

The background of the slide is a long-exposure photograph of a city skyline at night. The sky is a deep blue. In the foreground, a multi-lane highway is visible, with light trails from cars and trucks creating streaks of white, yellow, and red. The city buildings in the background are illuminated with various lights, and some have distinctive architectural features like spires or rounded tops. The overall scene is a vibrant, modern urban landscape.

NASEO: Truck Platooning

Mike Lammert

National Renewable Energy Lab

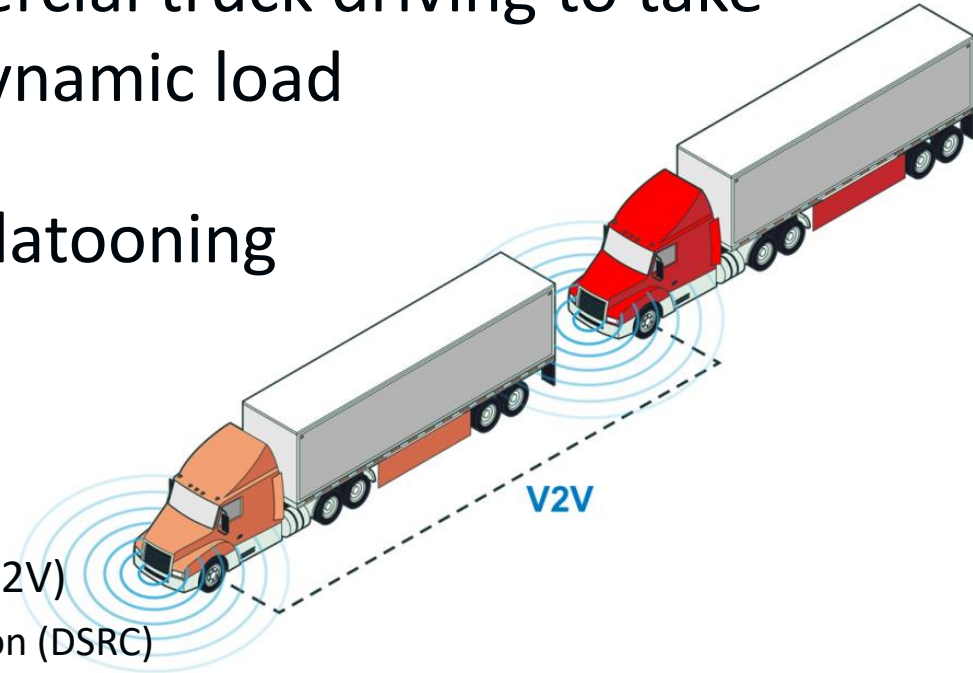
Only National Laboratory Dedicated Solely to Energy Efficiency and Renewable Energy

- Leading clean-energy innovation for over 35 years
- 1800 employees with world-class facilities
- Campus is a living model of sustainable energy
- Owned by the Department of Energy
- Operated by the Alliance for Sustainable Energy
- Energy Systems Integration Facility – newest national “users facility on NREL campus”



What is Platooning?

- Electronically linked commercial truck driving to take advantage of shared aerodynamic load
- Enabling technologies for platooning
 - Forward object detection
 - Radar
 - Lidar
 - Stereo cameras
 - Vehicle-to-vehicle communications (V2V)
 - Dedication short-range communication (DSRC)
 - 5G
 - Vehicle-to-infrastructure communications (V2I)
 - Cloud
 - Direct road way communication
 - Vehicle braking and torque control interface
 - Driver displays & communication interface



Effect of Platooning on Fuel Consumption of Class 8 Vehicles Over a Range of Speeds, Following Distances, and Mass

Michael P. Lammert and Adam Duran
National Renewable Energy Laboratory
Jeremy Diez and Kevin Burton
Intertek



Potentials for Platooning in U.S. Highway Freight Transport Preprint

Matteo Muratori, Jacob Holden, Michael Lammert, Adam Duran, Stanley Young, and Jeffrey Gonder
National Renewable Energy Laboratory



Correlations of Platooning Track Test and Wind Tunnel Data

Michael Lammert and Kenneth Kelly
National Renewable Energy Laboratory
Janet Yanowitz
Ecoengineering

