Run on Less Report

ABSTRACT

This report documents the *Run on Less* cross-country roadshow by NACFE, a first-of-its-kind demonstration of high mpg using currently available technologies. It shares the methods used to select the participating fleets, routes, and equipment deployed, and to determine the efficiency of the fleet of seven participants and puts the results in context. It is hoped that this work encourages end-user fleets to explore and adopt more of the technologies and practices, for manufacturers to improve their products for quicker return on investment, and for others to better support the efforts of the trucking industry. Thanks to all of those who contributed to this important work.

Run on Less by NACFE was a joint effort between NACFE and Carbon War Room, which is now a part of Rocky Mountain Institute. The mission of the initiative is to double the freight efficiency of North American goods movement through the elimination of market barriers to information, demand and supply.

Acknowledgements:

***Run on Less* Drivers and Participating Fleets:**

Henry Albert, Albert Transportation
Bradley Long, Hirschbach
Roberto Sandoval, Mesilla Valley Transportation
Clark Reed, Nussbaum
Tommy Revel, PepsiCo's Frito-Lay Division
Joel Morrow, Ploger Transportation
Mark Risien, US Xpress, Inc.

Figure 1: Run on Less and NACFE 2017 sponsors

CONFIDENCE REPORT: EXECUTIVE SUMMARY

RUN ON LESS

This report documents the Run on Less cross-country roadshow by the North American Council for Freight Efficiency (NACFE), a first-of-its-kind demonstration of high mpg using currently available technologies. The report shares the methods used to select the participating fleets, the routes, and the equipment deployed, and to determine the efficiency of the fleet of seven participants and puts the results in context. It is hoped that this work encourages end-user fleets to explore and adopt more of the technologies and practices, manufacturers to improve their products for quicker return on investment, and others to better support the efforts of the trucking industry. Thanks to all of those who contributed to this important work.

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ACKNOWLEDGMENTS

NACFE Report Team:

Yunsu Park, NACFE
Mike Roeth, Executive Director, NACFE
Denise Rondini, Communications Director, NACFE
David Schaller, Industry Engagement Director, NACFE
Bianca Wachtel, Marketing Manager,
Transportation Programs, RMI

EXECUTIVE SUMMARY

Fuel costs are a significant part of the expense to operate a tractor-trailer in North America. Over the past decade fuel has been as high as $0.65 per mile driven and then dropped to $0.34 by 2016. At these two points, fuel costs accounted for 39% and 21% of the total cost respectively. The price per gallon for diesel as of February 2018 has now risen to around $3.00 per gallon ($0.44 per mile) from the 2016 yearly average of $2.30.

Given the work of the North American Council for Freight Efficiency (NACFE), three other motivations to improve the efficiency of over-the-road tractor-trailers are driving fleets, manufacturers, and others to take action. These include the general volatility of fuel prices and the long time it takes to adopt technologies. Investing in these technologies today will pay back if prices increase. Second, the United States Environmental Protection Agency (U.S. EPA) and the National Highway Traffic Safety Administration (NHTSA) have enacted greenhouse gas regulations on commercial vehicles extended to 2027 that require manufacturers to develop and sell technologies to improve efficiency. And finally, actions to reduce the use of fuel are becoming key elements of corporations' plans to meet their sustainability goals.

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 payback for investment in these technologies. To overcome those barriers and facilitate the industry's trust in and adoption of the most promising fuel efficiency technologies, NACFE partnered with Carbon War Room (CWR), now a part of Rocky Mountain Institute (RMI), to produce a series of Confidence Reports. The reports detail the solutions that exist, highlight the benefits and consequences of each, and deliver decision-making tools for fleets, manufacturers, and others. As of early 2018, NACFE and RMI have completed 16 such reports covering nearly all the 85 technologies available.

The completion of this first, comprehensive level of analysis of the plethora of technologies and practices available caused the NACFE and RMI teams to begin planning a major demonstration event.

This report highlights the results of Run on Less (the Run), a first-of-its-kind cross-country roadshow to showcase advancements in freight efficiency. The goal of the Run was to highlight the best possible current use of the combinations of technologies, operational practices, and driver capabilities to show what the most innovative fleets in the real world can accomplish in terms of fuel economy and freight efficiency.

The goals of this Confidence Report are: (a) to demonstrate that 10.1 mpg is possible for Class 8 trucks, (b) to illustrate the importance of understanding the real-life conditions to put the performance in context, and (c) to highlight the technologies and practices that make ultra-low fuel consumption possible.

METHODOLOGIES

This report's conclusions were generated through the data collection and calculations from Run on Less. Data was collected by Geotab, using, where practical, two separate methods for collecting and calculating each metric. Fuel use and distance traveled were the two most critical parameters tracked. Additionally, to supplement the mpg data, the team recorded other factors that can affect fuel efficiency, including gross weight, vehicle speed, wind, and elevation change. A NACFE analysis team completed this work with advice from multiple organizations, such as telematics companies, mpg data mining, fleets, manufacturers, and governmental and non-governmental groups.

OBJECTIVES OF THE RUN

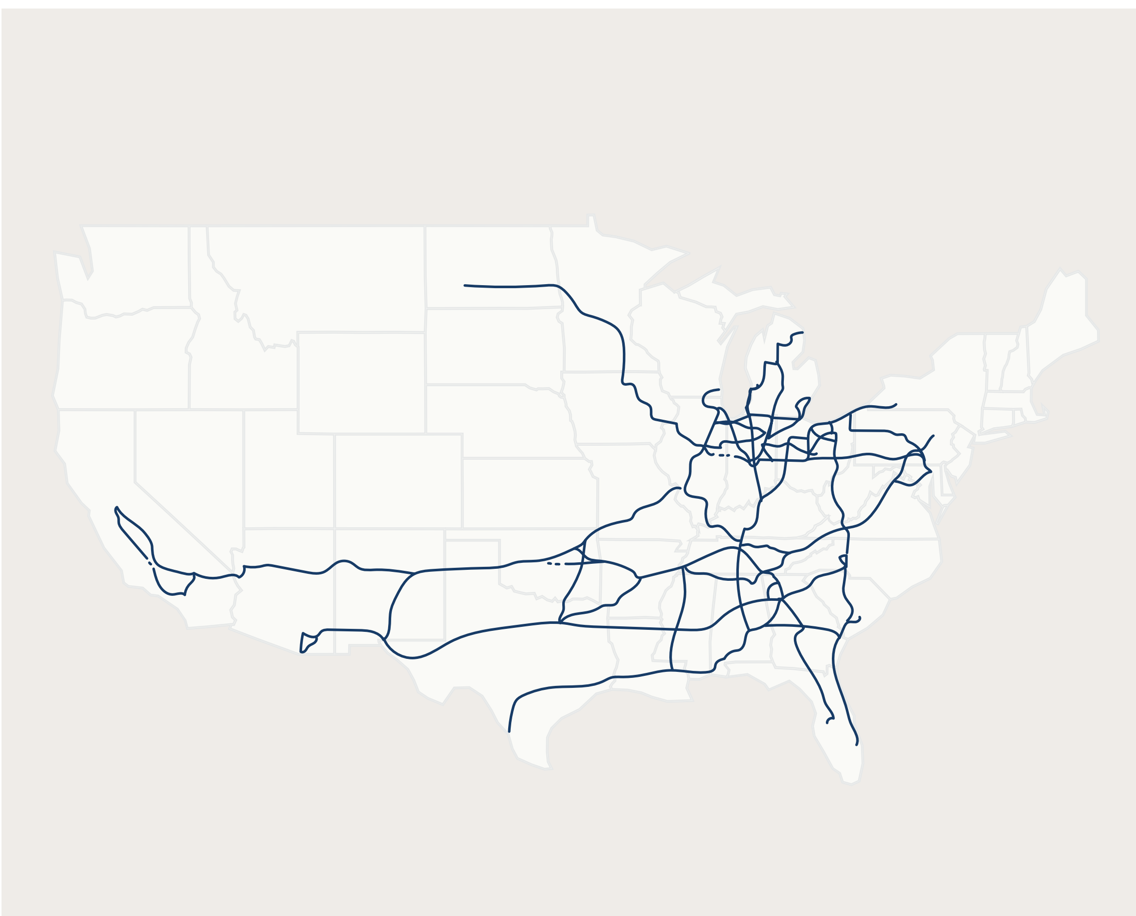
Run on Less demonstrated how Class 8 tractors and trailers can use different technologies to achieve the best fuel economy possible. The three-week experience kicked off from multiple locations across the United States and culminated at the North American Commercial Vehicle (NACV) inaugural show in Atlanta. Seven fleets participated in the Run: Albert Transport Inc., PepsiCo's Frito-Lay division, Hirschbach, Mesilla Valley Transportation, Nussbaum Transportation, Ploger Transportation, and US Xpress. The trucks were equipped with current, commercially available technologies, and the participants represented large, medium, and small fleets and one owner-operator. They also operated in a variety of duty cycles and routes. Many of the routes were representative of where the majority of truck traffic travels in the continental U.S. Their duty cycles included:

- A daycab driving the same dedicated route each day.
- Two for-hire fleets with disparate routes that would travel anywhere in the U.S. and Canada.
- A for-hire fleet that spent the first days of the Run on disparate routes then added a trainee driver and changed to a dedicated route operating as a team, driving twice the daily miles.
- A refrigerated van doing mostly Midwest regional routes.
- An owner-operator with a mix of routes.
- A hauler who generally has multiple stops daily.

The goal was to demonstrate how to achieve the best fuel economy in today's highway tractors, with a target of surpassing 9 mpg.

ES1

ROUTES OF THE RUN ON LESS TRUCKS



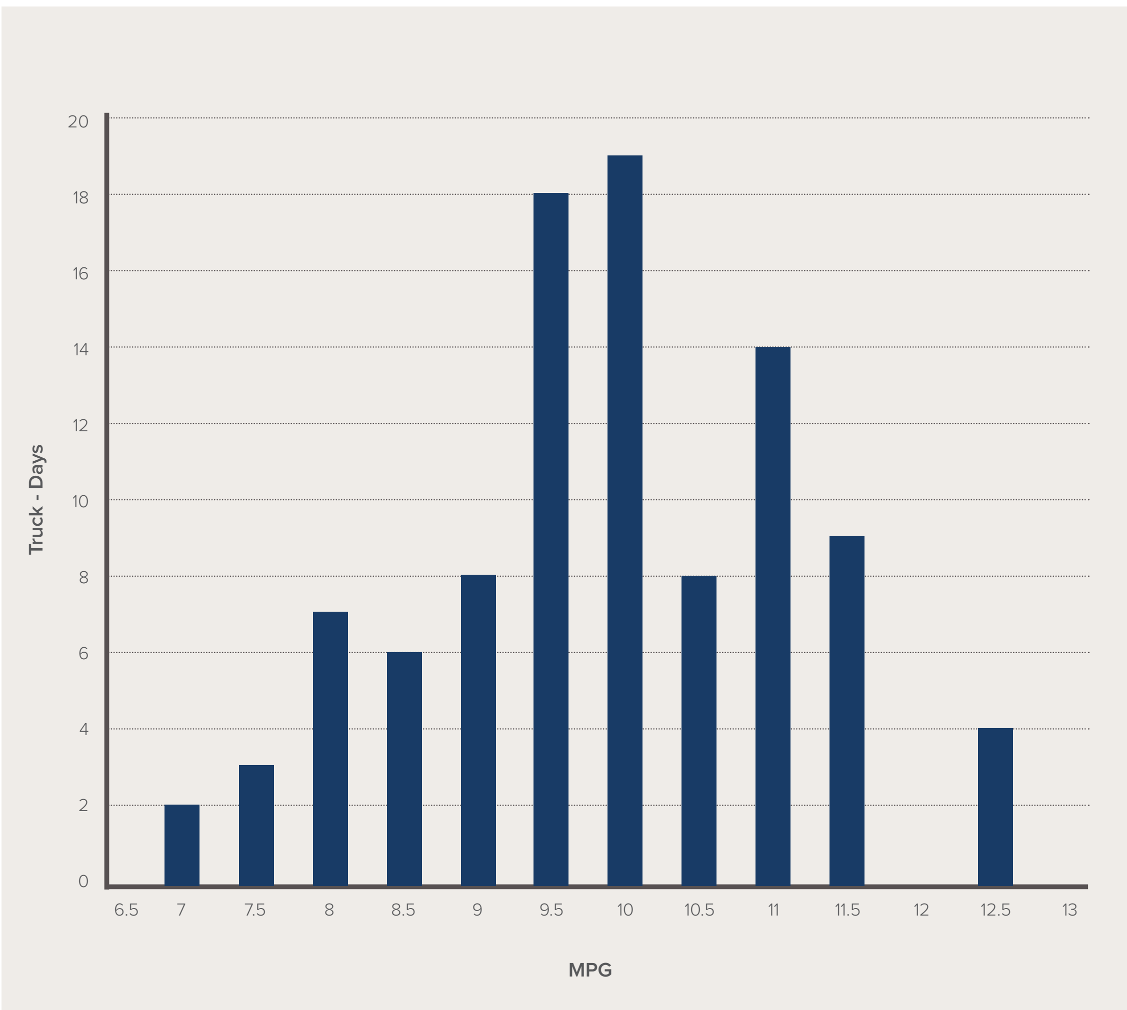
RESULTS

In total, the seven trucks averaged 10.1 mpg over the 17 days of Run on Less. This was compared to a national average of 6.4 mpg for the over-the-road tractor-trailer population. The trucks in the Run covered a total of 50,107 miles at an average gross weight of 55,498 lbs. As expected, the distribution of daily average mpg (ES2) is centered between 10.0 and 10.5. Five truck-days (one truck on one day equals a truck-day) were between 7.0 and 8.0 mpg and four truck-days were between 12.5 and 13.0 mpg. There were 99 truck-days during the 17 days of the Run. The trucks totaled 543,903 feet in elevation gain, and dealt with various weather conditions, including the effects from Hurricanes Harvey and Irma.

The overall average speed during the Run was 54 mph. Keeping speeds low is one method drivers can use to reduce their fuel consumption. Several of the drivers kept their highway speeds below 60 mph for much of Run on Less although others spent most of their time in the 62 to 64 mph range. While all drivers recorded some time above 65 mph, very little time was spent at 68 mph or higher. The drivers kept idle time very low, aided by the available array of idle reduction technologies, and the fact that the event occurred for two and a half weeks in September when temperatures are fairly moderate.

ES2

DAILY MPG DISTRIBUTION



COLLECTED DATA

The data collected during the Run as well as profiles of the drivers and equipment and 41 short videos are available at www.runonless.com. These videos could be a great tool for a company's training programs for new employees, field sales, and service personnel, etc. The pages were frozen as the data collection ended on September 23, 2017. Data collection was stopped just over 24 hours prior to press announcement to allow the team to quickly analyze and report the final results.

ES3
SCREENSHOT OF RUNONLESS.COM

EFFECT OF CONDITIONS ON MPG

The team collected and showed data on the conditions and speed during Run on Less in part to demonstrate that the Run on Less trucks were not operated in carefully controlled settings but in the real world where wind, elevation changes, and other factors can and do impact fuel efficiency. On a test track, when examining the effectiveness of a new technology, wind, temperature, speed, and other factors are closely monitored and limited. Once the technologies are put to use by the fleets, they encounter a variety of conditions. Run on Less became an opportunity to understand how much each of these conditions actually impact fuel efficiency.

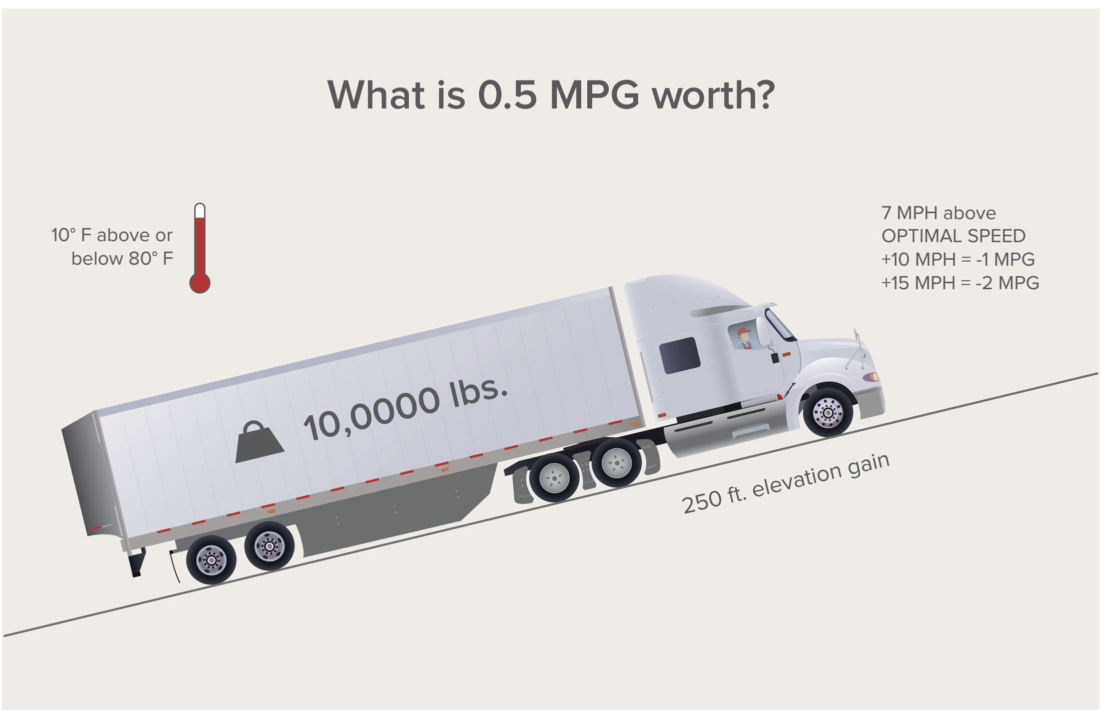
The team developed a multiple regression model from the data collected during Run on Less. Regression analysis is a tool often used to understand the relationship between a dependent variable to one or more independent variables (also referred to as predictors). In this case, the regression shows which and by how much the predictors—elevation, temperature, wind speed, vehicle speed, and vehicle gross weight—affect mpg at highway speeds. ES4 summarizes the results by showing how much each predictor must shift to change fuel consumption by 0.5 mpg. A more complete discussion of the method, analysis, and results can be found in the complete report.

