USE OF TELEMATICS DATA IN FLEET MANAGEMENT

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Executive Summary

The Drexel LeBow team investigated telematics technology and telematics use case studies in the government sector and the utility industry to answer the following questions:

- How do other organizations use telematics data?
- What are the critical factors required to achieve the benefits of leveraging telematics data?
- What are the key performance indicators that other organizations are using?
- What are the best practices for the use of telematics data?

Industry research indicated that telematics is indeed impactful in an organization. Specifically,

- Case studies show that fleets demonstrate operational, safety, and compliance benefits through the use of telematics.
- Benefits are realized along the spectrum of telematics deployment.
- Individual KPIs may lead to multiple types of improvements.

Additionally, Comcast supplied the team with idle time data from their telematics implementation, as well as maintenance and fuel records for the fleet. This data was analyzed to answer the following questions:

- What is the current state of idle time across the fleet? Can the goal of having less than 30 minutes of idle time per vehicle per day be met?
- What are the factors that influence idle time?
- What are the trends in maintenance and fuel costs across the fleet? What opportunities are presented by the use of telematics to lower these costs?

Detailed data analysis showed that:

- The idle time goal is not currently met.
    - Average daily idle time per vehicle is 80 minutes, with half of the vehicles above 69 minutes per day.
    - 16.8% of the vehicles met the goal.
- Division and temperature are significant factors in determining idle time.
    - Northeast has higher idle times than Central and West.
    - Warmer days exhibit higher idle times.
- Vans have more idle time outliers than other types of vehicles.
- Two groups of special cases merit further study.
- Use of telematics by Comcast has the potential for cost savings:
    - 83% of the maintenance costs are due to unscheduled maintenance activities.
    - Vans constitute the majority of vehicles and fuel costs.
    - Bucket trucks have disproportionately high fuel costs, but their costs have decreased significantly with change in use of power take-off.
    - Reducing daily idle time to below 30 minutes/day is expected to reduce fuel costs by 5.8%, or approximately $5 million annually for the fleet.

Business Problem

Telematics is a group of technologies for monitoring and transmitting data in real-time. Over the last decade, telematics has become an effective tool in fleet management by enabling managers to track their assets, collect vehicle sensor data, and communicate with drivers. Using this tool, enterprises have realized improvements in efficiency, productivity, driver safety, and costs.

Comcast currently manages a fleet of approximately 30,000 vans, bucket trucks, pick-up trucks, and other vehicles across the United States. The organization has recently launched the first phase of a new telematics implementation and is tracking vehicle locations and recording idle times greater than 2 minutes. Upcoming phases of the study include monitoring speed and engine data as well as tracking driver behavior.

As Comcast's telematics implementation is in its initial stages, this represents an ideal opportunity to investigate best uses of the collected data and provide guidance for future phases of data collection and goal setting. The Drexel LeBow team investigated telematics technology and telematics use case studies in the government sector and the utility industry to answer the following questions:

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Data Exploration & Cleaning

Comcast provided the Drexel LeBow team with telematics data collected during the new implementation as well as existing records of maintenance and fuel expenditure. Below are the data sets that were used in the analysis:

- Idle Time Data: Provided for each individual idle time instance of more than 2 minutes in duration. Contained information about the date/time and duration of the idle time instance, division/region/state of the idling vehicle, the job type for the stop and the job title of the driver, and the make/model/year of the vehicle. The idle time instances occurred between 04/27/2019 and 05/31/2019.
- Maintenance Data: Line item costs and descriptions of every maintenance charge as well as the corresponding ATA codes were provided. The maintenance instances were also grouped by whether they were scheduled or unscheduled. The maintenance records were for 2017 (full year), 2018 (full year), and 2019 (January and March only).
- Fuel Cost Data: Total fuel cost, fuel quantity, number of transactions, and average cost/gallon per vehicle during the period November 2016 to April 2019. Vehicle information, odometer readings, and calculated miles per gallon, average miles per month, and average fuel cost per month were also included.

Initial exploration of the data in the files above provided the following information:

- Location: Vehicles are grouped into three divisions: West (covering states on the West Coast), Northeast (covering states in the mid-Atlantic region and northeastern United States), and Central (covering the South and the mid-West). Within each division, there are several regions, and regions are further divided by state.
- Number of vehicles: The idle time data included 10,733 vehicles pre-selected by Comcast for analysis. The maintenance data included 39,057 vehicles in operation between January 2017-March 2019. The fuel cost data included 30,902 vehicles in operation during March 2019.
- Types of vehicles: The fleet includes vans, bucket trucks, pick-up trucks, and other vehicles of a variety of makes and models. The model years ranged from 1990 to 2019.
- Maintenance types: There are four types of maintenance ("Tires, Tubes, Liners, Valves", "Lube, Oil", "Air Intake System", and "Transmission – Main, Manual") which are always listed as scheduled. All other maintenance types are currently unscheduled.
- Fuel efficiency: While most vehicles have fuel data for 2.5 years (or their lifetime, if the model year is recent), the fuel efficiency is calculated from the last 6 months of fuel purchases for most vehicles. 45 vehicles have their fuel efficiency calculated for the lifetime of the vehicle and 6 vehicles have insufficient data.

The idle time data required minimal cleaning. There were two VIN numbers that were each recorded as operating in two nonadjacent divisions on the same day and were removed as errors. The data for May 3 and 4 were only for the Northeast Division and did not include idle time readings for the other two regions, and there was no data provided for May 20 or 22.

The maintenance data contained 4,251 records (out of 2,463,863 or less than 0.2%) whose dates did not match the date range of the maintenance records and were removed.

The fuel data file included 198 vehicles for which the transaction dates, counts, and amount were not available. However, the miles per gallon and average fuel cost per month were still provided for these vehicles so they were included in the overall analysis.

All three types of files included the VIN for each vehicle, and this field was used as the main key to connect information across the files.

Telematics Industry Research

Telematics Data Collection Methods

Telematics data are collected from *on-board diagnostic ports* that store performance data from vehicle sensors and location information from the Global Positioning System (GPS). Vehicles can also be outfit with *video systems* that record videos to track driver behavior and performance. The data can be tracked in real-time via on-board computers and can be reviewed constantly by the fleet managers.

OEM OBD-II Port

- **Device Installation**

On-Board Diagnostics (OBD) ports are standardized systems that connect and gather data from the vehicle's computer system. Most vehicles come with an original equipment manufacturer (OEM) telematics system that is programmed to read proprietary vehicle codes. OBD-II ports are designed for temporary devices and are aftermarket systems. The advantages of OBD-II ports are that they are highly customizable for fleet managers and can read engine codes across more manufacturers than OEM systems. Furthermore, aftermarket telematics systems can include advanced features such as:

  - Monitoring unsafe driving
  - Helping reduce idling
  - Giving maintenance alerts
  - Reporting fuel consumption

Figure 1: Telematics device (left) and Subaru Forester OBD-II port (right)

- **Methods of Data Capture**

The following are some methods of capturing data from telematics:

OBD-II Engine Data: OBD ports provide data about vehicle's odometers and mileage reading. This helps capture the vehicle miles travelled (VMT). Similarly, these ports also provide alerts about engine issues, fuel issues, brake failures, and powertrain malfunctions. Identifying acceleration and braking is done by converting momentum changes in the accelerometer. Some advanced telematics systems can track fuel levels and consumption through the use of fuel sensors. All of this information can be useful to fleet managers in optimizing their fleet performance.

