fuel economy from their maintenance procedures include:

- As most fleets today are continually monitoring their fuel economy, if a fleet manager notices a trend of decreasing miles per gallon on a vehicle, the vehicle should be brought in to the shop to determine the root cause of the problem.
- To minimize downtown and not impact your drivers' service hours, bundle maintenance events with recalls, service campaigns and other inspections, thereby eliminating the need to take the truck off the road for an additional service event.
- Collect and record data from every maintenance and repair event. Develop trending reports that allow you to spot trouble areas in certain asset classes, for examples assets of a certain age, in a certain duty cycle or with a specific brand of component. When you've identified wear and failure trends, modify your maintenance program so trucks will be brought into for maintenance
- Predict the fuel economy benefits of improved maintenance for your particular duty cycles, business practices and equipment and use this to justify investments in an improved maintenance process.

8.1 Sample Checklist

Getting more specific, one large private fleet shared their practice of "Over-The-Road Fuel MPG Equipment Intervention" when a decrease in fuel mileage was noticed. It is shared here:

1. Before jumping into the inspection process, take some time to investigate the following things, which may be contributing to the loss in mpg:
    - Driver habits that impact fuel economy
    - Changes in routing, road conditions, traffic and weather
    - Changes in trailer load profile
2. If there have been no changes to those areas, look at the vehicle's service history for the past six to eight weeks.
    - Pay special attention to repairs related to tires, aerodynamic devices, brakes, fuel system, drivetrain, and air conditioning system.
    - Review the oil analysis, looking for signs of component failures.
    - Check for any outstanding service bulletins, campaigns or recalls that relate to fuel economy.
3. Conduct a walk around inspection, including the following:
    - Look for damaged or missing body parts
    - Inspect condition, security of mounting and placement of aerodynamic devices
    - Check tire pressure, tread depth and wear patterns
    - Use a tire square to make sure dual tires are within ¼ inch of each other
    - Check the level of engine oil, power steering fluid and coolant
    - Inspect air filter minder for proper vacuum level
    - Inspect fuel filter housing, lines and brackets and make sure mountings are secure
    - Inspect fuel pump, fuel lines and brackets
    - Inspect exhaust manifold, gaskets and flanges
    - Inspect turbocharger assembly, oil lines and clamps
    - Inspect waste gate actuator
    - Inspect radiator, fan shroud, charge air cooler, oil cooler, top tank and support rods
4. If no problems were found during the walk around inspection, test drive the truck for at least four tenths of a mile, being sure to:
    - Look for smoke and listen for unusual noises
    - Verify that the transmission is shifting properly
    - Test the brakes noting any pulling, vibration or pulsation
    - Test steering response and verify that vehicle alignment is correct
    - Check fan engagement and disengagement
    - Verify that the coolant fan clutch cycles on and off
    - Inspect coolant fan for balance
5. If no problems were found during the test drive, perform engine diagnostics by connecting the engine to the proper OEM diagnostic program.
    - Check for active diagnostic trouble codes and determine if the code has an impact on fuel economy

    - Check for inactive diagnostic trouble codes and determine if the code has an impact on fuel economy
6. Perform cylinder balance test
    - Perform injector cutout test
    - Perform compression test
    - Perform EGR/EPG function test
    - Confirm engine speed parameters
    - Perform DPF manual regeneration
7. If no faults are related to fuel economy performance, perform under chassis and engine component tests.
    - Inspect fuel tanks, lines and valves
    - Inspect air lines, tanks and brake chambers
    - Inspect brake assembly, hardware and return spring installation
    - Rotate drive line and inspect yoke flange nuts, slip yokes, U-joints and pinion bearing
    - Remove the turbocharger inlet boot and exhaust pipe and charge air cooler piping
    - Inspect turbine blades and housing
    - Verify shaft end play and side play
    - Inspect charge air cooler internally for fluid accumulations and obstructions
    - Use a stethoscope to confirm bearing condition on all accessory pulleys
    - Confirm pressure reading for air conditioning compressor

A thorough checklist such as this will ensure that none of the needed inspections are missed. While the list of items to check whenever a fleet manager notices a loss of fuel economy does look long here on the page, a technician should be able to complete this work in two to two and a half hours. Rapidly fixing any items found during these inspections can save thousands of dollars in fuel per truck.