CONCLUSIONS AND RECOMMENDATIONS

The conclusions of the NACFE team are as follows and can be understood in more detail in the full report.

- 10 mpg does happen in the real world
- Conditions matter and need to be understood for decision making
- High mpg requires efforts in many areas
- Telematics reports and datalogging are worthwhile investments

ES4
IMPACT OF CONDITIONS ON MPG



The team also distilled the actions of these seven fleets to achieve high levels of performance into 10 actions that the industry should consider.

1. **Use Downsped Powertrains and AMTs**. It is important to use automated manual transmissions that enable other technologies such as downspeeding. The duty cycle is key to these choices and, in particular with downspeeding, buyers should only apply the most aggressive downspeeding to tractors with high average speed (mph) where the amount of starts and stops are low.
2. **Educate and Incent Conscientious Drivers.** Run on Less benefited by having the trucks operated by some of the most proficient drivers on the road. Hiring, educating, and incentivizing drivers for the best fuel efficiency possible is a critical part of a successful fuel management system.
3. **Buy All Available Tractor Aerodynamics**. Fleets should start their specification process with all available sleeper tractor aerodynamics. NACFE has found that tractor aerodynamics have a very high ROI for line-haul applications and fleets should only remove items if they suffer frequent damage in their specific operation.
4. **Adopt Appropriate Trailer Aerodynamics.** Fleets should address trailer aerodynamics in relation to the side, rear, and front (the tractor-to-trailer gap) and adopt the most appropriate technologies depending on routes, drivers, maneuverability, etc.
5. **Optimize Cruise Control and Vehicle Speed.** Fleets should maximize the parameter settings for cruise control to gain the most fuel savings. While a slower speed burns less fuel, there may be times when a faster speed can get a trucker more revenue. Thus the conditions dictate whether it make more sense economically to drive faster and burn more fuel.

ES5
10 FOR 10

6. **Keep Equipment Well Maintained.** The technologies employed on tractors and trailers work best when the trucks are well maintained. It is important to employ solid maintenance practices and utilize technology to help the equipment run as it is intended (e.g., automatic tire inflation on trailers, use of low-viscosity lubrication, alignment, replacing or cleaning all filters, etc.).
7. **Implement the Right Axle Configuration.** Fleets should use the correct axle configuration for the job, depending on the payload, speed, maneuverability, fleet practices such as tire management, and even resale value if the asset will be sold before its useful life is exhausted.
8. **Embrace Low Rolling Resistance Tires.** Low rolling resistance tires are critical for a fleet to get high mpg, but the most fuel-efficient tires are not right for every fleet, application, or region. A productive tire purchase and management process takes focus but will pay off.
9. **Provide Tools to Reduce Idle Time.** Drivers should shut the truck off whenever and wherever possible and use technology and engine parameter settings to reduce idle time.
10. **Build a Culture of Methodically Choosing Technologies.** Fleets should have a process to constantly monitor, adjust, and act upon new technology opportunities. Best practices include comprehensive understanding of the performance, either by testing or through industry involvement; robust payback or return on investment analyses; and supplier selection.

NACFE has completed Confidence Reports that provide unbiased views of more than 80 available technologies, including decision-making tools to help fleets and manufacturers in their efficiency efforts. See the technology guide at nacfe.org to learn more about how to improve your operations and performance.

NACFE

The North American Council for Freight Efficiency (NACFE) is a nonprofit organization dedicated to doubling the freight efficiency of North American goods movement. NACFE operates as a nonprofit in order to provide an independent, unbiased research organization for the transformation of the transportation industry. Data is critical and NACFE is proving to help the industry with real-world information that fleets can use to take action. In 2014, NACFE collaborated with the Carbon War Room, founded by Sir Richard Branson and now a part of RMI, to deliver tools and reports to improve trucking efficiency. **www.nacfe.org**

Run on Less by NACFE

Run on Less 2017 was a first-of-its-kind fuel efficiency roadshow that proved 10 miles per gallon is possible with various combinations of commercially available technologies. Seven participating fleets hauled real freights on real routes during the three-week run across North America. Fuel efficiency data was livestreamed via telematic devices on runonless.com, and Shell and PepsiCo were the title sponsors.

About Rocky Mountain Institute

Rocky Mountain Institute (RMI)—an independent nonprofit founded in 1982—transforms global energy use to create a clean, prosperous, and secure low-carbon future. It engages businesses, communities, institutions, and entrepreneurs to accelerate the adoption of market-based solutions that cost-effectively shift from fossil fuels to efficiency and renewables. RMI has offices in Basalt and Boulder, Colorado; New York City; Washington, D.C.; and Beijing. **www.rmi.org**

GET INVOLVED

Trucking Efficiency is an exciting opportunity for fleets, manufacturers, and other trucking industry stakeholders.
Learn more at: www.nacfe.org
Or contact: Mike Roeth at mike.roeth@nacfe.org

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Introduction

The North American Council for Freight Efficiency (NACFE) was created in 2010 to help the industry double freight efficiency. By early 2017, the group had completed five Annual Fleet Fuel Studies and Sixteen Confidence Reports covering 75 technologies that can improve the freight efficiency of Class 8 over-the-road tractor trailers. These reports include decision making tools for fleets to make adoption decisions, details for manufacturers to improve the return on investment of their products and for others, such as governments to consider regulations or incentives to encourage use.

The completion of this first, comprehensive level of analysis of the plethora of technologies and practices available, caused the NACFE and Carbon War Room (CWR) teams to begin planning a major demonstration event. The idea was to highlight the best possible current use of the combinations of technologies, operational practices and driver capabilities to show what is being accomplished by the most innovative fleets in the real world. It would not be a show of future technologies on these trucks and trailers, or an engineering test using fixed freight and a focused protocol, or even a short one-day effort with limited data. After months of formalizing various ideas and discussions with industry leaders, the group decided to find an "all-star" team of real truckers from fleets who haul freight every day. It was a three-week long effort that had NACFE following seven truckers, collecting data off the trucks, utilizing other information such as weather and topography data to put the performance of the trucks in context, communicating often with the drivers for stories from the road and creating a virtual event through an engaging website.

Cheryl Bynum, National Program Manager, US EPA SmartWay summarized the intent of the Run well by sharing, "For over a decade, EPA SmartWay has collaborated with industry and other stakeholders to advance cost-effective, cleaner technologies and practices. *Run on Less* offered an opportunity for several of our top trucking fleet partners, NACFE and others, to showcase the best of these cleaner, more efficient technologies and driver strategies. Together, our efforts contribute to a healthier planet and a healthier bottom line," said

This effort required a great deal of planning, industry consensus on the approach and the funding for the many aspects of the program. NACFE, Carbon War Room (CWR) and Rocky Mountain Institute (RMI) would like to thank the gracious support of the *Run on Less* sponsors and the 2017 general NACFE sponsors for helping make *Run on Less* possible. Shell and PepsiCo with their title sponsorship and Geotab and EPA Smartway as event sponsors provided much support during the Run's planning and execution. Thanks to you all.

Objectives and Plans

The objective of *Run on Less* was to raise broad industry awareness of and excitement for the opportunities created by efficient trucking, while celebrating the people, trucks and innovations that deliver our products every day.

Run on Less would

- Demonstrate low fuel consumption/high MPG (miles per gallon) through a 6-10 truck demonstration
- Highlight the technologies and practices that make it possible
- Promote key fleet decisions and technologies available from manufacturers along the way.
- Engage the industry and consumers on how trucking is becoming more efficient and sustainable.
- Accelerate the adoption of efficiency technologies and practices by creating a higher level of demand for them.

The details for the Run were:

- Target 10 fleets to participate in the Run, traversing the United States.
- The Run culminated at the inaugural North American Commercial Vehicle Show (NACV), with a major press event celebrating trucking ingenuity and significant carbon reduction.
- Major public relations buildup throughout the summer of 2017.
- Profile the participating drivers at a press event in August 2017.
- Demonstrate 9+ MPG, approaching double the average fuel economy of the current, entire U.S. over-the-road truck fleet of 5.9.
- It was very important for the Run to mimic real freight movement so that it would be a demonstration applicable, as best as possible, to the US trucking industry.
- Share information with significant media exposure inside the trucking industry and to the public, including live streaming of data from the event and videos of the truckers and industry personnel making it happen.
- Report metrics and video in real time along the route.
- Conclude the Run at the NACV show with all the drivers and tractor trailers at a major press event to announce the results and celebrate the technologies and practices that made it happen.
- Share other detailed findings in a *Run on Less* report to be published after the Run.
- Continue to support the industry's efforts for efficiency with continued work by NACFE, including updating Confidence Reports, conducting workshops, keeping the industry updated on emerging technologies, collaborating with fleets and manufacturers through engagements and other opportunities. Contact us and we look forward to working with you.

Figure 2: All eight Run on Less drivers at the Atlanta finale

Run on Less Fleets and Operation

During April and May 2017, NACFE asked fleets for self-nominations to participate in the Run and selected seven fleets to participate. The fleets then chose the tractor and trailer technologies, the specific driver, the routes and loads they would haul. This was important as NACFE wanted them to deploy equipment with features that the fleets believed provided acceptable payback on their investment as well as improved the fuel efficiency of their fleet. In a few cases, fleets considered certain technologies that they knew would improve their MPG but had already decided not to pursue the technology in their purchases. In these cases, it was tempting to include them in the *Run on Less* demonstration, due to adding to the MPG, but that was not in the spirit of the Run, and they chose not to employ them. An example, was a full trailer skirt, that extended from the landing gear to rear bumper. The fleet, had outfitted many of its trailers with this technology but had decided that currently they did not deliver an acceptable return on their investment., They chose to avoid using those trailers during the Run.

The requirements for the equipment used in the Run were as follows.

- 2015 Model Year tractors or newer. This would have all the tractors be Greenhouse Gas Phase 1 compliant.
- Knowing that some fleets would likely be dropping and hooking up different trailers, as they do normally, there were no specific requirements for the age of the trailers.
- The technologies employed must be commercially available, defined as being available from the tractor or trailer manufacturer or easily added to the equipment as a retrofit. Examples of easily added technologies would be the addition of aerodynamic features, auxiliary power units for HVAC, engine parameter settings, etc.
- In a few cases, NACFE mediated decisions by a fleet as to the commercial availability of a feature. Innovative fleets are constantly testing emerging technologies, which may not be commercially available. Decisions were made to include a new downsped axle ratio, but to not include some tractor trailer gap closures, for instance.

Figure 3: Nussbaum hauled multiple trailers during Run on Less due to drop and hook

Concerning the routes, the truckers would travel, NACFE had no specific requirements, but wanted fleets to travel much of North America and represent a good cross section of the North American goods movement. The fleets involved in the Run represented large, medium and small fleets and one owner-operator. Their duty cycles are described below.

- A daycab driving the same dedicated route each day. PepsiCo's Frito-Lay Division hauled snacks from a manufacturing plant to a distribution center using the same route every day.

- Two for-hire fleets (US Xpress and Nussbaum) with disparate routes that would travel anywhere in the U.S. and Canada.
- Another for-hire fleet spent the first half of the Run on disparate routes, but then added a trainee driver and completed the second half on a dedicated route with a team of two drivers driving twice the daily miles (Mesilla Valley Transport).
- A refrigerated van doing mostly Midwest regional routes (Hirschbach).
- An owner-operator (Albert Transport) with a mix of routes.
- A hauler who generally has multiple stops daily (Ploger).

Figure 4: Ploger Tractor Trailer

The expectations for the fleets and drivers included.

- Fleet selects driver to participate in *Run on Less*.
- Wear seat belt whenever the vehicle is in motion and drive with lights on.
- Comply with all speed limits, hours of service regulations and rules of the road.
- Tractor must be model year 2015 or newer with certified engine calibration.
- All equipment on the tractor trailer must be commercially available / orderable.
- All equipment must have operating emissions equipment and certified engine calibrations. May involve a dealer or OEM verification.
- Report fuel purchases per the *Run on Less* fueling process. This will include gallons purchased and location. May include the use of a *Run on Less* fuel card. Falsification of fueling information is grounds for immediate elimination from this promotion.
- Potentially display event logos on your vehicle throughout the effort.
- Work with us to achieve social media posting rules.
- Support event sponsors where appropriate.
- Provide a short daily report via cell phone, email, video, etc.
- Sign a non-disclosure agreement regarding data that will be collected from the vehicle.
- Meet with the NACFE team during July/August for a review/audit of the technologies on the participating tractor and trailer equipment.
- Allow videotaping during visit that will be displayed on runonless.com as driver profiles.

- Work with *Run on Less* organizers to complete a fleet profile for runonless.com with links to your fleet's website.
- Allow *Run on Less* electronic boxes to be installed in July/August and tested live prior to event start roughly the first of September.
- Allow interviews by *Run on Less* videographers/photographers as requested during the event if the requests do not interfere with their driving requirements or HOS rest period.
- Contact *Run on Less* anytime during the Run with any issue that might affect the mpg outcomes or appearance of the equipment.
- Join the ROL Finale at a luncheon press event on Sunday, September 24, 2017 in Atlanta at the inaugural North American Commercial Vehicle (NACV) Show.

Figure 5: Driver profile video with Brad Long of Hirschbach

"Other Items" (not required, but greatly appreciated)

- Taking photos of tractor-trailer along the Run at various points of interest
- Social media posts to social media promoting *Run on Less*
- Discuss *Run on Less* information with shippers, truck drivers or others during the event

In return participating fleets received

- High visibility for fleet and drivers on runonless.com and the associated media coverage
- No additional information, such as Engine Parameter settings was shared with others beyond the basics agreed to between NACFE and the RoL fleets.
- $1,250 in fuel via a fuel card donated by Pilot Flying J.
- VIP Pass for the entire week of the NACV show

A Demonstration, not a Competition

As described above the objective of *Run on Less* was to demonstrate the opportunities created by efficient trucking. NACFE knows, given the work completed to date that there is not a single tractor or trailer specification that all fleets should employ. The business of trucking is simply too diverse for a one-size-fits-all solution. Therefore, the group expected a diverse set of the technologies to be included by the various fleets participating in the Run. More will be discussed later, on the similar and dissimilar solutions used by the seven participants.

There are approximately 1.7 million Class 8 over-the-road tractors hauling the goods we want and need on our highways and there is a great deal of variation in the solutions employed. This group of seven represents some of the best of the best and the Run contained an early theme of "*Run on Less* with America's Best.". NACFE wanted, very specifically, to share the results of these innovators while not making the Run a competition among them. They are all winners in our industry's efforts in freight efficiency. The group also received strong industry feedback to stay focused on the team rather than the performance of each tractor and trailer or the combination of solutions employed. Therefore, the results were shared by each individual truck/driver, but the individual trucks/drivers were not identified.

Also, given the real freight, real routes strategy, it would be impossible to compare the individual performance of any single truck/driver. Payload and driving conditions varied and were not controlled in any manner. As will be described in detail later, conditions such as payload, vehicle speed, elevation travelled, wind speed and direction, etc. were documented along the way and used to reach various conclusions associated with the Run.

RunonLess.com

Runonless.com was created to follow the Run during the three-week long event. The website was used extensively during the Run and had a $3m advertising value, 10,000 video views and 168 million impressions on #runonless.

Figure 6: Sir Richard Branson helps announce mid-Run results on Sept 19th

The site includes such items as fleet and driver profiles, pages on the technologies employed, the results by truck by day and in aggregate, a national map showing the truck location and route with weather overlays for wind, temperature and precipitation and stories from the road. The pages were frozen as the data collection ended on September 23, 2017. Data collection was stopped just over 24 hours prior to press announcement to allow the team to quickly analyze and report the final results.

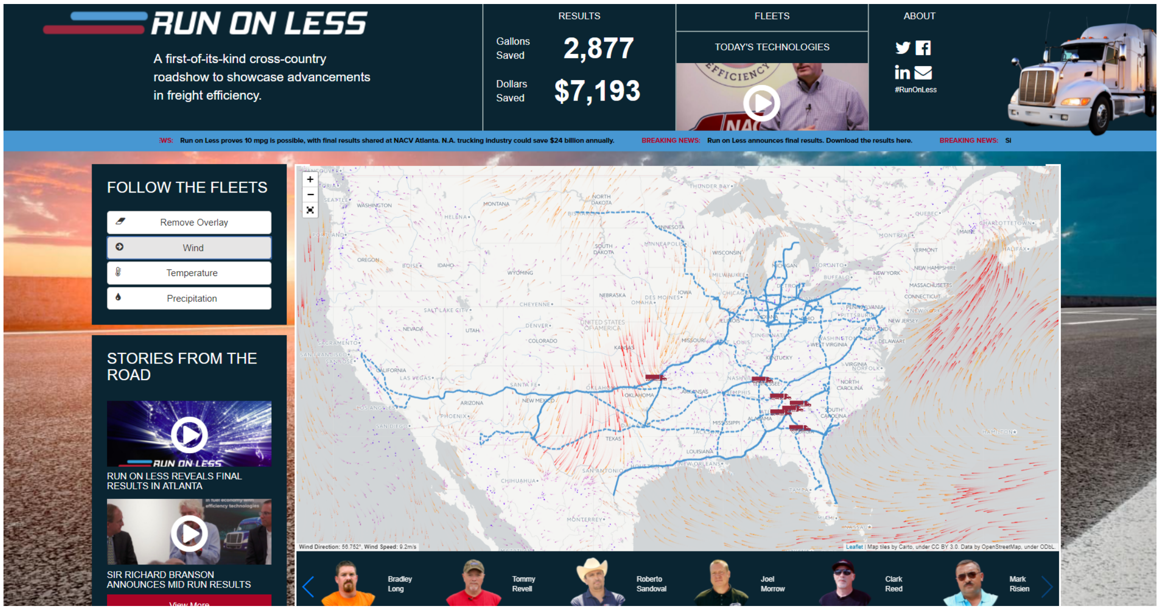


Figure 7: Screenshot of runonless.com

Of note to those trying to understand *Run on Less* and how this group achieved 10.1 MPG are the 41 videos that include profiles of each fleet, the driver and the equipment employed, stories from the road (media coverage, reports from drivers and insights from NACFE) and details on each of the technologies used. These videos could be a great tool for your company's training programs for new employees, field sales and service personnel, etc. Table 1 provides a listing of the videos contained on the website.