Automatic Vehicle Location (AVL): AVL is one of the primary features of telematics and is the ability to track mobile assets. It helps fleet managers track any vehicle's geographical location. This is especially useful when optimizing routes of service and to reduce vehicle overlap in certain locations. It also aids with prompt emergency responses in case of any incident. Similarly, vehicle safety can be achieved by finding vehicle's presence in unexplained location and by locating stolen vehicles.

Real-Time Video Camera

- **Device Installation**

Real-time video cameras are aftermarket installations. The videos are continuously recorded and available to fleet managers online to monitor driver behaviors and vehicle performance. The videos that are transmitted to online databases are useful later for multiple purposes as well to improve the driver performance.

Figure 2: Lytx driver and road views in video telematics system

- **Methods of Data Capture**

Driver specific measures: Video recording can capture events of drivers who may be texting or talking on cell phone, eating or drinking, smoking, drowsy driving or are engaged in other inattentive behaviors. These behaviors may result in increased rates of collisions or may be hampering the efficient use of vehicle speed and acceleration. Many advanced systems alert drivers in any of these cases. Furthermore, video recordings will be very helpful to review ways in which vehicles are being idled. Learning patterns of driver idling can reduce the cost from idling**.**

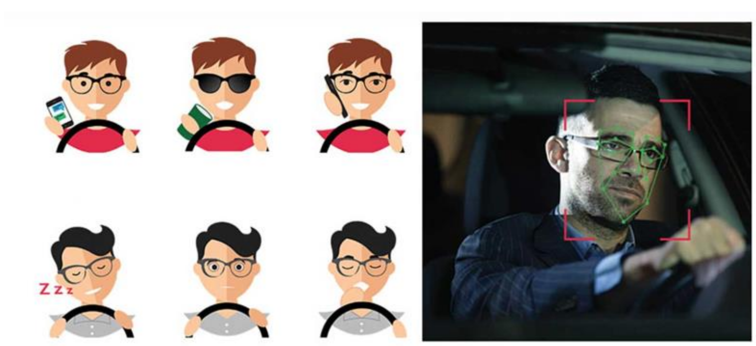


Figure 3: Advanced real-time video telematics (Reference 5)

Vehicle specific measures: Vehicle safety can be improved significantly by tracking videos of vehicle performance. For instance, the recordings to monitor speeding and unsafe braking can be useful to learn driving patterns. Occurrences of vehicle collision and airbag deployment can show the nature of accidents to reduce them in the future. In some cases, video telematics can provide information about the driver at fault and may reduce additional legal expenses.

Telematics Benefits to Stakeholders

There are numerous advantages of using telematics data in fleet management. There are three main stakeholders who can benefit from integrating telematics data:

- **Vehicles and Drivers:** Telematics data can be used to improve road safety and to increase productivity by monitoring driver's behaviors and keeping track of vehicle maintenance.
- **Fleet managers:** Managers can use predictive models to schedule preventative maintenance, make vehicle acquisition decisions (timing, right-sizing, and right-typing), and optimize routes and schedules.
- **Enterprise:** The company can realize lower operational cost, lower insurance rates and accident liabilities, and improve its sustainability.

Key Performance Indicators (KPIs)

In this section, the KPIs are ordered by their prevalence in the fleet management industry, as indicated on the 2016 Telematics Use Survey conducted by Fleet Answers (Reference 4).

1. Efficiency and productivity
KPIs designed to measure daily operations and utilization of vehicles can help increase efficiency and productivity, saving the company both money and time. These KPIs include:

- Fuel efficiency
- Miles driven
- Number of days out of service
- Idle time

2. Driver safety
Monitoring safety is critical for any fleet as improvements in safety can have positive effects on efficiency and cost savings. One of the best ways to measure the safety of the fleet is to track driving behaviors. Therefore, the KPIs that are important to look at include:

- Speed against posted limit
- Number of hard acceleration incidents
- Number of harsh braking and cornering events
- Seat belt use rate

3. Fleet acquisition and maintenance cost
Determining assets that are being over- or under-used can highlight potential ways to cut unnecessary costs. Doing so can help improve vehicle utilization in the short term and help with right-typing and right-sizing in the fleet in the longer term. Some of the relevant KPIs include:

- Vehicle utilization
- Engine codes and odometer readings

4. Route guidance and compliance

In an economy of rising fuel prices, routing has proven to be one of the most important features in fleet management. Optimizing routes can improve productivity significantly while reducing fuel and other costs. Important KPIs for route guidance and compliance are:

- Vehicle location
- GPS services

5. Service level

In today's competitive market, companies failing to create good customer services may suffer from customer churn as well as customer a negative reputation with customers. One important KPI is

- Response time to service calls

6. Sustainability

Creating sustainable impacts on environment and reducing greenhouse gases are always important concerns for fleet managers. KPIs that can be considered important for sustainability are

- Carbon emissions
- Other environmental impacts

Telematics Use Case Studies

The State of Utah

The State of Utah fleet management case study is available as Reference 1.

About the State of Utah Division of Fleet Management:
The division directly manages approximately 4,500 vehicles with a wide range of types, from sedans to one-ton trucks to accommodate the widely varied functions of employees in departments such as Human Services, Corrections, Public Safety, and Agriculture.

Overview of the telematics pilot:
The key objective of the State of Utah Division of Fleet Operation (DFO) in conducting the large telematics pilot was to validate the effectiveness of fleet tracking systems in reducing overall operating costs and lowering the cost per vehicle mile.

Some goals the state hoped to achieve:

- Reduce fuel costs
- Reduce maintenance costs
- Reduce accident costs
- Reduce unnecessary fleet vehicles
- Increase productivity

There were 1,296 units installed during the first year of the pilot, which began in January 2017. This represented approximately 25% of the fleet managed by the DFO and included a broad variety of use types across the state. The pilot rollout lasted 18 months, from January 2017 to July 2018.

Improvements:
Fuel Savings
Fuel savings were achieved primarily through a reduction in idling and speeding. After implementation within the four pilot agencies (DAS, DABC, DHS and Corrections), the average MPG increased by approximately 4 MPG, representing 20% improvement since Feb 2017. One year after installation, the average MPG increased by 6 MPG, representing 27% improvement from before installing telematics devices.

The State of Utah achieved the goal by proactively measuring idling and speeding and using in-cab real-time driver coaching alerts with supervisor feedback to discourage unnecessary idling and excessive speeding. Some examples to receive alerts were: idling more than 3 minutes, speeds greater than 85 mph or 20 mph over posted speed limit, and 10 mph over posted speed limit for more than 1 minute.