9 Conclusions and Recommendations

The study team reached the following conclusions regarding the situation of using maintenance to increase fuel economy in the trucking industry today:

- Fleets view maintenance as important to their operation, but tend to look at it as a means for reducing downtime rather than improving fuel economy.
- There is strong evidence that properly maintained trucks will enjoy improved fuel economy.
- While reducing downtime is the main pathway-to-payback from investments in maintenance, including information about the increased fuel economy of well-maintained trucks can make the ROI of an investment in maintenance technology, tools, bay space, technicians, or software an easier sell across fleet management.
- There are a variety of sources available, including the Technology & Maintenance Council, where fleets can find information about the maintenance needs of various components.

9.1 Looking Forward

Given the increasing sophistication of today's commercial vehicles, including the many new technologies being specified on them, it is likely that the need for maintenance will increase. Fleets have already moved away from reactive maintenance and repair, and are now focusing on preventive maintenance to keep their trucks in top operating condition.

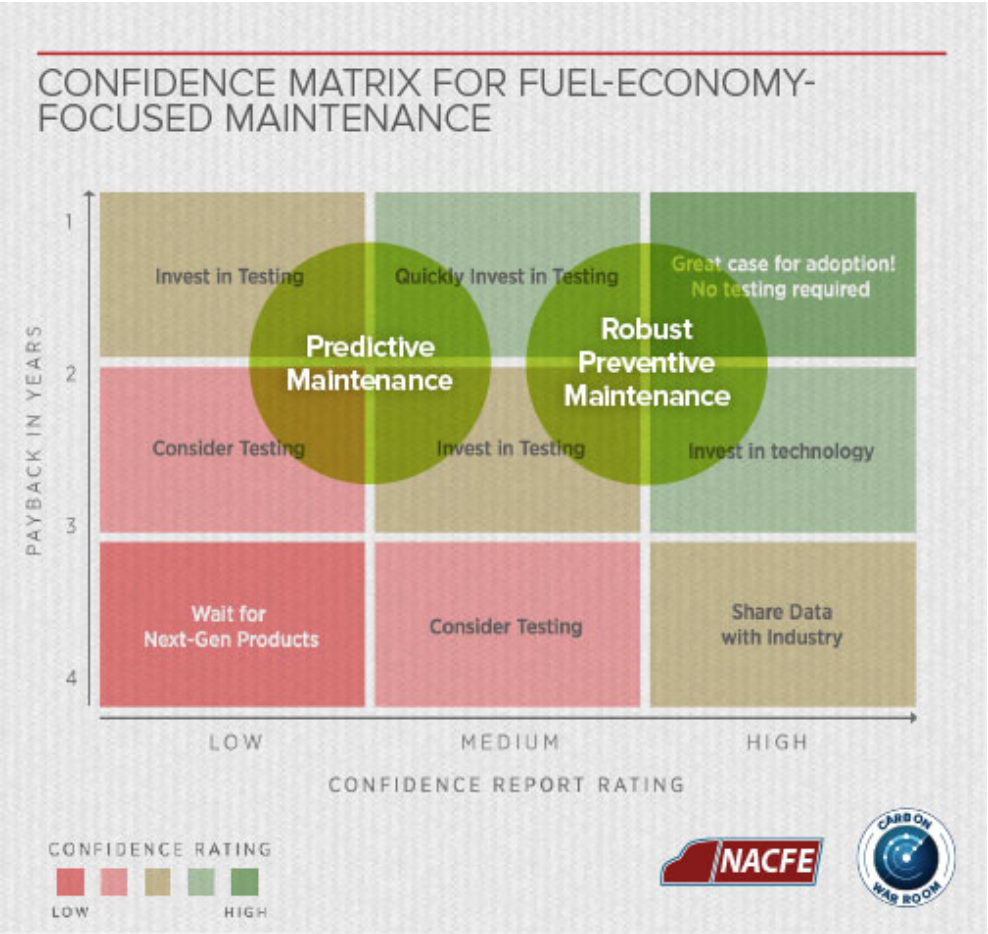
What fleets really want is to be able to fix a truck before it breaks. The next evolution in maintenance, therefore will be a new sort of "PM:" not preventive but *predictive* maintenance. Such a system functions using telematics devices and an array of vehicle sensors, which are now standard on many Class 8 trucks, in order to record and wirelessly relay vehicle performance data, including any issues that may arise, back to the fleet, who in turn can quickly respond.