Fleet Profiles	Stories from the Road	Technologies
Albert Transport, Inc.	Run on Less Recap	6x2 Axles
Hirschbach	Run on Less Reveals Final Results in Atlanta	Automated Transmissions
Mesilla Valley Transportation	Fuel Economy on Older Equipment	Determining Efficiency
Nussbaum	Sir Richard Branson Announces Mid-Run Results	Downspeeding
PepsiCo's Frito Lay Division	Run on Less Explores Drop and Hook	Electronic Engine Parameters
Ploger Transportation	Run on Less vs. DOE SuperTrucks	Idle Reduction
US Xpress, Inc.	Run on Less Proves 10 MPG is Possible	Lightweighting
	Freight Efficiency and Fuel Economy	Low Rolling Resistance Tires
	Team Driving and Run on Less	Low-Viscosity Engine Lubricants
	Celebrating the Heroes of American Roads	Maintenance for Fuel Economy
	Wind Results in a Boost of 1.5 MPG	Platooning
	Congestion and Fuel Economy	Solar
	NBC Evening News Showcases Run on Less	Tire Pressure Systems
	Introduction to Run on Less	Tractor Aerodynamics
	Run on Less on NBC and ABC Morning News	Trailer Aerodynamics
	Ready, Set…Run!	Variable Engine Accessories
	Run on Less 2017 Promo	
	Trucking Efficiency Operation	

Table 1: List of videos found on Runonless.com

Specifications, Drivers and Payback

Tractor and Trailer Specifications

Each fleet selected the technologies that are currently available, and which are meeting their return on investment requirements. As expected, the tractors and trailers used in *Run on Less* did include some of the most advanced technologies available today to minimize fuel consumption. This includes engines and engine ratings for maximum fuel efficiency, downsped powertrains, considerable attention to aerodynamics, and in some cases idle reduction equipment including solar panels. While some fleets have resources available for rigorous evaluations of various equipment, many learn from others in the industry to make their spec'ing decisions. The fleets in *Run on Less* were no different than the general trucking population in this regard. A summary of the tractor specs is in Table 2 while a more detailed specifications of the trucks and trailers can be found in Appendix A and B.

Fleet	Tractor	Engine	Transmission	Rear Axle
MVT	**2018 International ProStar LT**	**Cummins X15 400/1550/1750**	**Eaton DD AMT**	**Meritor 6x2 2.28**
Hirschbach	**2016 International ProStar**	**Cummins ISX 15 450/1750**	**Eaton OD AMT**	**6x4 2.64**
US Xpress	**2018 Freightliner Cascadia**	**DD15 400/1750**	**DT12 DD**	**6x4 2.28**
Nussbaum	**2018 Freightliner Cascadia**	**DD15 400/1750**	**DT12 DD**	**Detroit 6x2 2.28**
Albert	**2018 Freightliner Cascadia**	**DD15 400/1750**	**DT12 DD**	**Detroit 6x4 2.16**
Ploger	**2016 Volvo VNM**	**D11 385/1450 EcoTorque**	**i-Shift DD**	**Volvo Adaptive Loading 2.53**
Frito-Lay	**2018 Volvo VNL**	**D13 XE Economy 425/1450/1750**	**i-Shift OD**	**Meritor 4x2 2.67**

Table 2: Summary of Tractor Specifications

The specifications employed across the seven participants for some technologies were quite similar and for others very diverse.

Features that were common across all the seven participants included:

- All-inclusive tractor aerodynamics including sloped hoods, bumper dams, aerodynamic mirrors, chassis fairings, full height roof fairings, cab extenders, vented mud flaps and drive wheel fairings with wheel covers.
- Low rolling resistance tires on most wheel ends.
- All had automated manual transmissions.
- Downsped powertrains at 2.67 at faster.
- Low viscosity engine lubrication.
- All used engine programing for idle shutdown and diesel-fired heaters for idle reduction during cold weather.
- All trailers used automatic tire pressure systems.
- All employed some sort of trailer aerodynamics under and back of the trailer.
- Telematics of various kinds were used on all the equipment.

There was though, diversity amongst the features deployed by these participants, some specific to the duty cycles of that route and fleet, but also due to the differing fleet business cases that favors one technology choice over another. Diverse solutions are described below.

- Axle configurations with fleets using 4x2, 6x4, 6x2 tag and 6x2 liftable.
- Wide variation on engine size from 11 to 13 and 15L engines.
- Battery HVAC was the most common choice on four trucks, one used a diesel APU and two without any idle reduction technology for hot weather.
- Tires were diverse with respect to wide-based and duals as well as differing tire choices for 6x2 drive and tag axles.
- The trailers used three different tail devices, side skirts predominately with one trailer using an undertray device.
- The Frito-Lay trailer was a high-cube drop-frame to maximizing loading and incorporated side skirts, a trailer tail and a nose cone.
- Most drivers utilized various driver behavior tools in the cab. In some cases, a driver used multiple devices.

Figure 8: Ready to roll

The Drivers

The drivers that participated in *Run on Less* are some of the best at maximizing MPG. It takes skill and experience to make use of the technology, and even among this group, it can be strenuous. In fact, drivers commented that maximizing fuel economy takes constant vigilance. One driver mentioned how tiring it was to be on his 'A' game for the entire Run while another commented that he was taking over for the cruise control as soon as he felt it was not doing what he wanted. Another driver lamented the fuel he wasted hurrying to a hoped for overnight stop where there turned out to be no parking. He ended up stopping earlier than planned, with 20 minutes left in his day, which in his mind was a missed opportunity to slow down and save some fuel (using some simple assumptions, this calculates to about 0.5 gallon). A driver also noted that he did not get his truck washed during the event because he did not want to waste fuel while waiting in line, another example of the lengths drivers went to maximize MPG during *Run on Less*. Several of the drivers have continued to stay in contact with each other and NACFE since the event. Of the drivers NACFE has heard from, some had minor regrets during the event such as picking up a less than ideal trailer or having used a truck with new tires, but all are ready to do it again. Maximizing fuel may require vigilance, but for these drivers it also creates camaraderie and a healthy level of competition.

Payback

Fleets select technologies, basically one at a time, given individual payback on their investment. This is generally a very challenging effort to understand all of the elements of the total cost of ownership of a particular technology. Such items as purchase cost, fuel efficiency performance and maintenance impact are at times difficult, but generally easier than other cost element affects such as driver attraction and retention, other technology performance interrelations, resale value, etc. Each Confidence Report prepared by NACFE addresses the total cost of each benefit or challenge of adoption, but individually fleet must evaluate the actual financial numbers of all of these for their own specific duty cycles and business models.

For an overall perspective, at $3.00 per gallon for diesel fuel, these fleets at 10.1 MPG and driving 110,000 miles per year, would spend about $33,000 on fuel per year. Using an average of 7.0 MPG (as an estimate for a truck without the technologies) a "typical" truck would spend $47,000 on fuel. This equates to a $14,000 savings per year. Given the high performance of these drivers and that it might be unrealistic to assume all drivers will perform at this level the savings might be reduced to $12,000. The NACFE team estimates the all-in up-front costs to get to this 10+ MPG level to be about $30,000. This then provides about a 2.5-year payback at the $3.00 per gallon fuel price.

Obviously, this is a very high-level estimate of payback for these combinations of technologies. Each fleet must complete their own analysis to predict their specific return on investments.

Data Collection and Calculations

Reliably collecting data and calculating results was critical to *Run on Less* and the team selected Geotab as its data collection partner. Where practical, two separate methods for collecting and calculating each metric was used. Additionally, to supplement the MPG data, some factors that can affect MPG including gross weight, vehicle speed, wind and elevation change were recorded.

Distance

Along with fuel, distance travelled by each vehicle was one of the most critical parameters that were tracked for *Run on Less*. The Geotab devices allowed for two methods for capturing distance. One is to use position data that can be converted into distance traveled with one of several commonly used algorithms such as the Haversine formula or even Pythagoras' Theorem since the distances between points is small. Geotab uses position data to record a vehicle's path and trip distance on a dashboard. The second method is odometer readings from the engine control module (ECM) transmitted by telematics. An advantage of using the odometer is that the values can be referenced and reconciled with the driver much more easily since an odometer reading places a truck at a particular location at a particular time (such as at the end of the day). Geotab transmits odometer data less frequently than GPS data, typically once per hour. However, after each driving day, total miles could be checked against the distance shown on the Geotab dashboard and it allowed data to be reconciled with fuel data more directly as discussed in the next section. At the conclusion of *Run on Less*, the difference between the GPS based calculation and the odometer data was 230 miles or less than 0.5% of the 50,107 total miles.

Fuel

As with distance, it was important to *Run on Less* that fuel was tracked accurately and could be verified using two independent methods. The primary method was readings from the ECM transmitted by telematics. The Geotab device reads total fuel used and keeps a running total that is transmitted in liters. It is known that ECM reported fuel consumption is not based on measured fuel flow but the engine maker's fuel algorithm, and studies have indicated that these can have a significant error rate. However, since the data is easily accessible, many fleets use ECM reported values in their internal measurement and some studies have indicated that while there is an error rate, it remains relatively fixed and can therefore be used as an adjustment factor. As verification, *Run on Less* also asked drivers to record fuel purchased with a visual odometer reading. Similarly, to ECM fuel readings, calculating MPG based on fuel purchased has potential for errors. In order for MPG calculations to be accurate, there is an assumption that the tanks are filled to the same level at each fuel stop, which may not always be the case. For fleets that use this measurement, over the course of several months this error would average itself out although it could affect calculations over shorter periods. Additionally, fuel dispensed at retail locations is not required to be temperature adjusted in the continental United States. The average temperature experienced by the drivers (while the vehicle was moving) was just over 70° F while the reference standard temperature for fuel measurement is 60° F. Therefore, assuming fuel was dispensed at the average temperature, this would lead to a reduction of 0.7% in the energy content of each gallon. For fleets purchasing thousands, if not millions of gallons of fuel every year, this may be a factor to consider in their operating practices (e.g. re-fueling early in the morning when the fuel is likely to be the coldest), but for *Run on Less*, this was not considered to be a significant factor.

Prior to the start of *Run on Less*, it was assumed the ECM fuel consumption values and thereby the MPGs would be adjusted based on the fuel purchased data. In the end, no adjustments were made. Six of the seven vehicles reported their fuel fill data. In total, 46 fill-ups were recorded. The least number of fuel stops by one vehicle was five, two recorded 10 with the rest recording between five and 10 fill-ups. The data did not show a clear bias in either direction. Figure shows by vehicle cumulative MPG following each fill-up versus the vehicle's respective cumulative MPG at the end of each day of the fill-up (i.e. if a vehicle required it's fourth fuel stop on day 10, the cumulative MPG through day 10 is shown). A solid line indicates the cumulative MPG as recorded from the ECM while the dashed line of the same color indicates the cumulative MPG of the same vehicle.

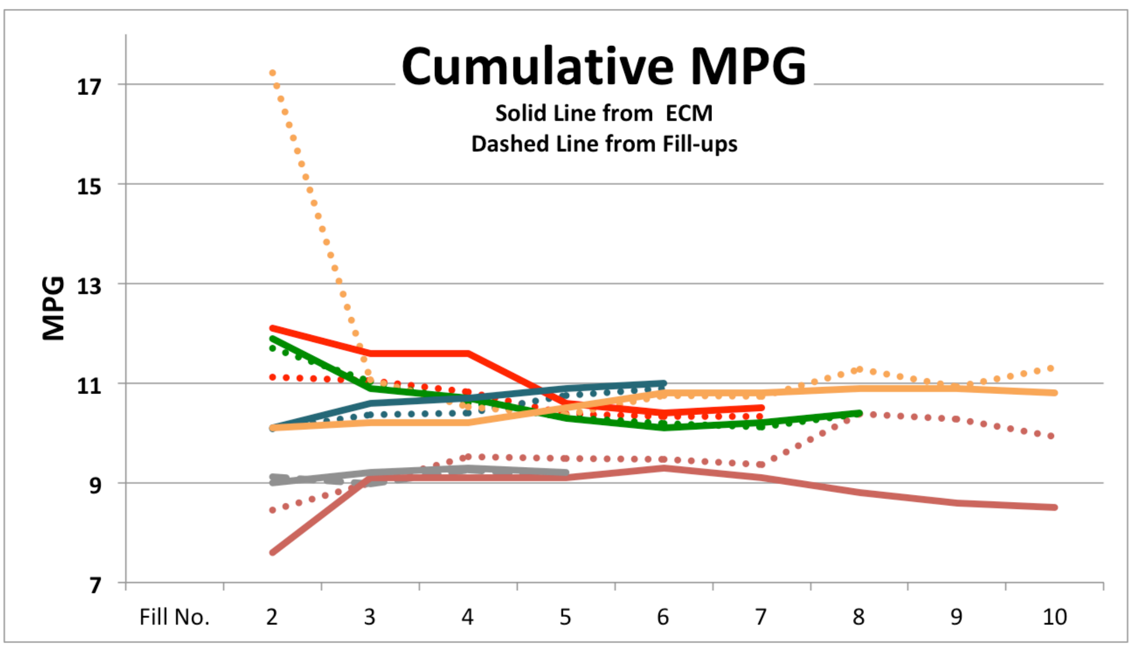


Figure 9: Comparison of each truck's ECM MPG and MPG based on fill-ups

At the end of the event, two of six vehicles had a divergence greater than 0.2 MPG between the two measurements, two others diverged by more than 0.1 but less than 0.2 MPG and the last two had a difference of less than 0.1 MPG. For the two vehicles for which the MPG measurements diverged by more than 0.2 MPG, one was re-fueled at irregular intervals and both showed a higher MPG when calculated using fueling data than the ECM. There also was no consistency among engine makes or model years in terms of the direction or magnitude of the difference, leading NACFE to conclude that there was not enough evidence to warrant an adjustment in the reported fuel consumption. The conclusion that ECM calculated MPG can be reliably used is supported by an SAE paper published on September 2016 by Waltzer, Johnson, Wei, and Wilson of the US EPA. The paper, "Fuel-Savings from Aerodynamic Efficiency Improvements for Combination Tractor-Trailers Relative to Vehicle Speed," focused on the efficiency gains of aerodynamic devices at various vehicle speeds. However, they also compared ECM measured MPG using fueling rates to that calculated using the gravimetric test method prescribed in SAE J1321 and concluded that the two methods "showed strong agreement". The test in the paper is limited to one engine make (2012 Freightliners with DD15 engines) during very specific conditions and presents fuel savings data as opposed to absolute MPG but it is a further indicator that ECM based MPG can be reliable.

MPG Adjustments

As stated previously, the MPG calculation was based on the odometer reading and ECM reported cumulative fuel consumption with the following adjustments.

Trip Length: To minimize large fluctuations in the reported MPG during the event, data for days when a vehicle accumulated less than 50 miles were not displayed in the results and excluded from the overall calculations. The duration adjustment reduced miles and fuel consumed by less than 1% and did not significantly affect the overall totals. See Table 3 for total miles and fuel with and without the trip length adjustment.

Data Error: One of the vehicles may have experienced a loss of power to the telematics device, disrupting the accumulated fuel used calculation. The error overstated the MPG of the vehicle (the telematics device was not recording fuel used for a portion of a trip). It was not possible to reconstruct the missing data and since the disruption occurred on a trip that spanned two days, both of those days' data was discarded and removed from the total. The data error adjustment is also detailed in Table 3.

Day	Miles	Gal. Fuel Consumed	MPG
1	3,586	360.6	9.9
2	3,638	372.6	9.8
3	3,473	339.7	10.2
4	3,242	304.0	10.7
5	2,140	211.1	10.1
6	653	62.2	10.5
7	3,139	307.2	10.2
8	4,133	407.5	10.1
9	3,590	353.3	10.2
10	3,900	385.9	10.1
11	3,199	328.6	9.7
12	2,605	266.1	9.8
13	3,384	322.3	10.5
14	2,626	275.8	9.5
15	2,013	206.4	9.8
16	3,690	336.5	11.0
17	1,098	112.1	9.8
Total Shown	50,109	4,951.9	10.1
Trip Length Adj.	144	30.3	
Total w/o Adj.	50,253	4,982.2	10.1
Data Error Adj.	830	48.6	

Table 3: Miles, Fuel Consumed and MPG by Day

Gross Weight

The weight of the vehicle is known to be one of the factors that affect MPG. Efficient freight movement is best defined as moving the greatest amount of goods possible for each unit of energy. Therefore, *Run on Less* tracked gross weight, the weight of the unladen tractor and trailer and the payload being hauled. The expectation for *Run on Less* was that the vehicles would be used in the normal on-going operation for each fleet. No minimum weight requirement was given to the fleets participating in *Run on Less*, but fleets were informed that gross weight would be recorded and shown. This encouraged the fleets to run routes that were very typical of their businesses. Each driver was asked to transmit payload data as given by the bill of lading. In some instances, drivers provided additional information by transmitting copies of scale tickets. As a backup, *Run on Less* also monitored gross weight using an algorithm that used engine load and other data from the Geotab device to estimate total gross weight of the vehicle.

Elevation Gain

The change in elevation each vehicle experienced during *Run on Less* was monitored using position data. A position was recorded approximately every 1.5 miles, resulting in slightly over 33,000 points. The elevation of each point was then retrieved using the Google Maps Elevation API (https://developers.google.com/maps/documentation/elevation/start). If a subsequent elevation was higher than the prior one, this was recorded as an elevation gain.

Wind

Several drivers informed NACFE that wind can be a significant determinant in MPG although there was no agreement on the magnitude of the effect or whether a head wind or cross wind is worse. The impact of wind angle is difficult to predict since the size and shape of an irregular object such as a truck changes when it is viewed from different angles. To account for this in wind tunnel testing, wind angle and speed are taken into consideration by rotating the vehicle through various angles relative to wind direction and calculating a wind averaged drag coefficient (Ortega, Salari, Brown, Schoon, 2013). For *Run on Less*, to track wind speed and direction, data was collected from [OpenWeatherMap (https://openweathermap.org/current)](https://openweathermap.org/current). Since wind speed and direction relative to the vehicle's bearing are both relevant and in order to be able to average the effect of wind over the 17-day event, wind speed and direction were reduced to one number representing the component of wind in the direction of travel. The calculation is illustrated in Figure .