Maintenance savings
Since the deployment of telematics, there was a 20% improvement in the cost of work orders 1.5 years after installation. Maintenance savings were achieved by proactively monitoring aggressive driving and managing check engine light alerts and low battery notifications to help guide the agencies on when to

take a vehicle in for maintenance to avoid catastrophic failures. This strategy also helped reduce costly roadside failures and dead batteries. Reducing unscheduled downtime brought down costs for the agency and increased overall productivity.

Safety impact

Since implementing telematics within the four pilot agencies, the State of Utah improved seat belt usage from 96% to 99% of the total distance travelled.

The State of Utah achieved the goal by using in-cab real-time driver alerts to provide warning of seat belt usage, as well as to reduce speeding and aggressive driving behaviors.

PECO

The PECO fleet management case study is available as Reference 2.

About PECO's Fleet:

The PECO Fleet Department had an oversight of 1,420 vehicles as of December 31, 2016. Being a utility company, vehicle types ranged from small service cars and pickups to heavy duty bucket trucks.

Overview:

Many of PECO's fleet maintenance performance goals were not being met between 2008 and 2013. PECO then developed a risk-based model to support the fleet department's vehicle replacement decisions using information about maintenance cost, down-time and vehicle age. Their main goal from this project was to meet the key performance indicator goals between the years 2013 to 2016. The KPIs provided them insights into operating, maintenance decisions and in making future repairs and replacements.

Data collection:

PECO collected data on engine hours, idle time, location, active fault codes, and miles driven by the vehicles. Then, they focused on the 5 most troublesome fault codes. Doing so allowed them to switch their maintenance schedule to be based on actual miles driven and fault codes, rather than on calendar.

Maintenance Success Metrics:

By creating benchmark goals for the company and striving to meet these goals, PECO has successfully used information from telematics to meet improved operational standards. Some of the KPIs used by PECO and their results in the four years of tracking fleet performance data are listed below:

- Average days out of service data: reduced from 37 in 2013 to 32 in 2016
  Goal: ≤ 32 vehicles per year
- Mean time to service: reduced from 112 days in 2013 to 17.7 days in 2016
  Goal: ≥ 14.8 days
- Preventive maintenance adherence schedule: increased from 95.8% in 2015 to 96.3% in 2016
  Goal: ≥ 96% of all vehicles
- Preventive maintenance backlog: decreased from 35 to 48 to 31 from 2014 to 2016
  Goal: 31 per year

For Comcast, going a step further and aligning various KPIs with industry standards will be very beneficial in being an industry leader in terms of fleet performance and management.

U.S. Marine Corps

The U.S. Marine Corps fleet management case study is available as Reference 3.

About the U.S. Marine Corps Fleet:
The U.S. Marine Corps has about 10 years of experience with fleet telematics and nearly three quarters of its non-tactical fleet are now equipped with telematics. The study consisted of 11,170 vehicles in its domestic inventory in 2016, and 8100 were telematics-enabled vehicles. They used Lytx, Verizon Network Fleet, and WBC Fleet service as their contractors in their telematics efforts.

Metrics and Applications:
Safety is a serious concern for the Marine Corps. Therefore, they collected many data points to aid in their goal of maximizing fleet performance and improving driver behavior.

Method of Data Capture	Data Point	Application
Video recording	Texting, talking on cell phone Eating or drinking Drowsy driving Seatbelt unfastened	Identify unsafe driving behavior
OBD-II port	Speed driven Extreme acceleration count Excessive speed duration Total idling time	Reduce unsafe behavior, highlight overall performance
OBD-II port	Vehicle collision Airbag deployment	Notify first responders, inform fleet managers
GPS/ AVL	Trip mileage, fuel consumption, geofencing	Identify inefficient vehicles, reduce fuel usage and cost

Improvements in Safety and Compliance:
The Marine Corps benefitted from telematics in the following ways:

- After implementing telematics systems, they reduced speeding by 40%. Some managers even saw reductions in violations from 10-15 per month to approximately 1 per month, after issuing letters to speeding drivers.
- Number of accident damages reduced by 35% in a 2-year period.
- Marine Corps reduced fuel cost, carbon emissions, idle time by 60% in the Southwestern region.
- The video recording helped exonerate some marine drivers in disputed cases. It further saved repair costs by providing video evidence of personally owned vehicle driver at fault.
- Real-time oversight helped reclaim 80% of costs associated with vehicle abuse, determining responsibility, and collecting payment.

Data Analysis

Telematics data on Idle time

One of Comcast's business challenges in fleet management is to reduce idle time to increase efficiency and reduce operating cost. Telematics data were collected among 10,733 vehicles recorded from 4/27/2019 to 5/31/2019 and contained the vehicle information, number of idle stops, idle duration, and vehicles' job functions. Comcast's goal on idle time reduction is to ensure less than 30 minutes of idling per vehicle per day. In order to help achieve the goal, this analysis provides an in-depth overview of current fleet performance and suggestions to support the business decision-making.

- **Daily Idle Time**

Currently, the minimum idle duration captured by the telematics instrument is 2 minutes. Among the 10,733 vehicles, a vast majority are vans used by Business/Residential Installation Technicians. The tables below show a breakdown of the vehicle count in each job function, as well as in each vehicle type.

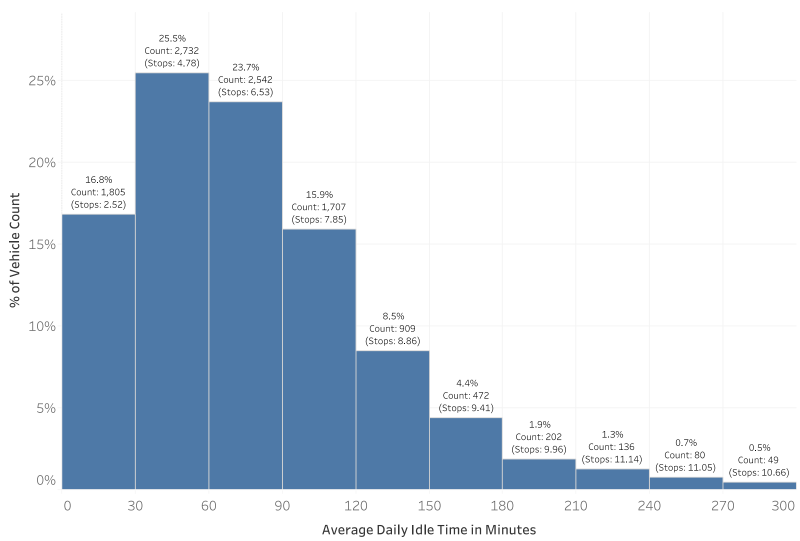
Installation Technicians	10669
Installation Managers	49
Maintenance Technicians	21
Site Construction	2
XFINITY Store Manager	1
Unknown	36