A one-size-fits-all approach to maintenance will defeat the purpose of predictive maintenance. Instead, it will require each fleet to capture and analyze all of the data being generated by the ECM, sensors, and telematics devices of all of their trucks. Proper data analytics will allow fleets to spot wear and break-down trends, and to schedule pre-emptive repairs. Technology and connectivity are the keys, but just as important is the collection and analysis of data from all maintenance and repair events on all assets, and the cross-referencing of that data with information about vehicle age, miles driven, duty cycle, etc.

9.2 Confidence Rating

It is difficult to quantify the overall fuel savings due to maintenance. There are some areas like tire inflation or the cleaning of diesel particulate filters for which there is plenty of specific evidence as to how much these measures can increase fuel economy. For other components like tires, axle alignment, oil, and aerodynamic devices there is demonstrative evidence of the fuel economy loss when those components are poorly maintained.

This Confidence Rating indicates that fleets should be willing to invest in technologies and/or staff to optimize their maintenance protocols, and that they should monitor fuel economy savings in order to justify those investments. In particular, fleets should consider investing in telematics technologies, which will allow them to transition from preventive to predictive maintenance practices. The benefits of investments in predictive maintenance are still emerging as there are many solutions and the capabilities for better decision making with the much larger available data are not yet mature. It is expected that the payback and amount of information available on predictive maintenance will improve over the next 12 to 18 months.


CONFIDENCE MATRIX FOR FUEL-ECONOMY-FOCUSED MAINTENANCE
PAYBACK IN YEARS
1
2
3
4
Invest in Testing
Quickly Invest in Testing
Great case for adoption! No testing required
Predictive Maintenance
Robust Preventive Maintenance
Consider Testing
Invest in Testing
Invest in technology
Wait for Next-Gen Products
Consider Testing
Share Data with Industry
LOW
MEDIUM
HIGH
CONFIDENCE REPORT RATING
CONFIDENCE RATING
LOW
HIGH
NACFE
CARBON WAR ROOM

10 Appendix A

Key Recommended Practices for Maintenance from the Technology & Maintenance Council

- RP 211C Rim And Wheel Selection And Maintenance
- RP 230B Tire Test Procedures For Tread Wear, Serviceability And Fuel Economy
- RP 301C Maintaining Air Intake Systems
- RP 311A Cold Weather Operation
- RP 313C Checklist For Cooling System Maintenance
- RP 318C Used Oil Analysis
- RP 320C Inspection, Maintenance And Tension of Accessory Belt Drive Systems
- RP 333A Heat Exchanger Exterior Maintenance And Cleaning
- RP 334B Guidelines For Establishing Proper Engine Oil Drain Intervals For Heavy-Duty Diesels
- RP 336A Aluminum Radiator Maintenance
- RP 338A Extended Service Interval Coolants
- RP 339 Maintaining Fuel/Water Separators
- RP 345A Diesel Fuel Housekeeping Guidelines
- RP 347A Fan Drive Maintenance And Troubleshooting
- RP 354 Fuel Economy Tracking Guidelines
- RP 355A Maintenance And Inspection Guidelines For OEM-Installed Exhaust Particulate Filters For Diesel-Powered Vehicles
- RP 358 Charge Air Cooler Maintenance And Testing Guidelines
- RP 360 Diesel Exhaust Fluid Guidelines
- RP 361 EGR Cooler Diagnosis And Cleaning
- RP 362 Guidelines For Used Coolant Analysis Of Heavy-Duty Vehicles
- RP 365 Coolant Maintenance Guidelines
- RP 607B Preventive Maintenance and Inspection of S-Cam Foundation Brakes
- RP 609C Self-Adjusting And Manual Brake Adjuster Removal, Installation And Maintenance
- RP 622A Wheel Seal And Bearing Removal, Installation And Maintenance
- RP 624A Lubricant Fundamentals
- RP 638A Heavy-Duty Clutch Maintenance Guidelines
- RP 641A Maintenance Guidelines For Hydraulically Actuated Clutches
- RP 642B Total Vehicle Alignment: Recommendations For Maximizing Tire And Alignment-Related Component Life
- RP 643 Air-Ride Suspension Maintenance Guidelines
- RP 645 Tie Rod Inspection And Maintenance Procedure
- RP 646 Driveline Fastener Preventive Maintenance
- RP 650 Guidelines For Fifth Wheel Pre-Delivery Inspection, Preventive Maintenance And Troubleshooting
- RP 651 Steer Axle Maintenance Guidelines
- RP 655 Drive Axle Maintenance Guidelines
- RP 656 Hub And Spoke Wheel Fastener Maintenance
- RP 1110 Inspection And Maintenance Recommendations For Aerodynamic Devices

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