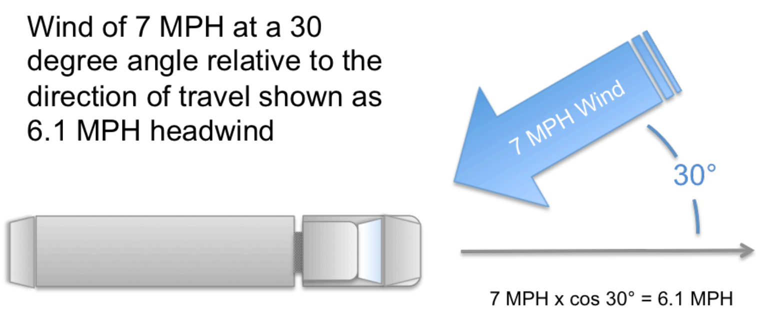


Figure 10: Wind Calculation

OpenWeatherMap updates wind data approximately every two hours (at the no cost API level, https://openweathermap.org/price) for any given location. However, since the vehicles were moving and changing not only their location but also their direction of travel, the wind speed calculation was updated every 10 minutes. The wind data points were then averaged to show the daily and cumulative effect from wind.

The primary purpose for tracking and showing some of the factors beyond miles and fuel during *Run on Less* was to demonstrate that the vehicles were in fact in the real world, making real deliveries. *Run on Less* was a demonstration of what is possible with traffic, elevation changes, actual payloads, and even the impact from severe weather events such as hurricanes. It was not known how each of these factors would affect the outcome of *Run on Less*. An attempt to quantify the contribution of each follows in Effect of Conditions on MPG.

Results

In total, the seven trucks averaged 10.1 MPG over the 17 days of *Run on Less*. The trucks covered a total of 50,107 miles at an average gross weight of 55,498 lbs. The results are summarized in Table 4.

MPG	Total Miles	Ave. Gross Weight	Ave Ton-Miles per gal.	Total Elevation Gain	Ave. Vehicle Speed	Average Wind Speed
10.1	50,107	55,498 lbs.	104	543,903 ft.	54 MPH	0.5 MPH Tailwind

Table 4: Summary of Results

As expected, the distribution of daily average MPGs (Figure 11) is centered between 10.0 and 10.5 MPG. Five truck-days (one truck on one day equals a truck-day) were below 8.0 but above 7.0 MPG and four truck-days were between 12.5 and 13.0 MPG. There were 99 truck-days during the 17 days of the Run.

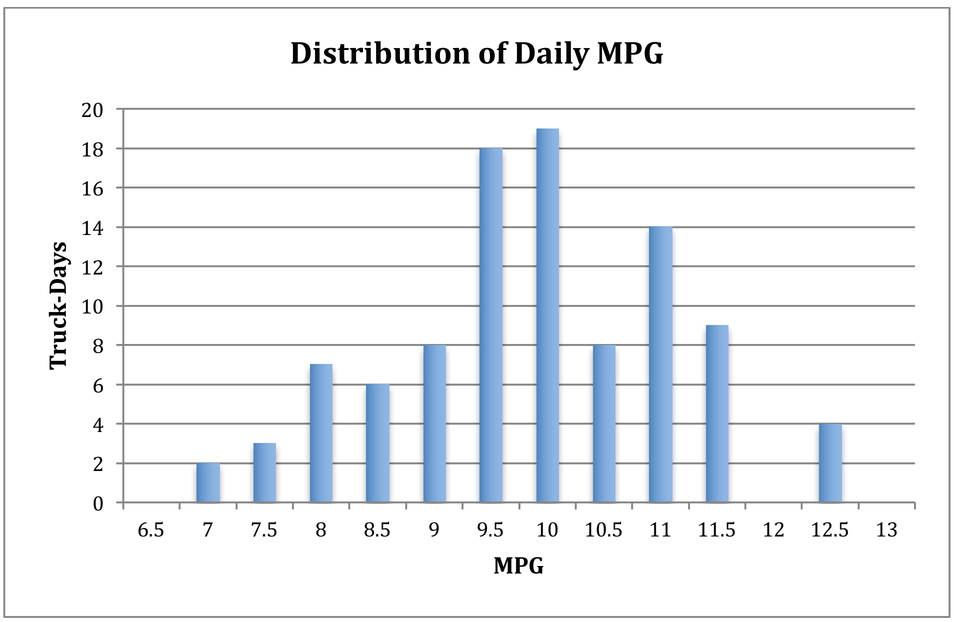


Figure 11: Daily MPG Distribution

NACFE used MPG primarily to report the efficiency of the trucks during the Run, but as shared throughout, the payload hauled matters to the MPG and needs to be considered when evaluating technologies. Figure 12, shows the distribution of the Truck-Days in Ton-Miles per gallon.

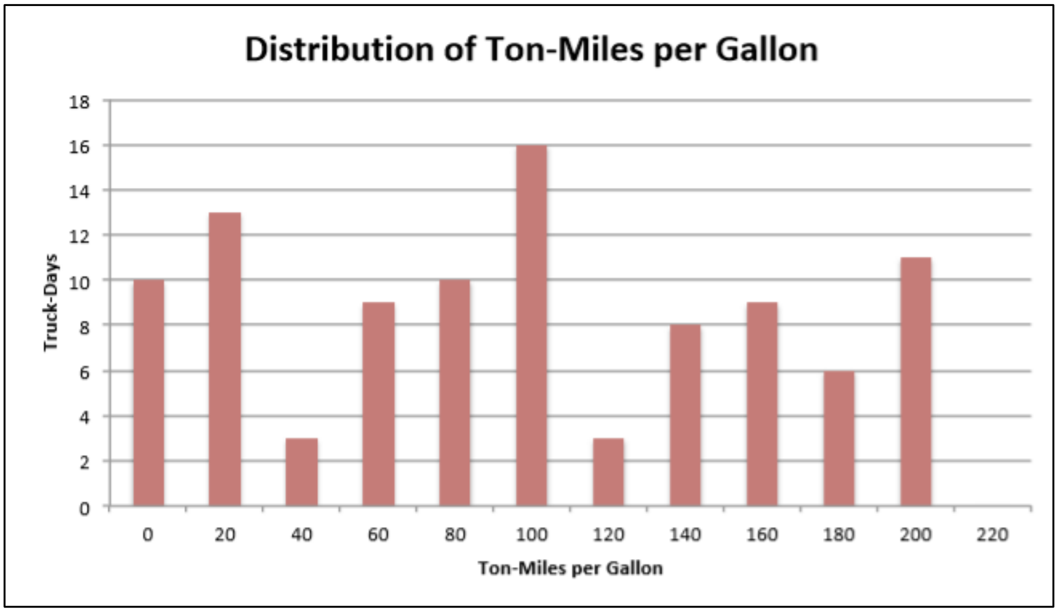


Figure 12: Daily Distribution in Ton-Miles per Gallon

Average of Lowest and Highest MPG Days

Each truck recorded their lowest and highest MPGs on different days. If they are averaged as if the lowest MPGs for each truck all occurred on the same day, the average is 8.8 MPG. The highest MPG days averaged to 11.6 MPG versus an overall *Run on Less* average of 10.1.

	MPG	Gross Weight	Elevation Gain	Wind	Ave. Speed
Lowest	8.8	63,227	1,303	0.5 MPH Headwind	52 MPH
Highest	11.6	48,006	1,299	2.7 MPH Tailwind	54 MPH

Table 5: Average of each truck's Highest and Lowest MPG Days

Duty Cycles and Routes

Within the seven *Run on Less* trucks, a variety of duty cycles and routes were represented. Two of the vehicles ran dedicated routes (one of which was a team), one pulled a refrigerated trailer and four others were general dry-van truckload. In total, except for the team truck, the vehicles covered an average of 6,362 miles during the 17-day event (the team truck completed 11,936 average daily miles, it was not operating as a team for the first two days). Many of the routes were concentrated in the Midwest and Southeast though several trucks did venture outside of those regions: four were west of the Mississippi at least once, one made a trip to California, one to Arizona and one up to North Dakota. None of the vehicles left the U.S. though two were within a mile of the border with Mexico and one passed within a mile of Canada on its way through Detroit.

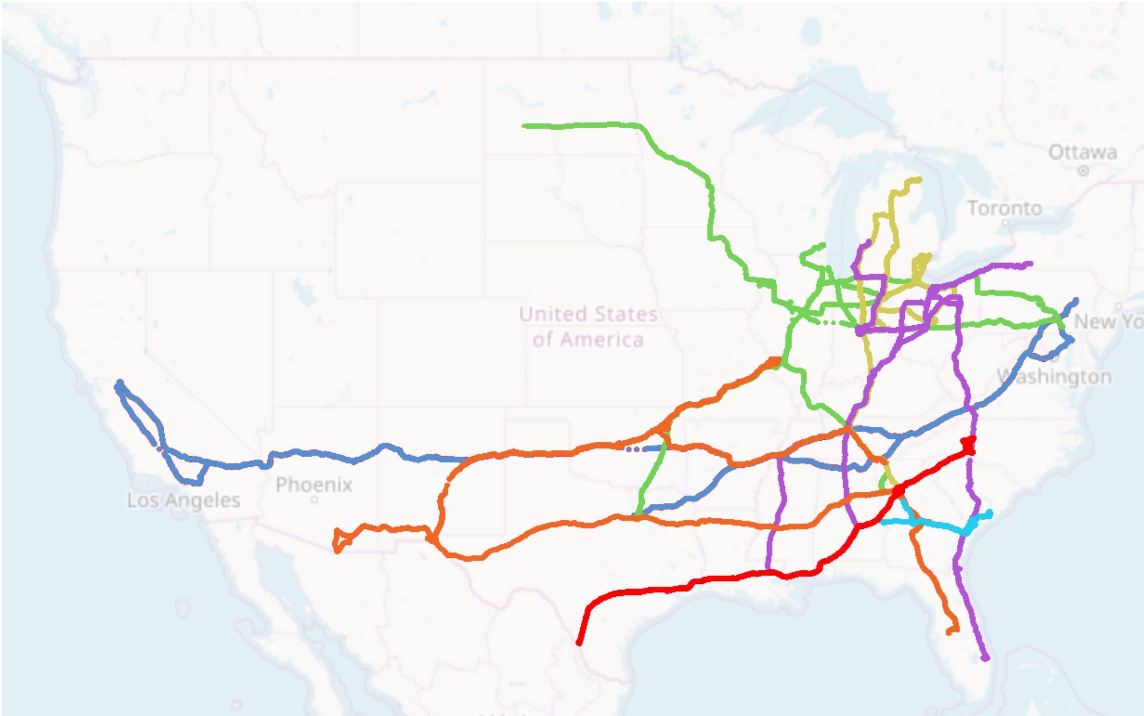
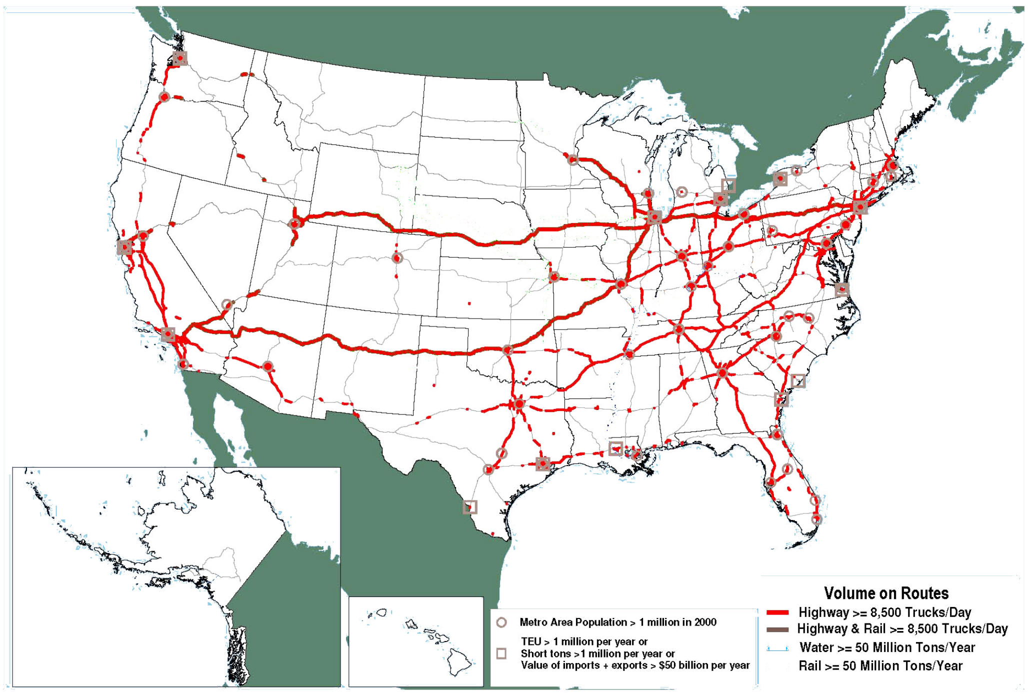


Figure 13: Routes of the Run on Less trucks (Routes displayed using the MyGeodata Cloud online tool (https://mygeodata.cloud/map/) which uses maps from OpenStreetMap)

A very close comparison between the *Run on Less* routes and the major freight corridors was not performed. But a simple visual comparison to the US Department of Transportation freight corridor map (Figure 14) shows that many of the routes are representative of where the majority of truck traffic travels in the continental US. Some of the larger routes that were not represented in *Run on Less* are I-80 between Chicago and Salt Lake City, some short but busy routes Northeast of New York and a segment in the Pacific Northwest.

Components of Major Freight Corridors



Note: Highway & Rail is additional highway mileage with daily truck payload equivalents based on annual average daily truck traffic plus average daily intermodal service on parallel railroads. Average daily intermodal service is the annual tonnage moved by container-on-flatcar and trailer-on-flatcar service divided by 365 days per year and 16 tons per average truck payload.
Source: U.S. Department of Transportation, Federal Highway Administration, Office of Freight Management and Operations, 2008.

Figure 14: US DOT FHWA Major Freight Corridors map with rail and water routes removed (https://ops.fhwa.dot.gov/freight/freight_analysis/freight_story/major.htm)

Elevation Change

In total, the seven trucks saw a total of 543,903 feet in elevation gain, though the elevation covered was not even among the vehicles. Only two of the vehicles saw elevations greater than 3,500 feet while three did not go above 1,500 feet. The highest elevation recorded during *Run on Less* was 7,343 feet, which occurred twice on I40 just outside of Flagstaff, Arizona. The impact of elevation change is covered in more depth in the section on the Effect of Conditions on MPG.

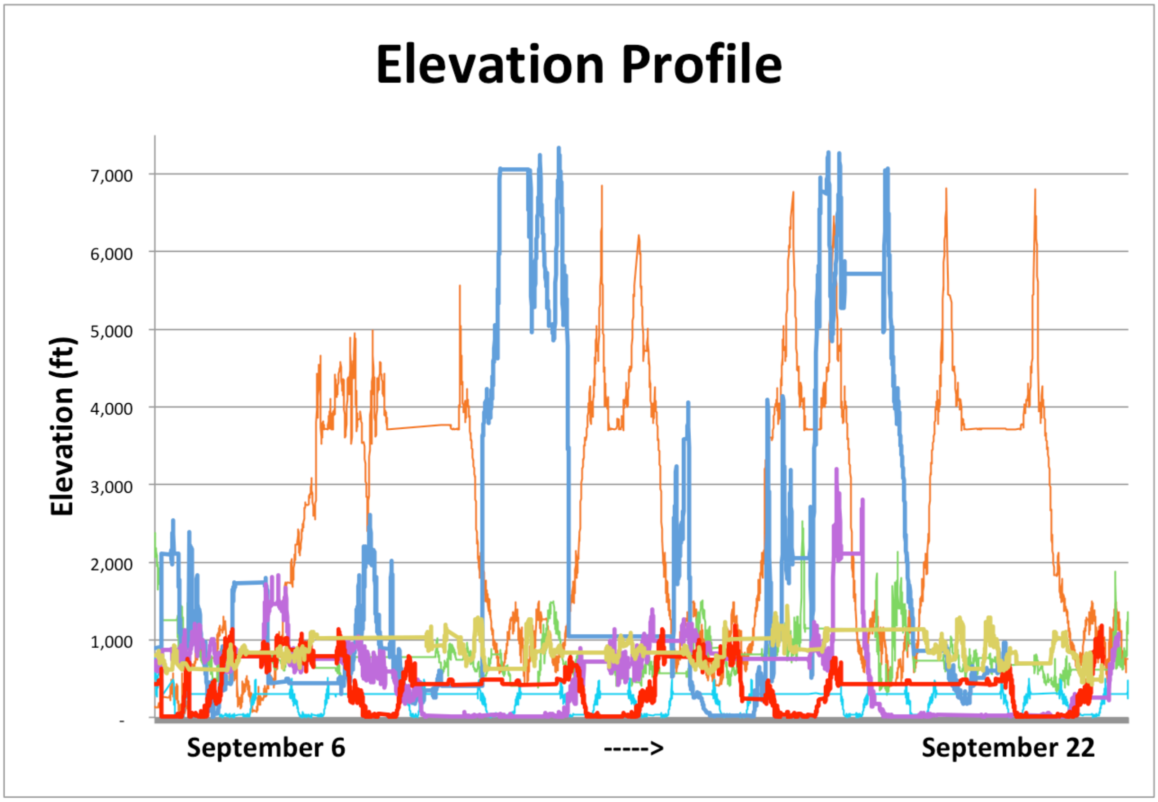


Figure 15: Elevation profile by truck (the colors for each vehicle correspond to the colors in figure 13)

Wind

All vehicles dealt with various weather conditions throughout the event including the effects from hurricanes Harvey and Irma. In some cases, there was a strong tail wind while in other instances drivers faced a significant head wind. The greatest tailwind recorded during *Run on Less* occurred on day four shortly after 3PM local time about 30 miles north of Savannah, Georgia when a truck traveling southwest benefitted from a 12.3 MPH wind blowing from the northeast. At the other end of the spectrum, the largest headwind occurred on the other side of the continent three days later. One of the trucks traveling west on I40 at 1:15AM local time faced into a wind blowing from the west at 13.9 MPH resulting in a calculated headwind of 12.1 MPH. Unfortunately for that driver, he did not benefit from a significant tailwind on the return trip through that same area one day later. The wind was still blowing from a similar direction but had died down to less than 2 MPH.