Number of Vehicles by Job

Van	10466
Pickup	89
Bucket	35
Null	143

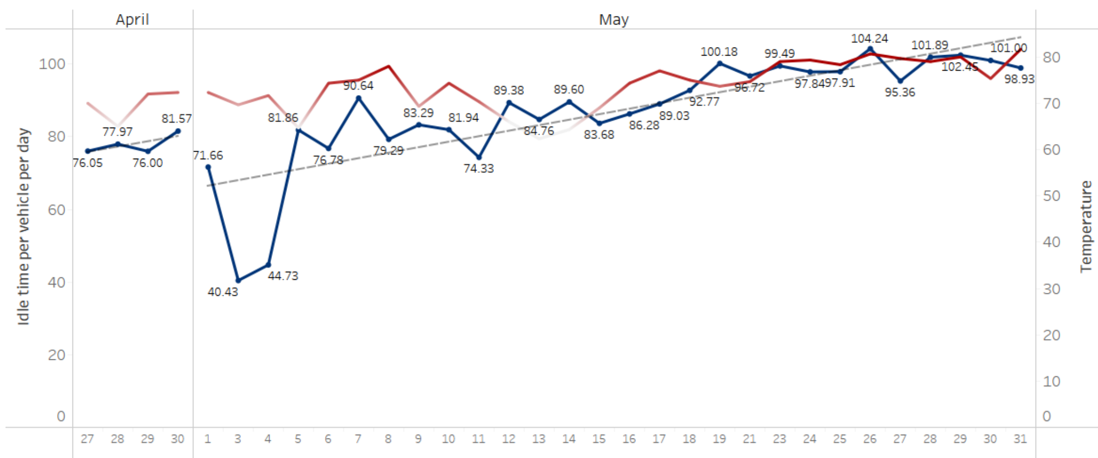
Number of Vehicles by Type

During 4/27—5/31, the overall average daily idle time was 80 minutes. Because different job functions and vehicle types operate differently, the idle time per vehicle can deviate and there were many large values in idle time, skewing the distribution and increasing the average. In fact, 50% of the vehicles have idle times of 69 minutes or less. Currently, 1,805 vehicles have met the goal of idling less than 30 minutes per day, accounting for 16.8% of the total. The chart below shows the distribution of idle time across all vehicles.



Graph 1: Idle duration distribution in general

As seen in Graph 1, *__the average number of idle stops and idle duration are positively correlated__*. Vehicles have longer daily idle time if more stops are made. Additionally, *__the idle time on a given day also correlates with the average temperature of that day__*. The line chart below shows the daily idle time (in blue) and the average temperature (in red) across all operating days from 4/27 to 5/31. The temperature is measured as the average of the daily high temperatures in New York City, Nashville, and San Francisco, cities chosen to be near the geographic center of each of the three regions in which the Comcast fleet operates. This supports the conclusion that the changes in temperature should be taken into consideration when evaluating idle times. Further analyses are conducted for different regions to show the difference in idling due to the change in climate. (Please note that the idle time data for May 3 and 4 are incomplete, leading to lower values.)



Graph 2: Average Idle Time and Temperature from 4/27 to 5/31

- **Idle Time by Region**

  Fleet idle time shows different patterns across different divisions. The map below shows the average idle time in all operating states with at least 30 vehicles and indicates that vehicles in the northeast tend to idle longer than the rest of the country.

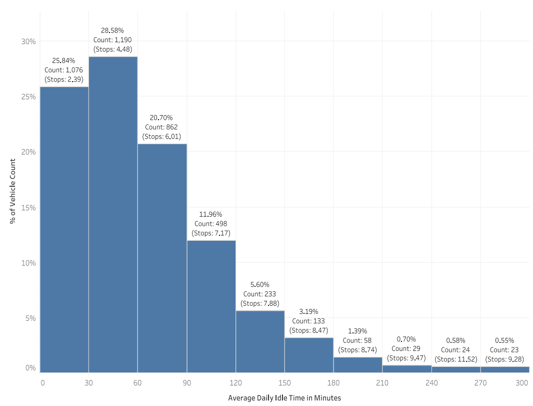
Graph 3: Average Daily Idle Time by State

The vehicles being evaluated here operate in three divisions: central, northeast, and west division. The table below shows the number of vehicles in each division.

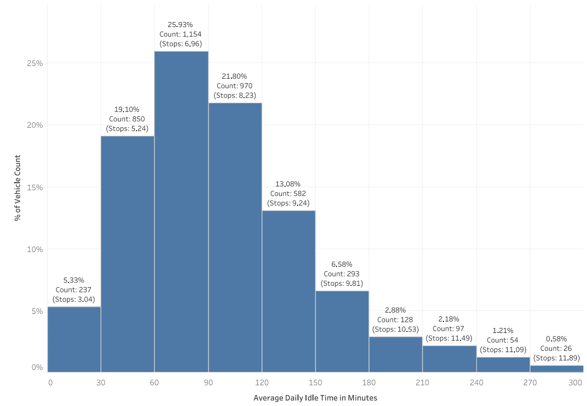
Central Division	4164
Northeast Division	4450
West Division	2121

Idle time in the northeast division is distinctly different from the other two divisions, with overall higher average idle time and only 5.3% of the vehicles meeting the goal of under 30 minutes of idling per day. By comparison, in the central and west divisions, over 20% of the vehicles have met the goal.

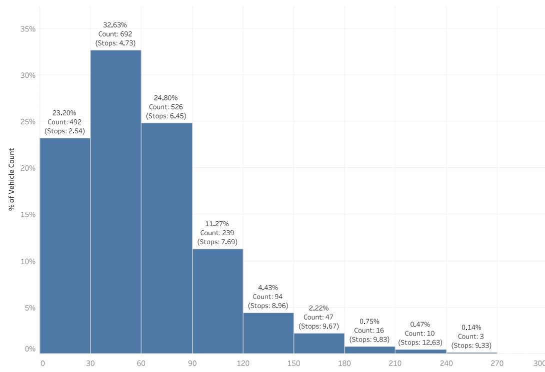
In summary, vehicles in the northeast division perform well below average and thus have the most potential for improvement. The following graphs show the idle time distribution in all three divisions.