NREL is a national laboratory of the U.S. Department of Energy Office of Energy Efficiency & Renewable Energy Operated by the Alliance for Sustainable Energy, LLC
This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Technical Report
NREL/TP-5400-68897
February 2018

Contract No. DE-AC36-08G028308

2014-2018

- Lead or been involved in 3 truck platooning track testing campaigns
- 2 National Impact of platooning Big Data studies
- Correlation of LLNL wind tunnel platooning studies to track studies
- Reanalyzed Volpe “naturalistic” truck driving behavior as relevant to background platooning
- <https://www.nrel.gov/transportation/fleettest-platooning.html>
- ARPA-E NEXTCAR advanced platooning team
- DOE Fuel Efficient Platooning FOA teams

NREL/CP-5400-70438. Posted with permission. Presented at WCX18: SAE World Congress Experience, 10-12 April 2018, Detroit, Michigan.

2018-01-1083 Published 03 Apr 2018

Exploring Telematics Big Data for Truck Platooning Opportunities

Michael P. Lammert, Bruce Bugbee, and Yi Hou National Renewable Energy Laboratory
Andrea Mack Montana State University
Matteo Muratori, Jacob Holden, and Adam Duran National Renewable Energy Laboratory
Eric Swaney Volvo Group

Citation: Lammert, M.P., Bugbee, B., Hou, Y., Mack, A., et al., "Exploring Telematics Big Data for Truck Platooning Opportunities," SAE Technical Paper 2018-01-1083, 2018, doi:10.4271/2018-01-1083.

Abstract

NREL completed a temporal and geospatial analysis of telematics data to estimate the fraction of platoon-able miles traveled by class 8 tractor trailers currently in operation. This paper discusses the value and limitations of very large but low time-resolution data sets, and the fuel consumption reduction opportunities from large scale adoption of platooning technology for class 8 highway vehicles in the US based on telematics data. The telematics data set

a one-hour resolution, resulting in a significant fraction of data be uncatagorizable, yet significant value can still be extracted from the remaining data. Multiple analysis methods to estimate platoonable miles are discussed. Results indicate that 63% of total miles driven at known hourly-average speeds happens at speeds amenable to platooning. When also considering availability of nearby partner vehicles, results indicate 55.7% of all classifiable miles driven were platoonable. Analysis also address the availability of numerous partner

NREL/CP-5400-70868. Posted with permission. Presented at WCX18: SAE World Congress Experience, 10-12 April 2018, Detroit, Michigan.

2018-01-1181 Published 03 Apr 2018

Influences on Energy Savings of Heavy Trucks Using Cooperative Adaptive Cruise Control

Brian McAuliffe National Research Council Canada
Michael Lammert National Renewable Energy Laboratory
Xiao-Yun Lu and Steven Shladover University of California-Berkeley
Marius-Dorin Surcel FPrinnovations
Aravind Kallias Volvo Group

Citation: McAuliffe, B., Lammert, M., Lu, X.-Y., Shladover, S., et al., "Influences on Energy Savings of Heavy Trucks Using Cooperative Adaptive Cruise Control," SAE Technical Paper 2018-01-1181, 2018, doi:10.4271/2018-01-1181.

Abstract

An integrated adaptive cruise control (ACC) and cooperative ACC (CACC) was implemented and tested on three heavy-duty tractor-trailer trucks on a closed test track. The first truck was always in ACC mode, and the followers were in CACC mode using wireless vehicle-vehicle communication to augment their radar sensor data to enable safe and accurate vehicle following at short gaps. The fuel consumption for each truck in the CACC string was measured using the SAE 11321 procedure while travelling at 65 mph and loaded to a gross weight of 65,000 lb, demonstrating the effects of inter-vehicle gaps (ranging from 3.0 s or 87 m to 0.14 s or 4 m, covering a much wider range than previously reported tests), cut-in and

cut-out maneuvers by other vehicles, speed variations, the use of mismatched vehicles (standard trailers mixed with aerodynamic trailers with boat tails and side skirts), and the presence of a passenger vehicle ahead of the platoon.