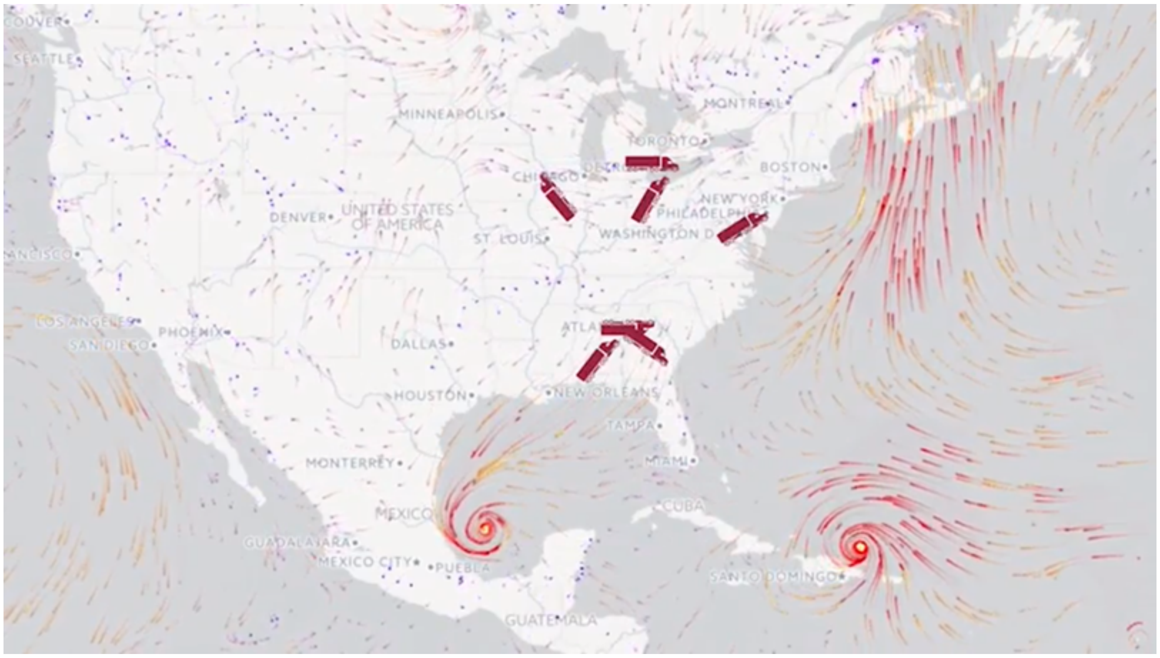


Figure 16: Run on Less Screenshot of Hurricanes - Sept 2017

The effect of wind on MPG can be difficult to measure in the real world (i.e. not in a controlled setting such as on a test track). As can be seen in Table 6, when comparing each vehicle's day when the average wind was most favorable to the day when it was most unfavorable, MPGs were better in four of the seven cases. However, the reason MPGs were not consistently higher most likely lie in the other factors known to affect MPG. Gross weight and elevation gain varied on each of the days in the comparison, making it difficult to discern the impact of wind on any given day. A further attempt to isolate the effect of each condition is discussed further in Effect of Conditions on MPG.

Favorable Wind				Unfavorable Wind			
Tail Wind	Gross Weight	Elevation Gain	MPG	Headwind	Gross Weight	Elevation Gain	MPG
7.5	44,551	628	11.8	-2.7	72,960	3,270	9.7
5.6	28,569	564	10.6	-1.5	37,097	914	9.2
6.7	45,999	2,691	10.4	-6.3	65,001	882	9.8
7.6	51,551	2,118	11.9	-6.8	54,505	73	10.0
6.5	37,735	1,642	11.9	-2.3	41,541	66	11.9
1.2	57,251	915	8.1	-3.4	34,000	221	8.9
4.3	77,301	3,827	10.1	-4.7	43,710	4,204	11.1

Table 6: Comparison of each truck's most favorable to unfavorable day with respect to wind

Average Speed

Keeping speeds low is one of the methods drivers can use to reduce their fuel consumption. Several of the drivers kept their highway speeds below 60 MPH for much of the Run although others spent most of their time in the 62 to 64 MPH range. While all drivers recorded some time above 65, very little time was spent at 68 MPH or higher.

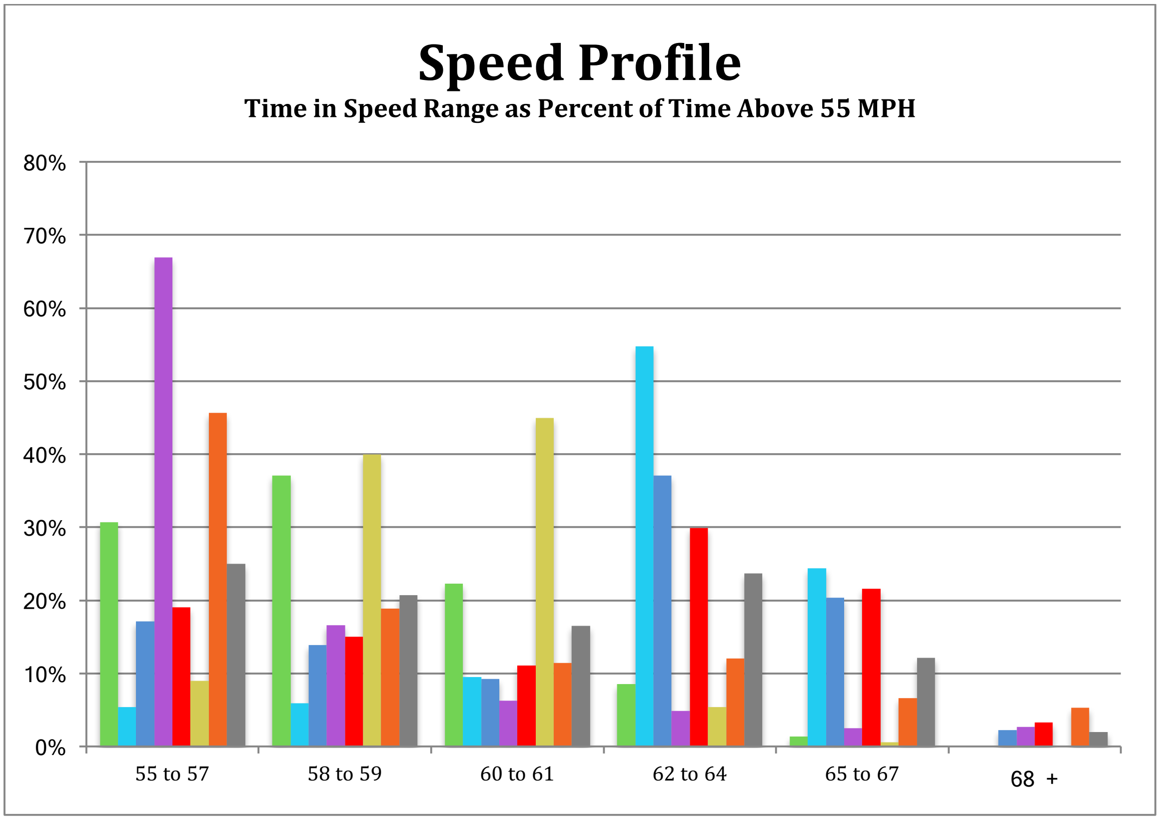


Figure 17: Speed profile by vehicle. The colors correspond to ones used in the route map and elevation profile.

The overall average speed during *Run on Less* for all trucks was 54 MPH calculated from data when the vehicle was moving at 5 MPH or greater. As discussed earlier, no minimum or maximum speed criteria were given to the participating fleets (other than to observe posted speed limits). While drivers could use their discretion on top speed, the reality of every day operations, which include traffic, a need to find parking or make a delivery, often dictated the average speed as it would for any fleet. Fleets calculate average speed using varying criteria and comparable national data on average speeds of on-highway Class 8 trucks is difficult to find. However, an informal survey of some of NACFE's Annual Fleet Fuel Study (AFFS) participants indicates that their average speed is between 53 and 54 MPH, with governed top speed settings set in the range of 62 to 65 MPH, indicating that the *Run on Less* drivers were in line with how the AFFS fleets operate.

Idle

As expected, idle during *Run on Less* was kept low. The competitive nature of the drivers (the 'biggest non-competitive competition' as one driver put it), the fact that the event occurred for two and a half weeks during September when temperatures in large parts of the country are moderate, and the array of idle reduction technologies all helped in this regard. *Run on Less* idle, (defined as time when the vehicle is not moving with the engine on for more than five minutes) is shown in Figure .

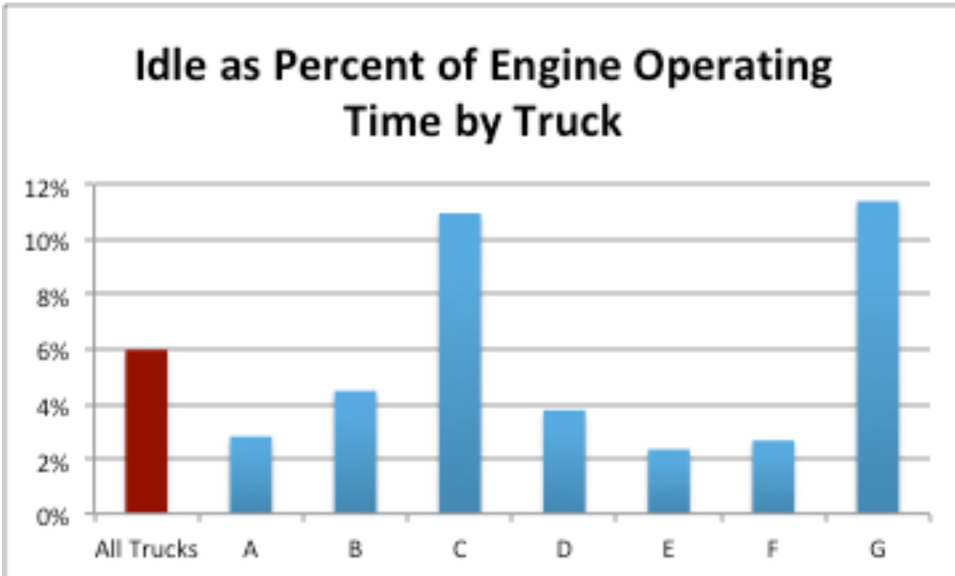


Figure 18: Idle percentage by truck

The same informal survey referenced previously of some the AFFS fleets reveals that idle percentages vary even among fairly fuel-conscious fleets, from a low of 5% to 40%. On average, the fleets that responded had an idle percentage of 18%, higher than the *Run on Less* drivers, but very reasonable as a long-term average.

Average Performance of the North American Fleet

As the *Run on Less* team developed the reporting protocol for the program, they considered various options to allow it to compare the participants in the Run to the current performance of the national fleet. One option considered, was to include various trucks in the Run that would have the range of MPGs operating on the road today. This would have required including for instance, a 10-year-old truck with very little to no technologies to a 2018 model with nearly all technologies and probably some number of others in between. This could determine a baseline for the national average. This option would have required significant resources and funds to execute and was deemed not an option.

A few other scenarios were considered with the selected approach to calculate the best estimate of the average fuel efficiency of the Class 8 over-the-road truck fleet nationally.

For 2016 the Federal Highway Administration (FHWA) reported that the total miles driven, and gallons consumed by U.S. combination trucks (tractor trailers) were 174,557,000,000 miles and 29,554,641,000 gallons. This calculates an average U.S. fuel efficiency of Class 8 tractor trailers as 5.91 MPG. FHWA publishes this data obtained via the International Fuel Tax Agreement (IFTA) and combination trucks include all tractor trailers which consume fuel and travel our roads. This approximately 5.9 MPG is the generally referenced number used by most organizations in defining the current efficiency of the U.S. tractor trailer fleet.

NACFE therefore has used this statistic in their Annual Fleet Fuel Study (AFFS) for comparing the AFFS fleets' performance to the national average, as its source is actual mileage travelled and fuel consumed by the U.S. fleet. Figure 19 shows the 14-year comparison of the fleet wide average of the 19 fleets that participated in the 2017 AFFS to the all-in national MPG data from the FHWA. The FHWA data includes tractors in over-the-road goods movement, pulling 53 and 28-foot dry van and refrigerated trailers as well as other types of trailers, typically referred to as vocational. This includes flatbed, tanker, dump, waste transfer, etc. which have a mix of over the road and off-road routes. These trucks are included in the miles and gallons of the FHWA data but are clearly outside of the scope of the *Run on Less* duty cycle.

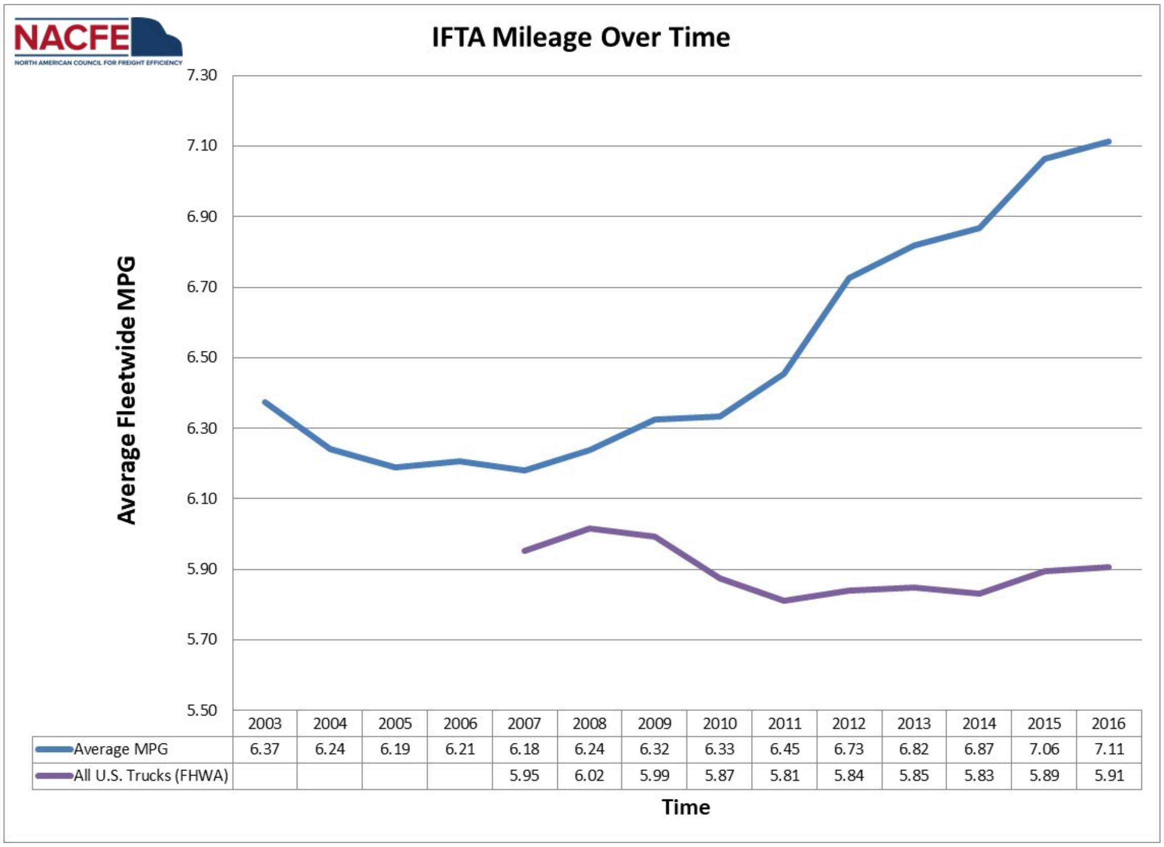


Figure 19: IFTA MPG 2003 to 2016

For another source of data, Geotab, NACFE's partner for the *Run on Less* MPG verification, provided NACFE with U.S. and Canada fuel efficiency by state for the trucks operated by their customers. This data, included all Class 8 tractors and showed an average of 5.96 MPG for the period of July 2016 to July 2017, very similar to the IFTA data.

With the *Run on Less* fleet operating only in the over-the-road duty cycle, the team calculated the national average given in-use tractor population in consultation with ACT Research and through an understanding that the vocational tractors tend to run lower MPG. This resulted in a 6.4 MPG national average, which the group believed was more representative of the U.S. over-the-road tractor trailer population. 6.4 MPG was used as the baseline for *Run on Less*. All calculations for fuel saved in gallons and dollars and emissions prevented are against this baseline.

Finally, the *Run on Less* team was asked several times how this level of performance, 10.1 MPG, compared to two other data points. First, the average of the most recent model year trucks provided by all the truck and trailer manufacturers and second, the performance level of the Department of Energy (DOE) SuperTrucks.

To understand the level of efficiency for new tractors, NACFE has analyzed our work with fleets and through other organizations analysis and available information. As a baseline, NACFE's AFFS in 2017 showed the average of the 19 fleets' current fleet to be 7.1 MPG. Many of those same fleets reported that their most recent model year trucks were attaining about 7.5 to 9.2 MPG. Given discussions with many, it is believed that the 2017 model year trucks and average payloads and routes deliver equipment that is performing at about 8 MPG.

A few other data points are of note with respect to high levels of efficiency. The US DOE SuperTruck1 program, which resulted in real world data collection by all four participating teams ended in 2016. These vehicles demonstrated levels of performance in the range of 11.3 to 12.8 MPG. During the summer of 2017, Cumberland International demonstrated consistent operation at 10 MPG in their program called #RaceTo10MPG. A concept tractor trailer, known as Starship, is being built by Airflow Truck Company, LLC in partnership with Shell. A coast-to-coast fuel efficiency demonstration is planned for mid-2018. And finally, tractor OEMs are consistently demonstrating their highest specifications of features to achieve high MPG. Figure20 places the *Run on Less* performance of 10.1 MPG with these other data points.