Graph 4: Idle Time Distribution – Central Division

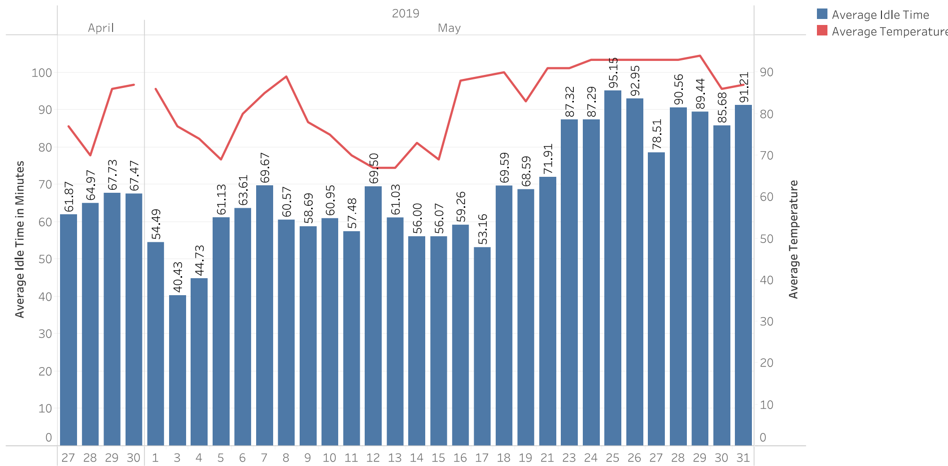


Graph 5: Idle Time Distribution – Northeast Division

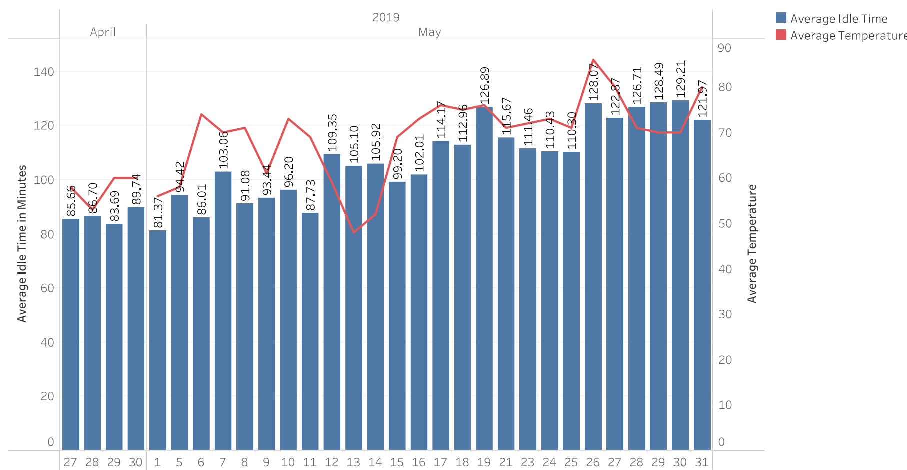


Graph 6: Idle Time Distribution - West Division

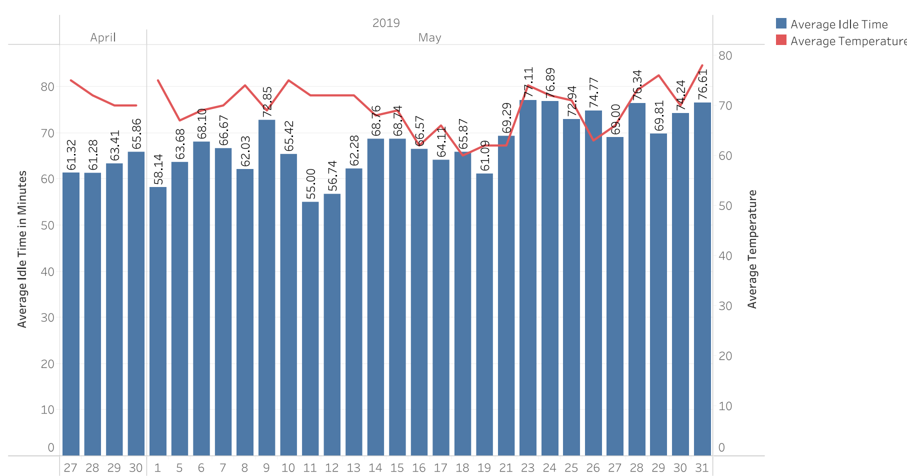
Furthermore, vehicles in the northeast division also have idle time that fluctuates more closely along with the temperature than other divisions. Because there was an increase in temperature towards the end of May, it was also observed that the idle time increased during that period of time. The following charts show how idle time changes with average temperature from 4/27 to 5/31 in all three divisions.



Graph 7: Idle Time & Temperature – Central Division



Graph 8: Idle Time & Temperature – Northeast Division



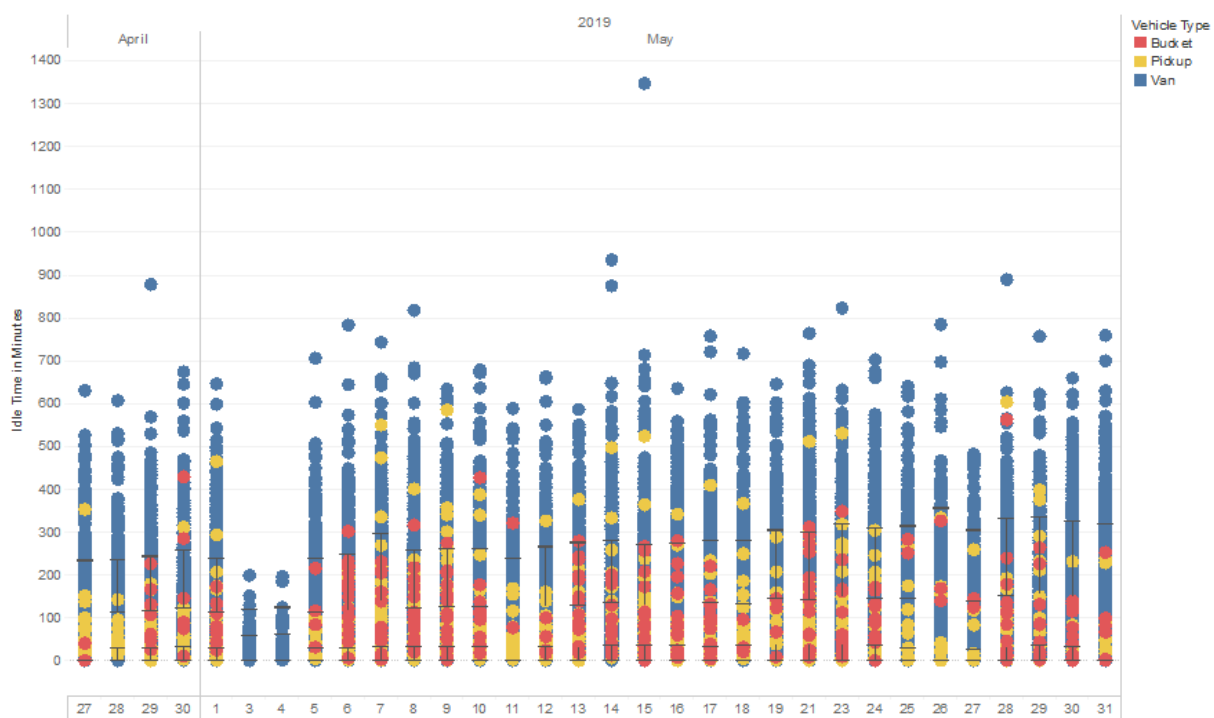
Graph 9: Idle Time & Temperature – West Division

To summarize, *it was found that the idle time tends to change according to the temperature and the northeast division is especially prone to that influence*.

- **Idle Time by Individual Vehicle**

This part of the analysis explores in detail the idle time for individual vehicles. In particular, the analysis looks into vehicles with exceptionally long idle times on a given day and identifies the vehicles which do not meet the goal on an average level but have shown they can idle less than 30 minutes on some days.