The results showed that energy savings generally increased in a non-linear fashion as the gap was reduced. The middle truck saved the most fuel at gaps shorter than 12 m and the trailing truck saved the most at longer gaps, while lead truck saved the least at all gaps. The cut-in and cut-out maneuvers had only a marginal effect on fuel consumption even when repeated every two miles. The presence of passenger-vehicle traffic had a measurable impact. The fuel-consumption savings on the curves was less than on the straight sections.

Keywords

adaptive cruise control (ACC), cooperative ACC (CACC), heavy-duty truck platooning, heavy-duty truck partial

automation, vehicle control performance, heavy-duty truck fuel economy

Introduction

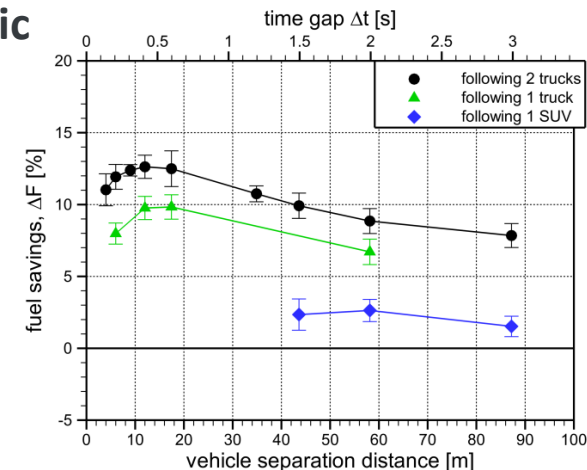
Cruise Control (CC) has been in use for several decades for automated vehicle control to assist the driver with speed regulation without distance control. The driver remains responsible to maintain a safe distance with respect to any forward vehicles. Adaptive Cruise Control (ACC) uses a radar or lidar (laser radar), and sometimes with the addition of a video camera, to add relative distance and relative speed control. Some passenger cars and heavy-duty trucks are currently equipped with this capability. The main problem for ACC is that if three or more ACC vehicles are driven consecutively, the system is string unstable [1]. A string of ACC vehicles on highways is less stable than a string of manually driven vehicles because the forward ranging sensors lack the ability to perceive the actions of vehicles ahead of the immediately preceding vehicle. The larger and larger cumulative delays

with the addition of greater numbers of vehicles to the string increases the unstable behavior. To solve this problem, cooperative ACC (or CACC) with V2V (vehicle-to-vehicle wireless communication) is a possible solution. With CACC, the simultaneous wireless communications broadcast from the lead vehicle to all the followers effectively removes the cumulative delay problem while the delay associated with the V2V communication is sufficiently small that it can be ignored.

In practice, the first vehicle of a CACC string can use ACC mode to follow other manually-driven vehicles in public traffic, or it can be driven manually. There are no special responsibilities or authority required for this leading vehicle or its driver. The second vehicle, and any subsequent vehicles, will be in CACC mode, assuming wireless communication is maintained and if there are no inter-vehicle cut-ins by other road vehicles. Ad-hoc joining and leaving by vehicles, when