Keep in mind that this report primarily uses MPG but that more important measures of ton-miles per gallon or cubic-feet of cargo per gallon are more important measures of freight efficiency.

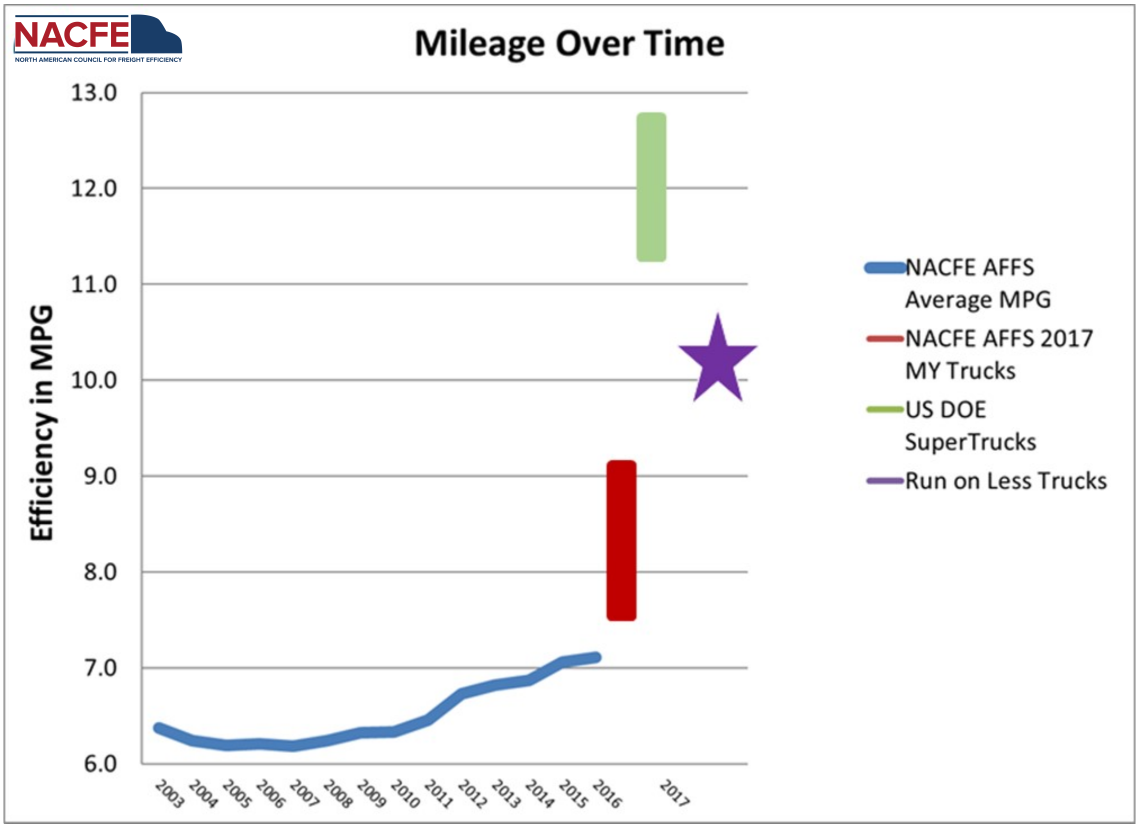


Figure 20: Comparison of NACFE AFFS MPG, DOE SuperTrucks, and Run on Less trucks

Effect of Conditions on MPG

Methodology

Data on the conditions and speed were collected and shown during *Run on Less* in part to demonstrate that the *Run on Less* trucks were not operated in carefully controlled settings but in the real world where wind, elevation changes and other factors can and do impact MPG. On a test track, when examining the effectiveness of new technology, wind, temperature, speed, and other factors are closely monitored and accounted for. Once the technologies are put to use by the fleets, they encounter a variety of conditions. *Run on Less* became an opportunity to understand how much each of these conditions impact MPG.

To determine the effect of weight, weather, speed, and elevation change on MPG, a multiple regression model was developed from the data collected during *Run on Less*. Regression analysis is a tool often used to understand the relationship between a dependent variable to one or more independent variables (also referred to as predictors). In this case, the conditions believed to affect MPG such as weight, elevation change, or wind speed are the predictors while MPG is the dependent variable, or the variable against which we want to test the effect of the independent variables.

Data Preparation

The first step in building the regression model was to build a dataset on which to run the regression. *Run on Less* results were shown in daily increments but as discussed in previous sections, data was collected more frequently. In total, there are four different datasets that were combined, containing from 132 to 35,276 rows of data (Table 7).

Table	Data	Rows
Odometer	Timestamp, truck ID, odometer,	2,637
Elevation	Timestamp, truck ID, latitude, longitude, GPS speed, elevation	35,276
Weather	Timestamp, truck ID, latitude, longitude, GPS speed, bearing, wind speed, wind direction, temperature	6,158
Weight	Truck ID, odometer begin, odometer end, gross weight	132

Table 7: Run on Less Datasets

Since MPG is the critical parameter against which the conditions are tested, the odometer and corresponding fuel data were used as the base against which all other condition data was matched. Each odometer record represents a particular instance in time for a vehicle. In Geotab, odometer data is reported separately from fuel. However, fuel data is reported at a much higher frequency than odometer readings, which allowed odometer and fuel consumption data to be matched up based on the timestamp. In instances where there was no fuel consumption data point at the exact timestamp of the odometer reading, straight-line interpolation with respect to time of the fuel data was used as illustrated in Figure 21.

Timestamp	Odometer	Fuel	Interpolated Fuel
9/15/17 07:58:00.000		100.00	
9/15/17 08:00:00.000	30,100		100.16
9/15/17 08:00:30.000		100.20	
9/15/17 09:00:00.000	30,150	104.92	

Figure 21: Illustration of interpolation used to populate fuel data in the odometer table

If the time gap between fuel records exceeded 15 minutes, no interpolation was performed and the odometer record was disregarded. Once the fuel and odometer data were matched, using consecutive data points, it was possible to create a distance-fuel record that represented an interval of time for which the distance and fuel consumption is known (Figure).

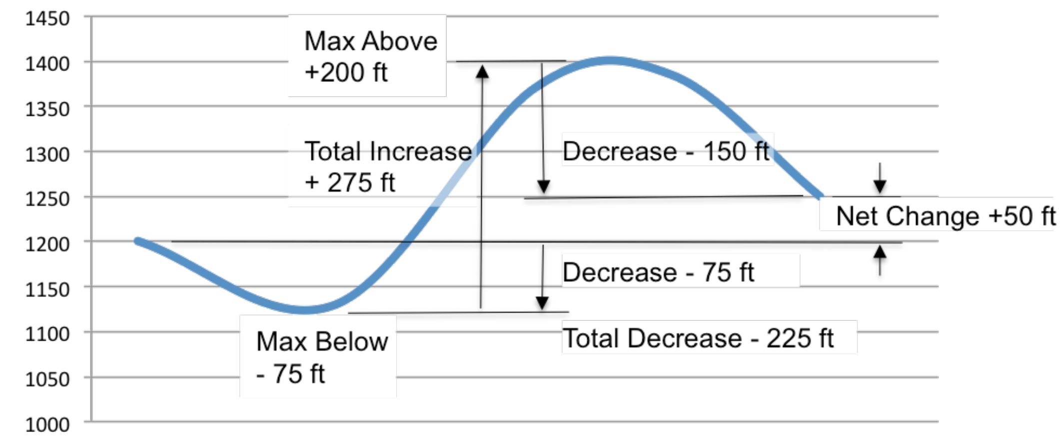
Timestamp Beg	Timestamp End	Odometer Beg	Odometer End	Fuel Beg	Fuel End
9/15/17 08:00:00.000	9/15/17 09:00:00.000	30,100	30,150	100.16	104.92

Figure 22: Illustration of resulting distance - fuel record

Elevation Data

Elevation data was collected much more frequently than other data, approximately every two minutes when the vehicle was moving, resulting in about 30 elevation data points per distance-fuel record. Since odometer readings were not recorded with the elevation data, it was matched to the distance-fuel records using the timestamps. Once the elevation data was matched, several elevation metrics were defined and calculated for each distance-fuel record as follows: (Figure)

Total increase – the sum of all increases in elevation
Total decrease – the sum of all decreases in elevation
Max above – the highest elevation reached relative to the starting point
Max below – the lowest elevation reached relative to the starting point
Net change – the elevation difference between the start point and end point



	Elevation	Elevation Increase	Elevation Decrease	Net Elevation Change
9/15/17 02:13:02.000	1200	0	0	0
9/15/17 02:15:23.000	1125	0	-75	-75
9/15/17 02:17:45.000	1370	245	-75	170
9/15/17 02:19:23.000	1400	275	-75	200
9/15/17 02:21:09.000	1250	275	-225	50

Figure 23: Definition and calculation of elevation metrics

Weather Data

Wind speed, wind direction and temperature were collected approximately every 10 minutes while a vehicle was moving resulting in approximately six weather data points per distance-fuel record. The impact of wind can be difficult to measure outside of a controlled environment. Ideally, wind speed is measured on a truck itself but since the truck is changing the wind around it, measuring it on a moving truck is not practical. On a test track, anemometers can be placed near the track at mid-height of the vehicle to get the best reading of wind speed. As discussed previously, the weather data for *Run on Less* came from OpenWeatherMap, which uses public and private weather station data in their models to provide conditions at any location at no cost (at the plan NACFE used). While having the weather data is significantly better than not having it, in comparison to controlled testing, there are limitations that may affect the accuracy of the model used to measure the impact of wind. Wind speed measurements from official weather stations are taken at a height of 10 meters (33 feet) above the ground (Automated Surface Observing System User's Guide, 1998). This combined with the fact that in hilly terrain, the weather station itself may be located above road height and perhaps several miles from the road means that measurements are taken well above mid-height and at some distance to the truck. Additionally, wind gusts are difficult to quantify. A wind speed reading from an official weather station is a two-minute average to account for gusts and lulls. Sustained winds and winds with many gusts and lulls can have the same average value over two minutes but may impact a moving vehicle differently. Finally, at the no-cost level, OpenWeatherMap updates condition data every two hours for a location. While temperatures typically fluctuate relatively slowly, winds can pick up and die down inside a two-hour period.

The calculation of wind in the direction of travel was previously illustrated in Figure and is repeated below.

$$V_{Wind@Truck} = V_{Wind} \times \cos\phi$$

where:

$V_{Wind@Truck}$ is wind speed in direction of truck travel
V_{Wind} is wind speed
ϕ is the difference in wind direction and truck bearing

As mentioned previously, in wind tunnel testing, a wind averaged drag coefficient is calculated to account for the effect of wind occurring at different directions. The standard method for calculating the effect of wind at an angle relative to the direction of travel is to treat wind and the direction of travel as vectors and to use vector addition to calculate a relative velocity. Using vectors considers the relative speed of the truck to wind speed, a component that is missing in the formula above, which was used to display wind speed on the *Run on Less* website. The formula for relative velocity (Ortega et al. 2013) referred to as relative wind speed in the rest of this report, is given below.

$$V_{Relative} = V_{Truck} \times \sqrt{(1+2(V_{Wind}/V_{Truck})\cos\phi + (V_{Wind}/V_{Truck})^2)}$$

where:

$V_{Relative}$ is the wind speed felt by the truck
V_{Truck} is truck speed
V_{Wind} is wind speed
ϕ is the difference in wind direction and truck bearing

Both methods allow wind speed and direction to be reduced to one number, making it possible to combine multiple readings and assign them to a distance-fuel record. As with elevation data, weather data is not associated with an odometer reading and was matched to each distance-fuel record using the timestamp. If a weather data point did not exist at the timestamp when a distance-fuel record began or ended, interpolation with respect to estimated distance was used to estimate a wind speed and temperature value at the beginning and ending of each distance-fuel record. Multiple weather points within each distance-fuel record were then averaged with respect to estimated distance. The results of the interpolation and weighted average calculations for wind as well as temperature are illustrated in Figure.

	Data					Calculated			
Timestamp	**Truck Speed**	**Truck Bearing**	**Wind Speed**	**Wind Direction**	**Temperature**	**Wind in truck direction**	**Relative Wind**	**Truck Spd - Rel. wind**	**Est. Distance**
9/15/17 07:58:00.000	57	225	3.1	100	74	1.8	58.8	1.8	1.9
9/15/17 08:00:00.000			*Interpolated*		*74.2*	*1.1*	*58.0*	*1.0*	6.6
9/15/17 08:07:00.000	56	190	4.6	115	75	-1.2	55.0	-1.0	10.3
9/15/17 08:18:00.000	59	190	4.6	115	75	-1.2	58.0	-1.0	10.8
9/15/17 08:29:00.000	60	210	4.1	105	76	1.1	61.2	1.2	10.0
9/15/17 08:39:00.000	61	215	4.1	105	76	1.4	62.5	1.5	10.2
9/15/17 08:49:00.000	63	215	3.1	90	77	1.8	64.8	1.8	10.5
9/15/17 08:59:00.000	61	200	3.1	90	77	1.1	62.1	1.1	1.0
9/15/17 09:00:00.000			*Interpolated*		*77.0*	*1.1*	*61.9*	*0.9*	
9/15/17 09:09:00.000	58	210	3.1	90	77	1.6	59.6	1.6	
Average (of shaded values illustrating a distance-record)					**75.6**	**0.5**	**60.1**	**0.6**	

Figure 24: Illustration of interpolated and averaged weather data for each distance-fuel record

A comparison of the results of the two formulas shows that there are small differences in how the impact of wind and wind direction are calculated (comparing the values in the Wind in truck direction and Truck Speed – Relative Wind columns). Both values will be tested in the regression model.

Gross Weight

Assigning weight to each distance-fuel record was a relatively straightforward process in comparison to the methods for assigning elevation and weather data. A truck's weight did not change very frequently, and the odometer was known every time the weight changed. If the truck's weight changed in the middle of one of the distance-fuel records, a weighted average with respect to distance was used.

Regression Model

Data Filtering

With elevation, wind, temperature and weight assigned to each distance-fuel record, it was possible to run multiple regressions on the data to determine how much each condition influenced MPG for the *Run on Less* trucks. After discarding records for which there was invalid condition data or when the truck did not move, a total of 923 rows of data remained although some filters were tested which reduced the row count further. The first filter was to remove rows of data from when the truck was not operating at highway speeds. Initially, this filter was not used since the data was collected from trucks during their regular operations. Some of that operation includes times when a vehicle cannot travel at highway speeds. Therefore, it made sense to include all data. However, in order to discern the impact each of the conditions has at highway speeds, it is necessary to apply this filter. Doing so reduced the row count from 923 to 604. An additional filter was tested that eliminated any periods with large speed variations. Each row of data represents approximately one hour of driving data. Within that hour, it was possible for a truck to have encountered severe traffic or other reasons to slow significantly below highway speeds for short periods. In those instances, the truck would have consumed additional fuel to re-accelerate to highway speeds, which could distort the regression model. When rows where the standard deviation in speed exceeded 5 MPH were also eliminated, the row count was reduced from 604 to 205.

Predictors (Independent Variables)

For the regression model, the conditions (load, speed, etc.) that were tracked during *Run on Less* are the independent variables, or predictors of MPG. For most of the predictors, there is an intuitive sense for the impact each will have on fuel economy. For example, it is expected that a heavier load on a truck will reduce its MPG or that a tailwind should improve it. In most cases, the question to be answered by the regression model is how much each variable changes MPG, not the direction in which it is affected. However, for some variables, there is the possibility of an optimal point. Average speed and temperature may be two variables for which an optimum point exists. In the case of average speed, as the truck increases speed, the aerodynamic drag the engine must offset increases, thereby reducing fuel efficiency. However, the engine and driveline do not operate at the same efficiency across the speed range and likely have an optimal speed where efficiency is maximized. Going above or below that optimal speed may reduce a truck's fuel efficiency. Similarly, temperature can affect MPG in different ways as well. As temperature increases, air density decreases reducing the aerodynamic drag on the truck. However, as temperatures rise, the truck has to work harder to keep the engine and driver cooled which consumes more power and will reduce efficiency. Therefore, for average speed and temperature, variables where there may be an optimal point above and below which MPG should decrease, variations of those variables around optimal points were tested. Each of the independent variables and their variations that were tested in a regression as well as the expected impact on MPG are listed in Table 8.

Condition	Variable	Definition	Range of Values	Expected Impact
Gross Weight	GWk	Gross weight of truck including payload given in 1000s of lbs	34 to 78 k lbs	Negative
Average Speed	AveSpd	Average speed of the truck in	50.4 to 65.7 MPH	Negative
	AveSpdDiffX	Speed difference to X	Varies with X	Negative
Wind	TailWind	Wind speed in direction of vehicle (negative values indicate headwind)	-11.0 to 14.1 MPH	Positive
	CrossWind	Wind speed perpendicular to truck's direction of travel	0.1 to 18.2 MPH	Negative
	RelWind-AveSpd	Difference between the calculated relative wind speed and average truck speed	-11.6 to 15.7 MPH	Positive
Temperature	Temp	Ambient temperature	45.4 to 98.9° F	Unknown
	TempDevY	Temperature above or below Y	Varies with Y	Negative
Elevation	ElevIncr	Total increase in elevation	0 to 1,970 feet	Negative
	ElevDecr	Total decrease in elevation	-2,557 to 0 feet	Positive
	MaxAbove	Maximum elevation reached above starting point	0 to 1,745 feet	Negative
	MaxBelow	Lowest elevation reached below the starting point	0 to -2,533 feet	Positive
	NetElev	Difference in elevation from start to end point	-2,533 to 1,745 feet	Negative

Table 8: Independent variables tested in regression model

When building a regression model, there are several indications as to whether a variable and the resulting model is valid. One indication was discussed above; the direction of the relationship should be intuitively correct. Another indication is what is called the p-value. The p-value is the probability that the variable is irrelevant to the outcome. In other words, if the regression model shows that every 1 MPH change in wind speed increases MPG by 0.1 but the p-value is 0.5, this means that in the data, there is a 50% chance wind had no impact on MPG and that the relationship is happening purely by chance. Typically, a p-value of less than 0.05 is desired indicating that there is a 95% or greater probability that the variable does impact MPG. A further indication of the usefulness of a variable is the impact it has on R squared (R^2), known as the coefficient of determination. In simple terms, the R^2 of a regression model shows how much the independent variables explain changes in the dependent variable (MPG in our case). If the model shows that gross weight, wind speed, and elevation change (the independent variables) all have p-values of less than 0.05 and the regression model has an R^2 of 10%, it indicates that all of the independent variables are valid but their combined impact on MPG is relatively small compared to some other unknown variable (perhaps the driver as an example). A model is best if it explains as much of the dependent variable (MPG) with the least number of independent variables. Therefore, if the addition of an independent variable, even one with a p-value less than 0.05 does not improve the R^2 of a model, it is probably not useful and can be left out. One more critical test for independent variables is that they are not significantly correlated with each other. In other words, if a change in the value of one independent variable is closely tied to a change in one of the other independent variables, the model will have difficulty discerning the impact from each variable. A test for correlation will be discussed later in this section.