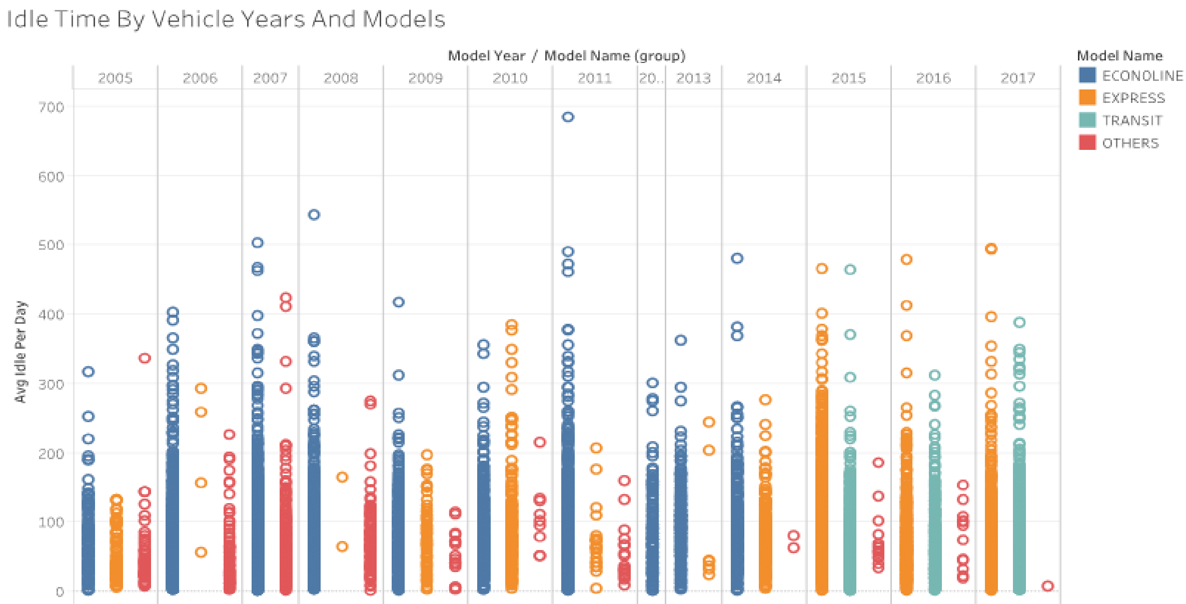
Outliers: The following plot shows each individual vehicle's idle time on each day, with each dot representing a vehicle. The color represents the type of vehicle, and the gray box is the middle 25-75% of idle time values for the day. It was found that *outliers, identified as over 500 minutes of idle time on any day, are typically due to vans*. These vehicles should be further looked into. It was also observed that *bucket trucks tend to have higher-than-average idle time*, as expected due to the idling necessary for power take-off usage in some model years.



Graph 10: Idle Time Per Individual Vehicle

- **Idle time by Van Models:**

Daily idle times differ by type of vehicles and locations. It was found that Econolines have the highest idle time among three types of models, followed by Express and then Transit Van. The majority of outliner falls into Econoline model.



Graph 11: Idle Time By Vehicle Years And Models

By looking at the average idle time per models across three regions, it was observed that vehicles in the Northeast have uniformly higher idle times than the other two regions. Although the Northeast has the different distribution of vehicle models than the other two regions, but the overall higher idle times in the Northeast cannot be attributed solely to this different distribution.

Special Cases: In order to help identify which vehicles should be targeted for further improvements, <u>*the analysis found two groups of vehicles to investigate*</u>:

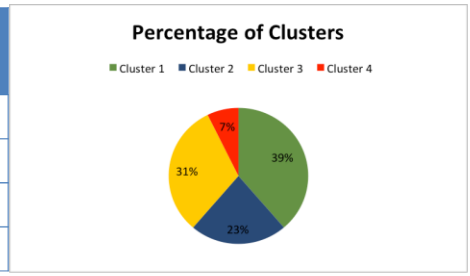
- Average daily idle time > 30 minutes and minimum idle time < 30 minutes
  There are 6,573 vehicles that failed the goal but do have individual days where idle time is less than 30 minutes. Among these vehicles, the average daily idle time is 77 minutes while the average minimum idle time on a given day is 10 minutes. These vehicles have the potential to meet the goal with management's further investigation on what caused the high average idle time.
- Average daily idle time < 30 minutes and maximum idle time > 30 minutes
  There are 932 vehicles that met the goal but still have individual days where idle time is beyond 30 minutes. The average maximum idle time among these vehicles is 62 minutes. Likewise, these vehicles should receive management's attention on how to reduce or eliminate days where the long idle time occurs.

- **Clustering Analysis on Idle time**

Cluster analysis was performed on idle time to gain better understanding about correlation among idle time and other factors. The K-means algorithm was used to maximize the distance among different clusters while minimizing the distance among the data points within the cluster itself. This ensures that each cluster is as distinct as possible from the others, while ensuring some uniformity within the cluster. The analysis included attributes from both idle time data and fuel data such as average idle time per day, average idle time per stop, average number of stops per day, type of vehicle models, miles per gallon, and current odometer. It was found that the average idle time per day and average idle time per stop are the two most significant variables to differentiate each cluster.

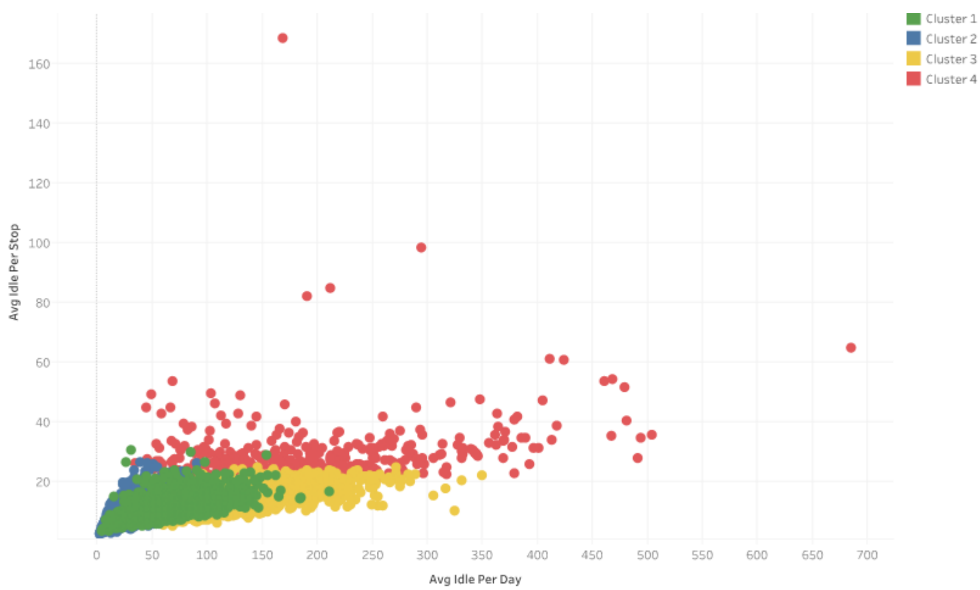
Cluster	Average Idle Time (minute)	Average Number of Stops	Average Idle Time Per Stop (minute)
Cluster 1	40	4.21	9.62
Cluster 2	67	5.88	11.5
Cluster 3	121	9.10	13.5
Cluster 4	175	6.21	29.2