2017 Truck Platooning Track Test Campaign with LBNL & NRC

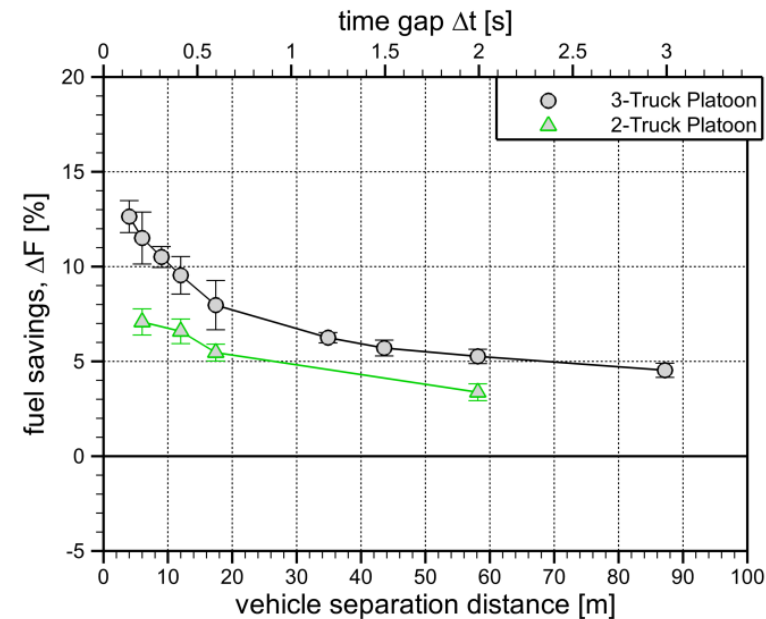
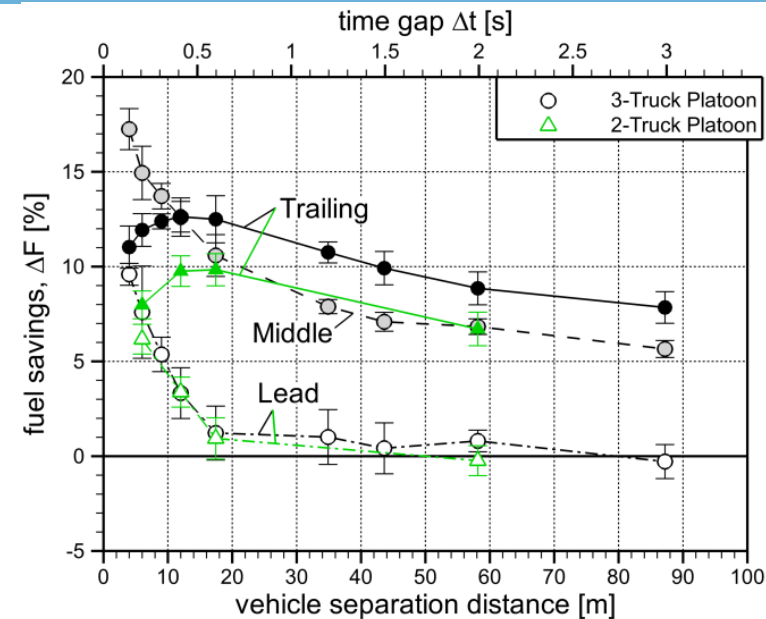
- 2017 Truck Platooning Track Test Campaign with LBNL & NRC
 - 26 two & three truck platooning scenarios investigated
 - Aerodynamic sleeper cabs, side skirts and trailer tails were tested
 - SAE J1321 gravimetric fuel measurement procedures
 - J1939 data collection
 - Additional wind/temperature/torque sensing on all trucks
 - Paper presented at SAE World Congress Experience April 2018 with LBNL & NRC
 - Findings match remarkably well to previous NREL & Auburn U. track testing and LLNL wind tunnel findings
 - **Confirms question on true “baseline” of trucks in traffic today**
 - 2% individual truck savings following compact SUV
 - 5-9% trailing truck savings at over 140' behind tractor trailer



2018 Paper Gravimetric Data Results

Two and three Vehicle Platooning results.

- Lead vehicles experience the same savings pattern
- Trailing vehicles experience the same savings pattern, including reduced savings at close following, but 3 vehicle system has larger savings for trailing vehicle
- Middle vehicle matches trailing vehicle of 2 vehicle platoon beyond 18m, but closer than 18m it has the pattern of the lead vehicle, but at higher savings
- Maximum Team Savings
 - 7% savings for 2 truck platoon team
 - 13% savings for 3 truck platoon team



“Potentials for Platooning in U.S. Highway Freight Transport”

- Presented at SAE World Congress Experience April 2017
 - SAE Journal Publication
 - Over 3 million miles of high resolution data
 - Over 200 class 8 tractors
 - Vehicle Speed and time duration analysis
- 65.6% of vehicle miles in this dataset can be considered to be platoonable.
- 76.6% of vehicle miles from “early adopter” subset considered platoonable.