Regression Results

As discussed in the section on data filtering, an initial regression was run on the entire dataset that included data when the average speed was well below highway speeds. The resulting model identified five conditions that impact MPG: Gross weight, average speed above or below 55 MPH, net elevation change, the number of stops, and temperature above or below 80°F. These five variables explained 63% of the change in MPG (R^2 of 63%) indicating that while the variables are relevant, about one third of the MPG change could not be explained by the data. While the model appeared to be valid, there were two related concerns. Both have to do with the fact that while over-the-road long haul trucks do have to contend with local roads and parking lots, most of the time is spent at highway speeds. Since the relationship between vehicle speed and MPG changes as speed increases (at lower speeds, momentum is lost mostly to rolling resistance while at higher speeds more is lost to aerodynamic drag) it is more useful to examine the relationship at highway speeds. The other related concern is that the data is concentrated mostly in the higher speed ranges, which may make an analysis across the speed range less meaningful.

Filters to remove data with an average speed below 50 MPH and where truck speed varied significantly (discussed in the previous section) were applied to limit the dataset to highway travel as much as possible. A regression on the remaining data returned the results found in Table 9.

Condition	Impact on MPG
Gross Weight	Lose 0.47 MPG for every 10,000 lbs. (payload or truck weight)
Speed	Lose 0.24 MPG for 5 MPH above optimal speed, lose 0.94 MPG at 10 MPH above optimal speed
Wind	5 MPH wind changes MPG by 0.11 10 MPH wind changes MPG by 0.48
Temperature	Lose 0.55 MPG for every 10° F above or below 80° F
Elevation Increase	Lose 0.22 MPG for every 100 feet of elevation increase
Elevation Decrease	Gain 0.14 MPG for every 100 feet of elevation decrease

Table 9: Impact of conditions on MPG

Gross Weight and MPG

The model indicates that weight (truck gross weight or payload) reduces the MPG of a truck by 0.047 MPG for every 1,000 lbs. (shown as 0.47 MPG for every 10,000 lbs. Table 9). Directionally and quantitatively, the number makes sense. In NACFE's Lightweighting Confidence Report (Halonen, Swim Roeth, 2015), the study team found that fuel efficiency improves by 0.5-0.6% for every 1,000 lbs. of weight reduction. For the *Run on Less* fleet, which averaged 10.1 MPG, that would mean 0.05 – 0.06 MPG per 1,000 lbs. A similar but slightly lower number is found in Smartway's Weight Reduction technical bulletin, dated June 2016, which states that a 3,000 lbs. weight reduction could reduce annual fuel consumption by 240 gallons. Assuming 7 MPG and 100,000 annual miles, 240 gallons equates to 0.04 MPG per 1,000 lbs. Therefore, the result from this regression model with respect to weight is very much in line with what others have found.

Speed and MPG

A rule of thumb with respect to speed and MPG is that long-haul trucks lose 0.1 MPG for every 1 MPH above 55 MPH. While it is not clear when this rule of thumb first came to be accepted, it can be found in a variety of industry publications going back more than 10 years. The rule applies to a truck with typical aerodynamics and it makes sense that a very aerodynamic truck would suffer a smaller MPG penalty at higher speeds. One of the *Run on Less* drivers believed that the MPG of his very modern very aerodynamic truck would not be affected significantly with increased speed.

Analysis of the *Run on Less* regression revealed two possibilities for how speed affected MPG. The relationship (speed to MPG) is known to be exponential (fuel consumption increases faster than speed). When an exponential term for average speed change is used, the model returned a result that indicates that the rule of thumb is a good approximation at speeds up to about 61 MPH[1], where both indicate that MPG has been reduced by 0.6 MPG. However, above 61 MPH, the *Run on Less* data shows that MPG declines much faster with increasing speed than the rule of thumb would indicate and by 69 MPH, they give a result that is different by more than one MPG. For fleets considering an increase in governed speed, the rule of thumb would underestimate the impact to fuel cost significantly. For example, a 100 truck fleet thinking about a governed speed change from 65 to 68 MPH, assuming the trucks have an optimal speed similar to the *Run on Less* fleet (53-54 MPH) and spend about 65% of their miles at the maximum governed speed, using the rule of thumb would lead the fleet to believe fuel cost would increase by about $29k while the *Run on Less* results show that penalty will likely be over $85k.

As an alternative, the linear variable (which assumes fuel increases at the same rate as speed) in the regression model gave slightly better results (improved the R^2) in the model. However, it indicates that 0.17[2] MPG is lost for every one MPH above 54 MPH, considerably more than the rule of thumb. The EPA study previously referenced (Waltzer et al.), contains data that supports this higher ratio. (The data in the study indicates that the relationship is not linear although the data matches closely in the 50-65 MPH range.) The trucks used for the EPA study were 2012 Freightliner Cascadia 125s pulling Wabash 53-foot dry van trailers with and without trailer aerodynamics. Data was collected at speeds from 35 to 62 MPH with trailers equipped with varying aerodynamic packages. With the help of one of the study authors, NACFE examined how MPG changed with increasing speed in the controlled conditions presented in the study. Four sets of data (baseline and experimental runs for the control truck and test truck) show that the average MPG dropped from 10.07MPG at 55 MPH to 8.96 MPG at 62 MPH, or 0.16 MPG per one MPH, very similar to the linear regression result of the *Run on Less* trucks. The EPA study data appears to confirm that a more aerodynamic truck's MPG declines slightly less quickly with speed although the dataset is small and very specific to the vehicles being compared.

Predictions for how MPG changes with speed according to the different methods are graphed in Figure 25 to illustrate the differences (EPA data was presented at four speeds and is extrapolated here using a curve fit.)

[1] The regression indicates that the speed that maximizes MPG for the *Run on Less* trucks is in the range of 53-54 MPH whereas the rule of thumb implies an optimal speed of 55 MPH. All calculations assume changes from optimal speed.
[2] The upper and lower control limits for the coefficient are -0.12572 and -0.21649 with a 95% confidence interval indicating that there is a 95% probability that the actual coefficient is between the upper and lower limits. The midpoint between the limits is -0.1711. Complete regression statistics are found in Appendix C.

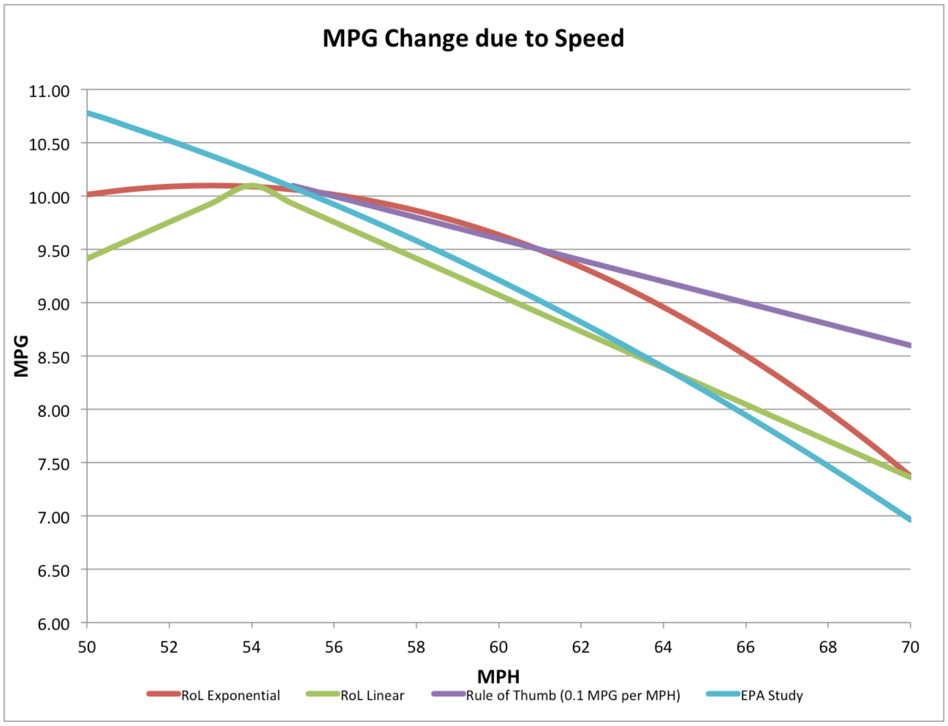


Figure 25: MPG versus speed using different methods

As noted above, average speed is a variable where an optimum point exists, above and below which MPG decreases. Several variations of the average speed variable were tested, to find the speed that increased the predictive value of the model the most. The variable that gave the best results in the regression model is variation to 54 MPH (the exponential model found a slightly lower optimal speed of 53 MPH), indicating that MPG decreases as speed increases above 54 MPH but also as speed decreases down to 50 MPH (data below 50 MPH was not included). There may be a few reasons for this. One may be very specific to the dataset in that there may not be enough data in the 50-54 MPH range (32 of 205 rows of data versus 70 or more for the next two 5 MPH increments). Another possibility is that an average speed of 50-54 MPH range may be correlated with another factor that reduces MPG (such as traffic or elevation increase). One more possibility is that since these trucks are highly downsped, a gearshift may have occurred between 50 and 54 MPH, which could be reducing fuel efficiency. The data from the EPA study points to a lower optimum speed, likely between 45 and 50 MPH although the trucks used in that study had numerically higher gearing and different aerodynamics.

Elevation Change and MPG

In theory, it makes sense that a truck traveling over flat terrain would achieve better MPG than an equivalent truck going up 1,000 feet and ending at the same location as the first truck. The *Run on Less* regression model indicates that the difference will be about 0.8 MPG, or about 10% for a truck averaging 8 MPG. It may be possible that the penalty for an average fleet is even greater. While the thermal efficiency of the engine has likely not changed dramatically in the last few years, it has probably increased, and these were mostly the newest trucks on the market. This combined with the fact that the drivers were very skilled at extracting the most miles from a gallon of fuel may mean that the *Run on Less* trucks had a smaller penalty than most fleets. For fleets, whose routes include significant elevation increases, changes in routing may not be practical. However, technology such as predictive cruise or even a hybrid electric drive may be worthwhile options.

Temperature Change and MPG

The effect of temperature on MPG is somewhat surprising. In terms of impact[3] on MPG, temperature was the least important in predicting MPG relative to elevation change, speed, load, and wind. However, temperature did have a measurable effect on the *Run on Less* results. As with average speed, the variables that worked best in the model were ones that assumed there was an optimum point above and below which MPG decreased. For the *Run on Less* data, that optimum point was 80°F. Every degree above or below 80°F reduced MPG by just under 0.05 MPG. The impact of temperature on a fleet's fuel cost may be more complicated than this model suggests. 80° F may have been optimal for this group of trucks but could result in more idling at some fleets. And, as with elevation and other factors, the ambient temperature is not something a fleet or driver can control.

Wind and MPG

Intuitively, one would expect wind to have the same impact on MPG as speed (in a wind tunnel, the two would be treated almost interchangeably). In terms of adding to the predictive model, wind had a greater impact than temperature but less than elevation change, weight or average speed. The potential sources of error in the wind speed data and the methods of calculating the effective wind speed were discussed previously. For the regression model, the wind related variable that returned the best result was the square of the difference of average speed and relative wind speed[4]. Models using a linear variable for wind (as opposed to the square) were less effective in predicting MPG and also changed the impact of average speed on MPG. Since using the square improved the model and the relationship is known to be exponential, it was used for this model. The fact that the impact of wind speed on MPG is different than the one for average speed may be more indicative of how the wind data was collected than anything else. The model indicates there is a clear relationship between wind and MPG. One way to interpret this result may be to think of it as the impact of wind speed as it was collected during *Run on Less* and MPG.

Multicollinearity and other Regression Statistics

Some of the possible explanations for the finding that MPG decreased as average speed declined from 54 MPH to 50 MPH is that other effects that also reduce MPG are occurring in that speed range including traffic, a lower gear, or an increase in elevation. Data on traffic or gear ratios were not collected, but the correlation (also known as collinearity) between average speed and elevation increase, as with all other independent variables was checked. A variance inflation factor (VIF) indicates how much one predictor is affected by all of the others. If the VIF for a predictor is high, it may indicate that it is not needed in the model and may be distorting the effect of other predictors. There is no firm rule on how high the VIF for a predictor can be and still be useful; it often depends on the variable itself. However, it is generally agreed that a VIF greater than four, indicating strong collinearity, requires further analysis. In the case of the MPG model, both elevation predictors (increase and decrease) had the highest VIF, though considerably less than four. A closer analysis of the elevation predictors shows that they are mostly correlated with each other, a finding that makes sense. In hilly terrain, it would be expected that elevation increases would be followed by elevation decreases. An alternative to using both predictors (increase and decrease) would have been to use the difference between the increase and decrease as a single predictor (the net elevation variable). However, doing so would mean that the model would predict no impact from a large elevation increase if the truck returns to the starting elevation by the end of the trip. As discussed in an earlier section, intuitively this does not make sense, therefore both predictors were kept in the model.

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[3] The temperature variable added about 6% to the R^2 of the regression model.

[4] The relative wind speed formula returns the speed 'felt' by the truck as a result of wind. Therefore, a truck traveling at 50 MPH with a 10 MPH tail wind would 'feel' as if it were moving at 40 MPH. For the purposes of the regression model, to separate out the effect of the truck's average speed from wind, the difference between average speed and the 'felt' speed was used (50 MPH – 40 MPH = 10 MPH tailwind in the example above). Regression models using the 'felt' speed in place of average speed and wind speed were less effective in predicting MPG.

The predictive value (R^2) of the overall model is 55%, which means that weight, elevation change, average speed, wind, and temperature explain just over half of the changes in MPG for the combined trucks in *Run on Less*. R^2 increases to a range of 72% up to 83% when a variation of the model is applied to a single truck[5]. The regression statistics indicate that this is a valid model on the combined truck dataset (full regression statistics and residual plots are in Appendix C & D). It does mean that there are other factors not captured by the data that explain the other 45% of the changes to MPG. A good portion appears to be related to the impact of the truck or trailer or difference among drivers.

Summary of Regression Model

It is important to keep the results from the *Run on Less* data in context. The data was collected over a relatively short period from seven vehicles configured with the latest technology for fuel efficiency, piloted by drivers known to be very good at maximizing MPG. These factors may influence the model in ways that have not been considered. However, the good corroboration of the relationship between weight and MPG as well as speed and MPG with some other recent studies indicate that the model is likely giving valid results albeit with a caveat on the impact of wind. As stated earlier, the relationship between wind speed and MPG should more closely mirror the relationship between speed and MPG. This may be an area for further study with a larger dataset.

For fleets there are several ways that the model results may be useful. The most obvious is in applying the relationships to their own fleet to understand the impact of spec'ing or operational decisions such as when considering a lightweight alternative or the cost of a change to governed speed versus other benefits or even the profitability of certain routes. For these purposes, Figure puts the various factors into context.

Figure 26: Half a mile per gallon equivalents

[5] Regressions models could only be developed for five of the seven trucks. For the remaining two vehicles, the filter criteria did not leave enough rows of data.

Further insight can be gained if a fleet undertakes a similar analysis of their own vehicles and routes. A fleet would gain a better understanding of their costs and may be able to make better spec'ing decisions based on their optimal speed, typical payloads and terrain profile.

Questions, Feedback, and Comments

Throughout the event and since its conclusion, some recurring questions have been asked regarding *Run on Less* by observers and even by some of the participants.

Q: How did the hurricanes really affect the Run?
A: Events such as hurricanes cannot be planned for and it was surprising to have two impacting Run on Less. The effect of wind on MPG has been discussed previously in this report and the videos on www.runonless.com highlighted the fact that some of the trucks experienced some strong winds as a result of the hurricanes. However, the effect goes beyond what was measured in the data. Trucks get rerouted, get caught in evacuation traffic, may lose loads as businesses refocus, gain loads (one truck delivered relief supplies to Texas during Run on Less), and are affected in other ways. The answer is we will never really know the whole impact, but it reinforces the fact that unpredictability is part of the business of trucking.

Q: Why did you not identify the results by named fleet?
A: A primary conclusion of this work is that there are multiple means to achieve high MPG and therefore, a fleet can achieve high levels with various collections of technologies and component makes. There is no one-size-fits all answer to getting the most miles from a gallon of fuel. Duty cycle, terrain, temperature, wind, elevation, etc. all play a role in achieving high MPGs. What works for one fleet might not necessarily be right for another fleet. Focusing on this amazing collection of equipment and capabilities provided the focus on the group rather than any individual unit's performance. Run on Less was a fuel efficiency roadshow, not a race, designed to demonstrate that 10.1 MPG was achievable in the real word. We'd like to think all the drivers, fleets that participated and the industry as a whole are winners as a result of our efforts.

Q: How much did each of the various technologies help in getting to 10.1 MPG?
A: The short answer is we do not know. Given the variety of technologies, applications, and routes in Run on Less, even if this had been an objective, it would have been very difficult to assess. All of the technologies have been covered in depth in the 16 Confidence Reports available on www.nacfe.org with assessment on payback and (many with) ROI calculators to check applicability to each fleet's situation.