Figure 3: Cluster summary



Graph 12: Percentage of clusters

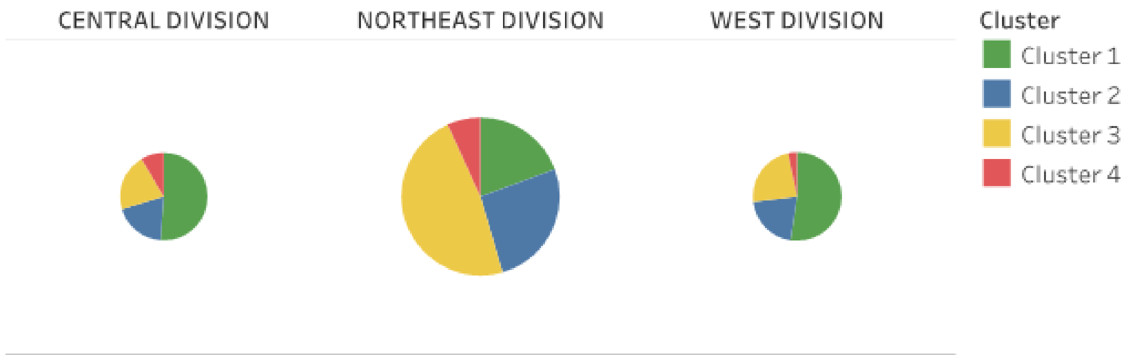
The vehicles were divided into 4 clusters based on differences in their idle times and other attributes. Cluster 1 represents the group of vehicles which has the lowest average idle time as well as the lowest average number of stops, followed by Cluster 2 and Cluster 3. Cluster 4, in contrast, includes vehicles that have the highest idle time due to the highest idle time per stop, not by the highest average number of stop per day. It was observed that this cluster also includes most of the outliers in the dataset.



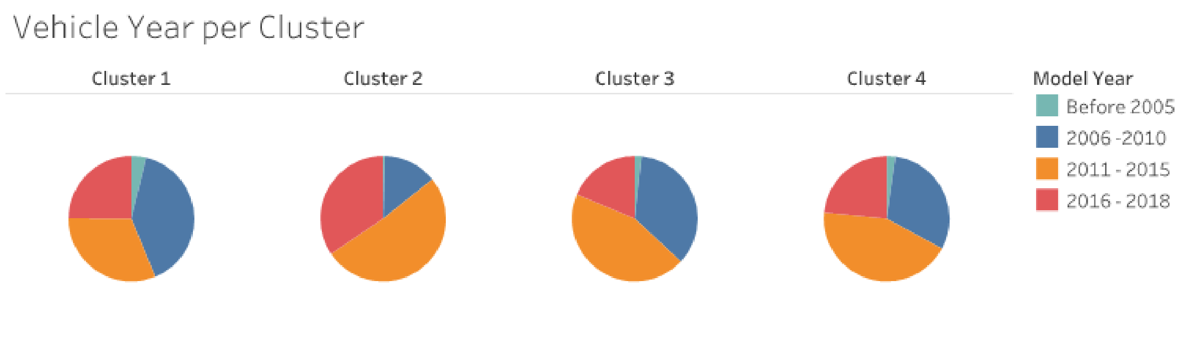
Graph 13: Cluster Visualization

<u>*Cluster distribution per division:*</u>

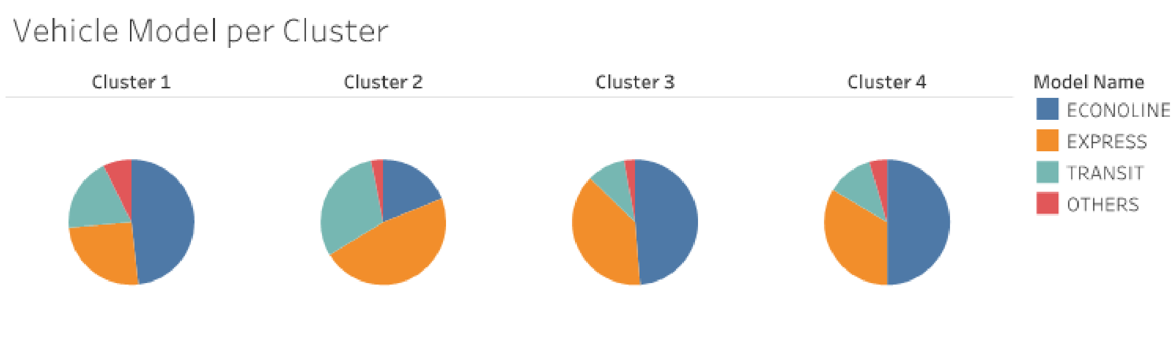
Cluster 1 makes up the largest proportion in both Central and West Divisions. The Northeast Division, by contrast, includes most of vehicles from Cluster 3.



Graph 14: Percentage of cluster per region



Graph 15: Vehicle Year Per Cluster



Graph 16: Vehicle Models Per Cluster

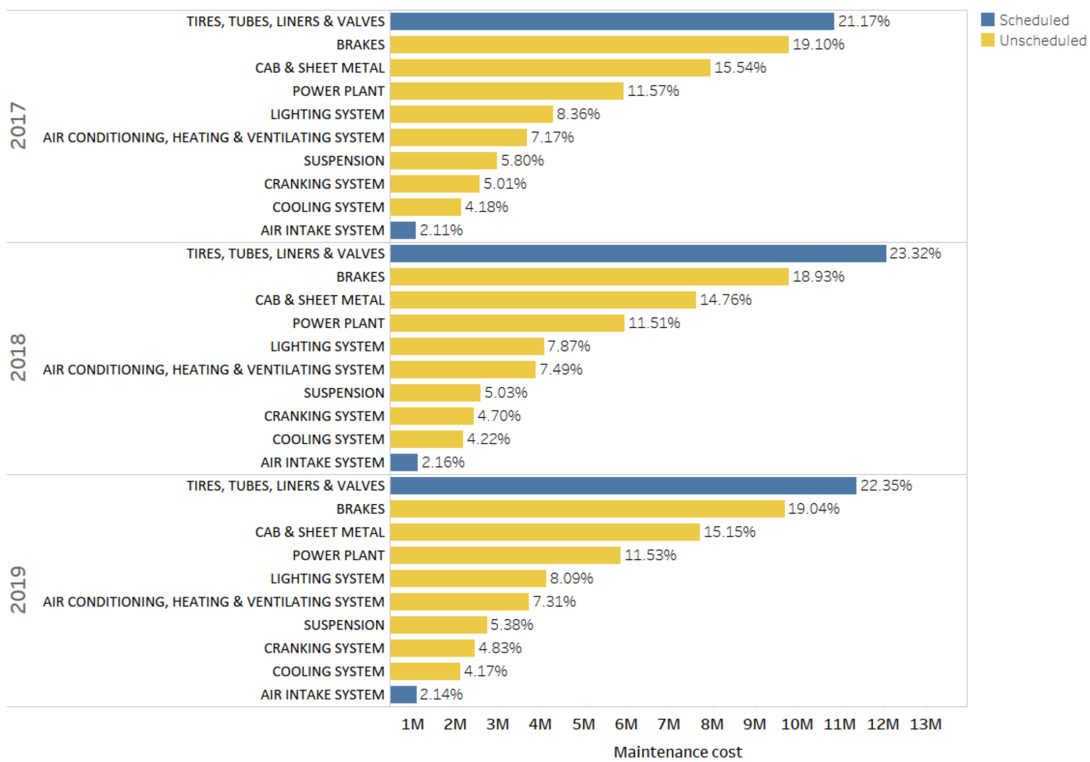
In terms of vehicle model and year, it was interesting to note that most of the Transit Vans, which are newer vehicles acquired with model year 2015 and later, fit in Cluster 2. In fact, the newer vehicles were more likely to be in Cluster 2 than in the other three clusters.