“Opportunities for Truck Platooning based on Telematics Data”

- Presented to SAE World Congress Experience April 2018 with Volvo Truck
 - Over 210 million miles telematics data provided by Volvo Truck
 - Over 57,000 class 8 Volvo tractors included
- Average Driving Speed Analysis Results
 - 63% platoonable miles at 50 mph; matches well with previous analysis
 - Top 32% of trucks would account for 54% of the total platoonable miles
- Geospatial Partner Single Day Analysis Results
 - 55.7% of all classifiable miles driven being platoonable (38% unknown)
 - Usually several partners are available if one is

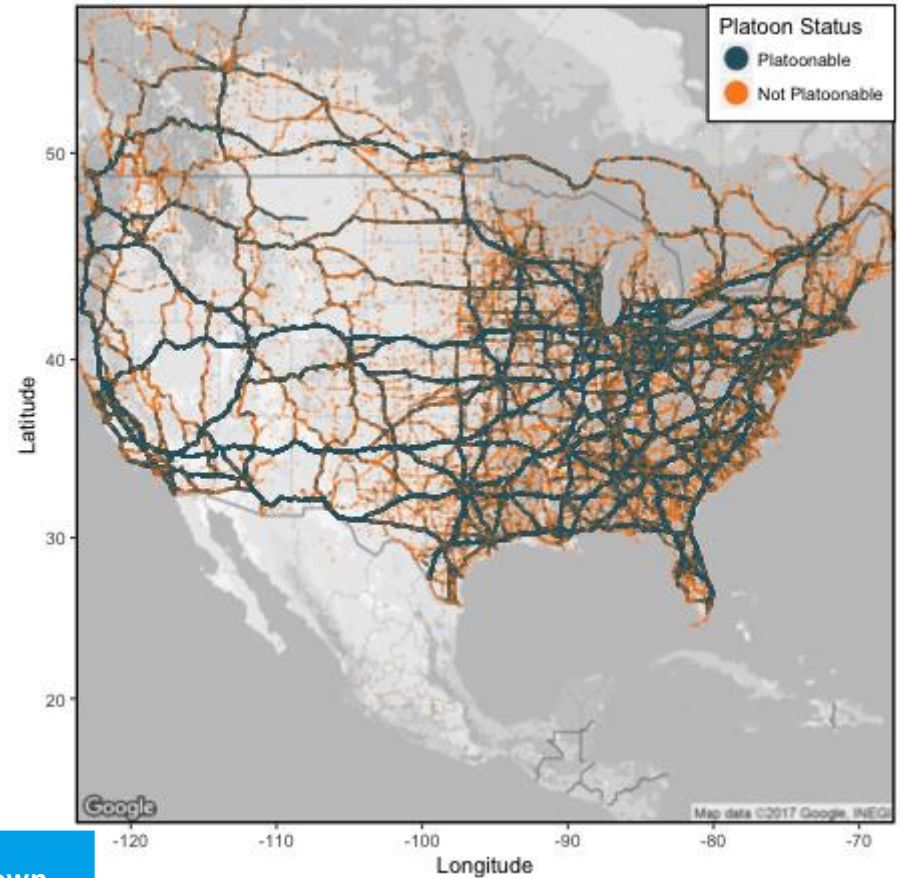
2018 Paper Geospatial / Partner Method Results

Spatial distribution of platoonable observations with partner considerations

- highest regions of platoonability occur across major shipping corridors and interstate highways
- significant opportunity on Canadian shipping corridors
- 55.7% of all classifiable miles driven being platoonable