Q: Will you do another Run?
A: Yes, we expect to do another Run on Less and will consider options such as adding fleets with the same requirements on technologies, or including vehicles in development, including such items as electric trucks, or a Run for older equipment. Potential collaborators have asked about a Run on Less solely in Canada or Mexico. Contact us with your ideas. Should there be another opportunity, it may be the chance to focus on a different segment of the market or to collect even more data for further analysis. Below are some of the items that have been discussed:

- *Monitoring DEF consumption*
- *Additional data logging*
- *Include 'more typically' equipped baseline vehicles*
- *Run on Less for older vehicles*

Conclusions

Run on Less provides insights for fleets trying to maximize the return on investment in fuel efficiency technologies, for manufacturers to improve their products exploiting benefits and mitigating consequences and for other industry supporters, data and information to help promote these successful uses of technology and practices. Upon completion of the Run, NACFE sought to better understand the data and information gathered during this important event and following are some conclusions the team reached.

10 MPG does happen in the real world
These seven fleets identified technologies that they believe provide them with a solid return on investment operated be real drivers. The routes and payload were actual and represent typical goods movement in the real world. But of course, duty cycles and other fleet business practices may not be capable of 10 MPG. NACFE suggests though, that major improvements are available for every fleet and these seven fleets have provided us with a strong road map for areas to focus on.

Conditions matter and need to be understood for decision making
There is much discussion about what can be achieved with currently available technologies. The old axiom "figures lie and liars figure" has been applied to truckers and manufacturers claiming high mpg performance. It is also important to be sure to have enough data for the claims. The NACFE team heard it all in the planning and execution of the Run. They must have been…

- Running empty or very light,
- Driving incredibly slowly,
- Only measuring going downhill or avoiding the mountains altogether
- Only recording when travelling with a tail wind.

The team measured and reported many of these conditions during the Run. Some of these conditions are uncontrollable — weather, routes and payload, while others the fleet has some control, such as vehicle speed. For decision making, fleets and manufacturers need to either design tests to control these conditions or understand them very well when making decisions or even in incentivizing driver behavior.

High MPG requires efforts in many areas
A diligent effort to improve operational costs through freight efficiency is needed to deliver the results demonstrated by these seven fleets. Each fleet used a different selection of technologies and practices, but many similarities were noticed and described in the 10 Actions for 10 MPG provided with this report. Most of the technologies require a higher investment in the equipment and in educating and incentivizing drivers. These fleets continue to invest in these technologies that payback within their financial controls or that will lower costs due to scaling in a relatively short time.

Telematics reports and datalogging are worthwhile investments
The cost of acquiring and storing data has come down significantly over the years, putting it within reach of nearly every fleet. This combined with the fact that even in the category of line-haul truckload there are differences in operations that may mean payback on technologies can vary significantly from one truck to the next. While there are similarities, the *Run on Less* trucks had some significant differences most notably axle configurations, idle reduction technologies, engine ratings and parameters, tires, and trailer aerodynamics. For fleets trying to negotiate their way through the array of original equipment and aftermarket technologies, good data will provide the best roadmap.

Recommendations

10 Actions for 10 MPG

The NACFE team has distilled the actions of these seven fleets to achieve high levels of performance into 10 actions that the industry should consider. Fleets make technology decisions based on their total cost of ownership, generally in terms of having an acceptable payback. NACFE has studied most of these actions and links are provided below to the appropriate Confidence Reports found in the [Technology Guide on nacfe.org](nacfe.org), where the payback levels and confidence ratings for each are presented.

- **Use Downsped Powertrains and AMTs**
  All seven tractors used automated manual transmissions that enable other technologies such as downspeeding as they employed some of the latest axle ratios. The duty cycle is key to these choices and in particular with downspeeding, buyers should only apply the most aggressive downspeeding to tractors with high average speed (MPH) where the amount of starts and stops are low. Axle ratio choices are available for both direct and overdrive transmissions. These new powertrains also seem to be favored by the next generation of truck drivers for their ease of operation and quiet operation.
- **Educate and Incent Conscientious Drivers**
  Run on Less benefited by having the trucks operated by some of the most proficient drivers on the road. There is no doubt that a portion of the 10 MPG is attributed to these drivers and as not everyone can play quarterback as good as Tom Brady, all truck drivers will not drive as efficiently as these seven. But hiring, educating and incentivizing your drivers for the best fuel efficiency possible, is a critical part of a successful fuel management system. The Run was not a competition, but its nature as a public event, showing off these truckers' performance, definitely had them doing their very best to achieve high MPGs. This "culture" of MPG competition can help a fleet increase its miles per gallon and lower its fuel costs.
- **Buy all Available Tractor Aerodynamics**
  As the fleets began to provide the specifications and photographs of their tractors for application to the Run, it was immediately obvious that they were buying all available aerodynamic features. All seven even had the most recent technology, drive wheel fairings. In NACFE's Tractor Aero Confidence report the group concluded that fleets should start their specification process with all the manufacturer's available sleeper tractor aerodynamics and only remove items if they have very good justification (such as frequent damage). For daycabs, oftentimes fleets avoid aero for tractors that do see significant highway miles at speeds were aerodynamics pay for themselves.
- **Adopt Appropriate Trailer Aerodynamics**
  Trailer aerodynamics have advanced over the past few years and continue to progress significantly. These fleets have technology in all three significant areas of opportunity; side, rear and front (the tractor-to-trailer gap). Many of these products were the most aggressive offered by manufacturers. The recommended action here is to adopt the most appropriate technologies for each fleet as this may vary with routes, drivers, maneuverability, etc. The important action is to address all three areas for large MPG gains.
- **Optimize Cruise Control and Vehicle Speed**
  There was much discussion concerning speed; how fast to drive, or when to drive faster, how best to manage hills and valleys, operations in various levels of congestion, passing traffic and on and on. A few of these drivers may be the rare ones, who can actually "out-drive" an automated transmission in cruise control. Most of the drivers used in-cab coaching tools to help with their fuel-efficient driving. In fact, it is these drivers that the equipment providers try to imitate as they design the hardware and software for their components and the parameters used to set operation. For fleets, maximize the parameter settings for cruise control to gain the most fuel savings. Finally, the science is

that the slower you drive the less fuel burned, but this may not be the most profitable way to run the truck. A run of freight that with speed can get a trucker more revenue, might be smarter to run faster and burn some more fuel. Or in one case it may make sense to drive faster to get around an urban area before an hours of service break where congestion would be much lower the next day.

- **Keep Equipment Well Maintained**
  The great technology employed on these tractors and trailers work best when the trucks are well maintained. This was clear with *Run on Less* as these drivers and their fleets were driven to run relatively new equipment whenever possible and to employ solid maintenance practices and utilize technology to help the equipment run as it is intended. Technologies on these trucks to ensure good operation included automatic tire inflation on trailers, use of low-viscosity lubrication and preventative maintenance practices such as alignment, replacing or cleaning of all filters, etc.
- **Implement the Right Axle Configuration**
  One of the more diverse areas of specifications on the seven trucks was rear axle configurations. The seven trucks included 6x4s, 4x2s, 6x2s and liftable 6x2s. To gain the most miles from a gallon of fuel in your fleet it is important to select the right axles for the jobs. This will depend upon the payload, speed, maneuverability, fleet practices such as tire management and even resale value if the asset will be sold before its useful life is exhausted. The benefit can be very high MPG by investigating, testing and buying the best axle configuration for your fleet.
- **Embrace Low Rolling Resistance Tires**
  Low rolling resistance tires are critical for a fleet to get high MPG, but the most fuel-efficient tires are not right for every fleet, application or region. Fleets have to recognize that tire selection has a huge impact on fuel economy and be sure to consider this along with tire cost and life in any tractor or trailer spec'ing choice. The more recent tire offerings are proving impressive gains in life, traction and fuel efficiency where the tradeoffs for any single attribute are not as high as they once were. A productive tire purchase and management process takes focus but will pay off.
- **Provide Tools to Reduce Idle Time**
  As NACFE found and these fleets confirmed, there are many tools, some technology and others via engine parameter setting to reduce idle time. These fleets were very focused on low idle times and shut the truck off whenever and wherever possible. Three of the fleets incorporated solar to improve the functionality of their battery HVAC systems.
- **Build a Culture of Methodically Choosing Technologies**
  The participating fleets in *Run on Less* clearly have a culture for improving MPG and a process to constantly monitor, adjust and act upon opportunities. They are on the leading edge with the technology developers, early testers to understand the appropriateness of the first generation of products and then either adopt or supply feedback to the manufacturers for improvements before buying. They include all functional areas in decision making — fleet management, equipment spec'ing, test, maintenance, driver recruiting and retention, finance, etc. Best practices include comprehensive understanding of the performance, either by testing or through industry involvement, robust payback or return on investment analyses and supplier selection.

Figure 27: Run on Less Recommendations

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Appendix

Appendix A – Truck Specifications

Fleet	*Tractor Year, OEM & Model*	Engine (Hp & Torque)	Oil	Transmission (# of Gears)	Idle Reduction	Tires	Axles	Rear Axle Ratio	Fuel Tank Capacity	Other
MVT	2018 International LT Sleeper	Cummins X15 (400 hp / 1550/1750)		Eaton DD AMT (10)	Idle Free Battery HVAC with tractor roof E-now solar panels (300w 25Amps)	Michelin Wide Based LRR	Meritor 6x2	2.28	140 + 100	Truck #2084P, High Rise (less cab room to cool), fixed 5th wheel, High Effy Denso 240A Alternator, Flow Below, vented flaps, SmartDrive, Spare WB tire, Disc Brakes, Full Safety techs (Bendix Fusion)
Hirschbach	2016 International ProStar Sleeper	Cummins ISX (450/1750)	Citgard 700 Syn 10-w30	Eaton OD AMT (10)	Tri-Pac Evolution & 3 minute timer	Michelin Wide Based LRR	6x4	2.64	200	FlowBelow, Eco Flaps, Wheel covers, Bendix Wingman, ACC, EZ Pass, Best Pass & PrePass
US Xpress	2018 Freightliner Cascadia Sleeper	DD15 (400/1750)		DT12 DD (12)	ParkSmart, Optimized Idle, Shorepower, Insulated curtains, Solar	Michelin Duals LRR	6x4	2.28		FlowBelow, vented flaps,
Nussbaum	2018 Freightliner Cascadia Sleeper	DD15 (400/1750)		DT12 DD (12)	ParkSmart, Optimized Idle & Shorepower	Michelin Energy Wide Based (Drive Not LRR, Tag LRR)	Detroit 6x2 Tag	2.28	220	ACC/PCC, FlowBelow, wheel covers, Eco flaps, Prepass Elite for toll & weigh station bypass, balancing beads in tractor rears, instantaneous MPG display in dash, Smart Drive event recorder with driver feedback lights
Albert Transportation	2018 Freightliner Cascadia Evolution Aero	DD15 (400/1750)	FA-4 (F/L factory fill)	DT12 DD (12)	ParkSmart, Optimized Idle, Shorepower, Insulated bunk curtains, windshield curtains, eNow 930 W system	Michelin Wide Based LRR	Detroit 6x4	2.16	240	ACC/PCC, Integrated drivetrain, lower bumper for 2018, Axle Lube Management, FlowBelow, wheel covers & thin soft soled shoes
Ploger Transportation LLC	2016 Volvo VNM62T630 Sleeper	Volvo D11 (385/1450 EcoTorque)	CK-4 Mobil 1 5w-30 LE	I-Shift DD (12)	2 aftermarket window fans, Webasto bunk heater	Yokohoma Duals (Steers 104, Drives 142, Lift 90)	Volvo 6x2 liftable front	2:53	225	FloBelow, V Spoiler Tabs, Pedal Coach, OBD Reader, & Jr Tennis balls!
Frito Lay	2018 Volvo VNL Day Cab	Volvo D13 (425 / 1450/1750)		I-Shift OD (12)	5 minute idle shutdown	Bridgestone Duals LRR	4x2	2.67	100+50	Flow Below wheel covers, vented mudflaps, **2 speed fan clutch,**

Appendix B – Trailer Specifications

Fleet	Used only 1 trailer for ROL	***Primary Trailer OEM (model)***	Model Year	Length	Aero Skirts (Y/N)	Aero Skirts Type	Trailer Tail Type	Nose Cone (Y/N)	Tire Inflation	Tire Inflation Type	Other	Curb Weight	Payload Weight
MVT	No	Great Dane Dry Van	2018	53'	Yes	Yes, Wabash Sectioned skirts	Stemco ATD	None	ATIS	ATIS by PSI	Flow Below hubcaps	13,920	46,060
Hirschbach	No	Utility 3000R	2013-2018	53'	Yes	SmartTruck, Ridge, Utility	SmartTruck	N/A Reefer	ATIS	Yes	EcoFlaps, Aluminum wheels, ATIS,	15,000	38k to 46k
US Xpress	No			53'	Yes	Yes	SmartTruck "top kick"	None	ATIS	PSI ATIS	Steel wheels		
Nussbaum	No	Wabash DVHDHPC	2017	53'	Yes	29' TransTex w/ modified axle release position	Yes, Stemco ATD	no	ATIS	ATIS	No rain gutter, Eco Flaps, Zero offset WBS to keep them inward, lisence plate out of air flow	13,700	10k to 45k
Albert Transportation	Yes	Utility 4000 DX Dry Van	2008	53'	Yes	Fleet Engineering Aero Classic that cover landing gear via extra panel	ATD	Nose Cone (3 Piece)	Monitor	PSI/TST Tire pressure inflation & monitors	3 Solar panels, Wheel covers, Aero Flaps by Flt Engr, Relocated License Plate, Reefer Plate over rain gutter, Cross member protecters by Flt Engr, Kwik Zip smooth side advertising	13,741	60k to 65k
Ploger Transportation LLC	No	Wabash Dura Plate HD Van	2018	53'	Yes	Yes, Wabash Sectioned skirts	Yes, Wabash	Yes	ATIS	PSI ATIS	Lift axle, D Aero behind tires, V Spoiler tabs	14,500	45,000
Frito Lay	No	Kentucky Trailer High cube Drop Frame Trailer	2018	53'	Yes	Yes, short ones due to drop frame	Yes, Stemco ATD	Yes	ATIS	Hendricks on ATIS - inflate and deflate	Vented flaps, a drop frame has 11% more cube than a std 53' dry van		

Appendix C - Regression Statistics

Linear Regression

Regression Statistics

R	0.74063
R-Squared	0.54853
Adjusted R-Squared	0.53485
S	1.17838
MSE	274.93911
RMSE	16.58129
PRESS	305.54079
PRESS RMSE	1.22084
Predicted R-Squared	0.49828
N	205

MPG = 15.66314 - 0.04675 * GW (k lbs) - 0.17111 * 54 + 0.00476 * RelWindVel - avespd^2 - 0.05541 * TempDev80 - 0.00713 * ElevIncr (m) - 0.00467 * ElevDecr (m)

ANOVA

	d.f.	*SS*	*MS*	*F*	*p-value*
Regression	6.	334.04662	55.67444	40.09447	0.
Residual	198.	274.93911	1.38858		
Total	204.	608.98573			

	Coefficient	*Standard Error*	*LCL*	*UCL*	*t Stat*	*p-value*	*H0 (5%)*	*VIF*	*TOL*	R-Squared
Intercept	15.66314	0.45294	14.76993	16.55634	34.58119	0.	*rejected*			
GW (k lbs)	-0.04675	0.00676	-0.06008	-0.03341	-6.91367	6.34639E-11	*rejected*	*1.0807*	*0.92530*	0.0747
54	-0.17111	0.02302	-0.21649	-0.12572	-7.43446	3.09739E-12	*rejected*	*1.04452783*	*0.95737038*	0.04263
RelWindVel - avespd^2	0.00476	0.00082	0.00315	0.00637	5.83782	2.13551E-8	*rejected*	*1.07529799*	*0.92997477*	0.07003
TempDev80	-0.05541	0.01049	-0.0761	-0.03472	-5.28178	3.35482E-7	*rejected*	*1.05774314*	*0.94540911*	0.05459
ElevIncr (m)	-0.00713	0.00072	-0.00855	-0.00572	-9.93717	0.	*rejected*	*1.18844633*	*0.84143472*	0.15857
ElevDecr (m)	-0.00467	0.00066	-0.00598	-0.00336	-7.04824	2.9424E-11	*rejected*	*1.22701409*	*0.81498657*	0.18501
T (5%)	1.97202									

LCL - Lower limit of the 95% confidence interval
UCL - Upper limit of the 95% confidence interval

Linear Regression

Regression Statistics

R	0.72752
R-Squared	0.52929
Adjusted R-Squared	0.51502
S	1.20323
MSE	286.65749
RMSE	16.93096
PRESS	329.33402
PRESS RMSE	1.26748
Predicted R-Squared	0.45921
N	205

MPG = 15.19261 - 0.04646 * GW (k lbs) - 0.00943 * 53^2 + 0.00447 * RelWindVel - avespd^2 - 0.05293 * TempDev80 - 0.00722 * ElevIncr (m) - 0.00461 * ElevDecr (m)

ANOVA

	d.f.	*SS*	*MS*	*F*	*p-value*
Regression	6.	322.32824	53.72137	37.10641	0.
Residual	198.	286.65749	1.44777		
Total	204.	608.98573			

	Coefficient	*Standard Error*	*LCL*	*UCL*	*t Stat*	*p-value*	*H0 (5%)*	*VIF*	*TOL*
Intercept	15.19261	0.44586	14.31336	16.07186	34.07468	0.	*rejected*	**	**
GW (k lbs)	-0.04646	0.0069	-0.06007	-0.03284	-6.72922	1.79478E-10	*rejected*	**	**
53^2	-0.00943	0.00141	-0.0122	-0.00665	-6.70206	2.08875E-10	*rejected*	**	**
RelWindVel - avespd^2	0.00447	0.00083	0.00284	0.0061	5.40481	1.85353E-7	*rejected*	**	**
TempDev80	-0.05293	0.01069	-0.07401	-0.03184	-4.95034	1.58156E-6	*rejected*	**	**
ElevIncr (m)	-0.00722	0.00073	-0.00867	-0.00578	-9.85724	0.	*rejected*	**	**
ElevDecr (m)	-0.00461	0.00068	-0.00594	-0.00327	-6.81121	1.13292E-10	*rejected*	**	**
T (5%)	1.97202								

LCL - Lower limit of the 95% confidence interval
UCL - Upper limit of the 95% confidence interval

Appendix D – Regression Residual Plots