Maintenance Records

Maintenance data was collected from January 2017 to March 2019 and contained information on 39,057 vehicles. There were 2,463,863 records in total, of which 4,251 were removed because of unmatched date.

In the graphs below, we examine the maintenance cost by ATA code. There were 48 distinct ATA codes in the data, and the graphs represent the top 10 codes. The total maintenance cost, as well as the costs of the individual ATA code categories, were stable across the three years of data. (For 2019, a month-to-month comparison was conducted for January and March.)

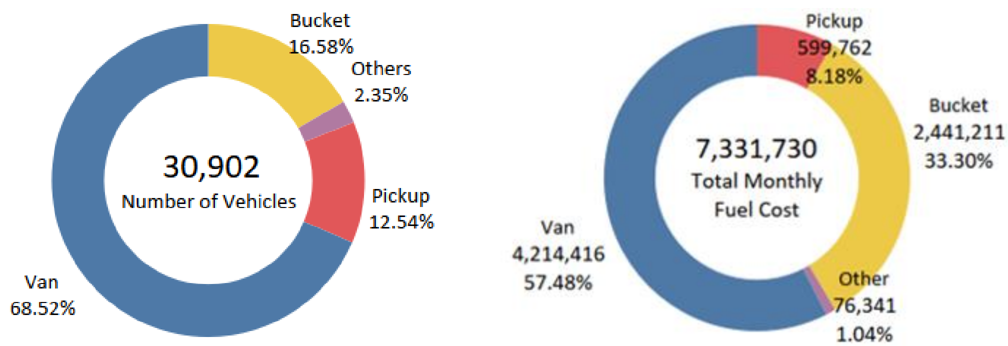
Currently, all maintenance activities of type "Tires, Tubes, Liners, Valves", "Lube, Oil", "Air Intake System", and "Transmission – Main, Manual" are scheduled, the rest of them are unscheduled. Data analysis shows that *only 17% of the total maintenance costs are due to scheduled maintenance*. With the help of telematics, early notification of problems would allow maintenance to be planned and scheduled properly, so systems are fixed before they break.



Graph 11: Maintenance Costs (as % of total) for top 10 ATA codes

Fuel Records

Fuel data was collected from November 2016 to April 2019 and contained information on 30,902 vehicles. *Nearly 69% of the vehicles were vans, with a total fuel cost of $126 million during this period. Only 16.58% vehicles were bucket trucks, but they represented $72 million dollars of fuel cost during the same period.* Monthly figures by vehicle types are depicted in the graphs below.



Graph 12: Percentage share of vehicles and monthly fuel cost by vehicle type

A better understanding of fuel consumption can help companies accurately forecast fuel costs. Moreover, idle time may also contribute to fuel consumption, and monitoring it as a KPI can help reduce these costs. Telematics can also help reduce those costs through greater route optimization, improved vehicle operation, and better fueling strategies.

Fuel Consumption and Fuel Cost Impacts of Idle Time Reduction

Argonne National Laboratories has published a journal article studying the fuel consumption impact of idling on various vehicle types (Reference 6). In the article, the authors state that the main determinants of idle time fuel consumption are (1) vehicle class by weight and type, (2) number of stops made each day, and (3) number of miles driven each day. For this study, we have chosen to use the data provided in the article for Multi-stop Vans, Service-Utility Trucks, and Other to represent the values we need for vans, bucket trucks, and pick-ups and other vehicles, respectively. (While the "Other" category is broad, fuel consumption values in the article for this category were conservative, so the calculations below will likely not overestimate the savings for these vehicles. Similarly, the authors state that their data represents idling periods of 30 minutes or more, and that idling with frequent shorter intervals will result in even higher fuel consumption.) The idle time fuel consumption data is reported as follows:

	Gallons / Idle Hour		
Miles Driven / Year	Multi-stop vans	Service – utility trucks	Pick-up and other
< 40,000	0.540	0.603	0.339
40-60,000	0.483	0.566	0.371
60-80,000	0.546	0.411	0.595
> 80,000	0.459	0.450	0.714

Idle Time Fuel Consumption by Vehicle Type and Miles Driven

Using these values, as well as the idle time and fuel consumption datasets provided by Comcast, the annual fuel cost savings per vehicle if the idle time goal is reached was calculated as follows:

$$\begin{pmatrix}\text{Daily Idle Hours}\\ \text{Reduction}\\ \text{to Reach Goal}\end{pmatrix} \text{ X } \begin{pmatrix}\text{Fuel Gallons}\\ \text{per Idle Hour}\end{pmatrix} \text{ X } \begin{pmatrix}\text{Fuel Price}\\ \text{per Gallon}\end{pmatrix} \text{ X } \begin{pmatrix}\text{Number of Days}\\ \text{Worked per Month}\end{pmatrix} \text{ X } 12$$

For example, a transit van with annual miles driven of 38,000, current average daily idle time of 45 minutes, average fuel price of \$3/gallon, 10 days of idle time data in May 2019 would yield

(45 – 30)/60 X (0.540) X (3) X (10) X (12) = \$48.60

in annual fuel cost savings. A similar van with current average daily idle time of 25 minutes would not yield any further savings because it is already meeting the idle time goal of 30 minutes per day.

Idle time and fuel consumption data that can be used in the above calculation was provided for 10,485 of the vehicles in the fleet. The current annual fuel cost for these vehicles is reported in the dataset as \$30,170,455. Using the above calculation, we estimate that the fuel cost savings due to idle time reduction is \$1,748,334. This means that *achieving idle time goals would yield a cost reduction of 5.8%.*

We estimate the fleet-wide savings by assuming that a 5.8% reduction can be achieved overall. The current annual fuel cost for the entire fleet is reported as \$87,980,756 in the dataset. *A 5.8% reduction in the fleet-wide fuel cost would yield annual savings of \$5,098,357.*

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