US Platoonability for Single Day

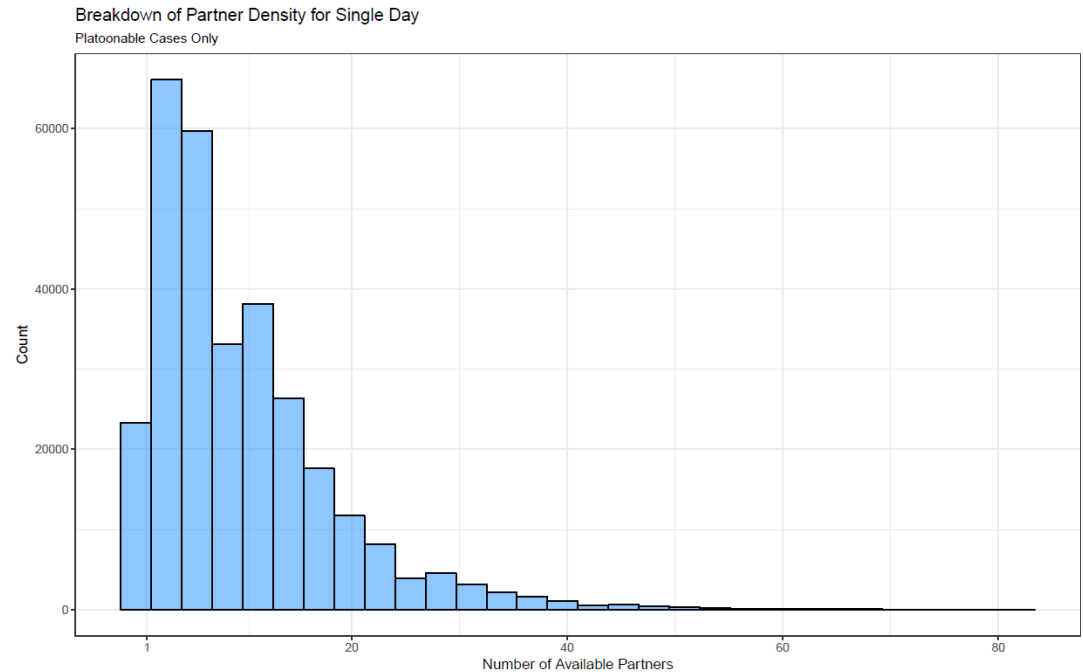
Only vehicles with road speed > 30 mph



	Platoonable	Non Platoonable	Unknown
All Data	34.0%	27.4%	38.6%
Known Data Only	55.7%	44.3%	NA

Volvo platooning partners:

- Usually more than 1
- Peak around 3 partners
- mean of 10 partners
- Opportunity for 3 and 4 truck platoons needs to be investigated
- Even some level of fleet/technology incompatibility minimal impact on partner availability



So where are we now?

- European Truck Platooning Challenge
- Demonstrations in Michigan I-96, Washington DC, Colorado...
- Most truck OEMs have CAV truck demos
- Semi autonomous “driver assist” platooning is close to market ready
- Level 4/5 driverless systems are a long way off

So where are we now?

- 2018
 - Lots of platooning papers at SAE & TRB conferences
 - DOE Platooning FOA awards 3d: Fuel Efficient Platooning - - \$2.5 million
 - Cummins
 - Advancing platooning with advanced driver assisted systems control integration and assessment
 - American Center for Mobility
 - Fuel-efficient platooning in mixed traffic highway environments
 - DOT FHWA
 - BAA- Truck Platooning Early Deployment Evaluation, Phase 1 - - \$500K
 - Proposals currently being evaluated

- Technical
 - Sensor & controls refinement stage
 - System interoperability standards
 - Fleet/user cooperation savings sharing
- Regulatory
 - Where can I platoon & when?
 - Who decides?
 - What happens at state lines?
 - Law enforcement knowledge?

Obstacles / Needs

- Liability/Insurance
 - What happens if there is an accident?
- Driver acceptance
 - Sure it saves fuel – but do I know/trust the guy in the lead?
- Public acceptance
 - My mom would panic if she saw 3 trucks driving 20' apart
 - Other drivers would cut right in between

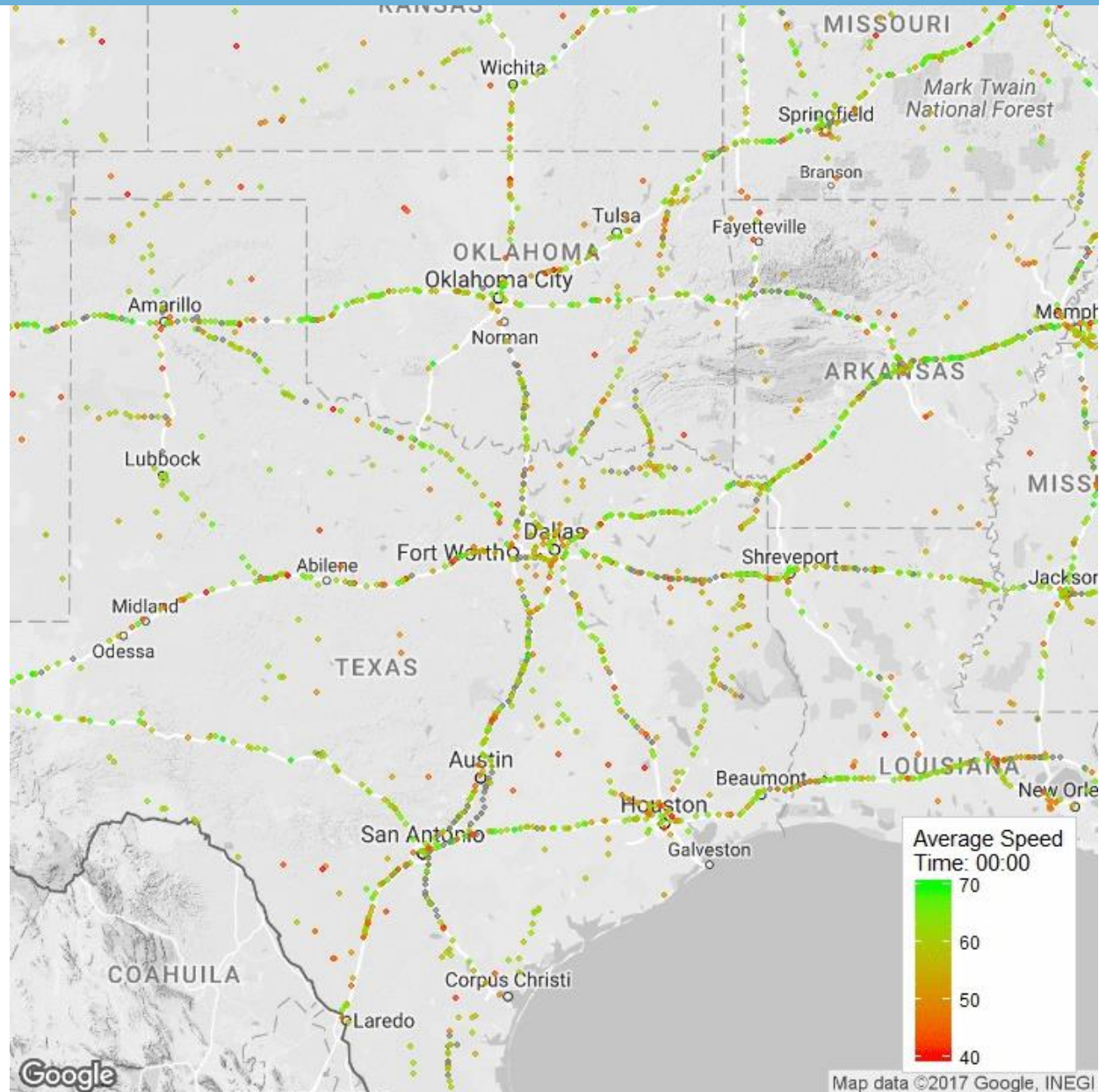
Opportunity

- Maximum Team Fuel Savings
 - 7% savings for 2 truck platoon team ** about 5.5% to begin with
 - 13% savings for 3 truck platoon team
- Big Data Truck Average Driving Speed Analysis Results
 - 63% platoonable miles above 50 mph; matches well with previous analysis
 - Top 32% of trucks would account for 54% of the total platoonable miles
- Geospatial Partner Single Day Analysis Results
 - 55.7% of all classifiable miles driven being platoonable (38% unknown)
 - Usually several partners are available if one is
 - ****Data set limitations; some fleets could be much higher****
- Safety increase from connectivity & synchronized braking

Opportunity

Truck speed distribution over time

2018 Telematics Big Data Paper Average Driven Speed Results



Opportunity

Truck speed distribution over time

2018 Telematics Big Data Paper
Average Driven Speed Results

