Document prepared by:

Efficacy of Blackburn Energy's RelGen®

Fuel Savings, Financial Benefits, and CO2 Emissions Reduction

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Background

About UMass Lowell ECRL & Blackburn Energy

The Energy & Combustion Research Laboratory at the University of Massachusetts Lowell is focused on developing solutions to the energy problems facing our world. Under the direction of Professor John Hunter Mack, they explore a variety of topics ranging from alternative fuels, novel thermodynamic cycles, and combustion-assisted material synthesis. Their research involves both experimental and computational approaches including machine learning, computational fluid dynamics, and chemical kinetics.

Blackburn Energy, Inc. is a leading provider of vehicle electrification solutions for commercial vehicles and fleets in North America, with more than 750K customer miles traveled, and over 220 metric tonnes of CO_2 sequestered. Blackburn's globally patented hybrid charging system, RelGen eliminates up to 100% of engine idle, provides clean power to reduce carbon dioxide emissions, and offers independent 48-volt closed loop power to electrify engine components and reduce fuel consumption. Strategically priced with a one-year return on investment, Blackburn increases fleet profitability by reducing operating costs and supporting driver retention while achieving sustainability goals. Blackburn Energy's RelGen was named one of the best innovations in trucking in 2019 by TMC – the Technology and Maintenance Council of the American Trucking Association. Blackburn Energy is headquartered in Amesbury, Massachusetts, and was founded in 2014.

www.blackburnenergy.com (800) 342-9194

Defining the Problem(s)

A discussion about why there is a lack of available electricity on commercial vehicles begins with distinguishing what an engine alternator was originally designed to do and what it was not designed to do. A vehicle electrical system is comprised of an energy converter (alternator), energy storage (batteries) and energy consumers (electric equipment). An engine alternator converts the rotational force of the engine into electricity when the engine is running to charge batteries that power electrical systems. Modern comfort and safety requirements result in a significant increase in the power demand in the vehicle electrical system. The output of today's alternators is less than the demand of electric equipment requiring batteries to supplement electrical power during vehicle operation.[1] In commercial vehicles, the engine alternator can also be connected to auxiliary batteries which are used to power electric accessories. The engine alternator, originally designed to replace the hand crank engine with an electric starter, is not able to keep up with the electric demands of modern trucking, especially vehicles with auxiliary batteries.

In the era of twentieth century trucking, internal combustion engine alternators efficiently charged the starter batteries that could power electrical components like clocks and radios in addition to the basic functions of the truck without much problem. However, as electric technologies evolved over the twenty-first century to make trucks more efficient, it became clear that a commercial vehicle's standard engine alternator and starter batteries were challenged to power the enormous electrical loads newer electric technologies like air conditioners, power liftgates etc. demanded. The heavy power draw from the starter batteries from these electrical accessories can often cause mechanical breakdowns and down trucks. This costs fleets expensive rescue and customer relations problems. To avoid costly and burdensome breakdowns, professional drivers often idle their engines to keep the engine alternator running to charge batteries. But this leads to other costly problems: excessive idling burns out engine alternators and wastes large amounts of fuel.

Many fleets understand that idling impacts their operational expenses and have invested in anti-idling systems to varying degrees of success over the years. But approximately 70% of all long-haul trucks have not yet switched to an electric APU precisely because even with a bigger engine alternator, it is often not efficient enough to charge an electric APU to 100%. [1] In turn, the driver will need to idle the engine at some point during his/her rest period to charge the sleeper cab AC anyway. These tradeoffs lead many fleets to conclude that investing in electric accessories is not worth their capital investment. Furthermore, instructing drivers not to idle their engines for things like air conditioning in their sleeper cabs leads to strenuous working conditions for drivers. The trucking industry has a driver turnover rate above 90% and it costs the average fleet about $11.5K to replace a driver.[2] Since fleets are keen to retain drivers, some prefer diesel air conditioners to keep the driver comfortable even though it costs more in fuel.

The lack of available electricity on commercial vehicles has resulted in an ongoing environmental disaster. According to the US Environmental Protection Agency, the transportation sector is responsible for the largest share of greenhouse gas emissions in the United States with gasoline and diesel comprising over 90 percent of the fuel for transportation.[3] The long-haul sleeper cab sector alone requires 1 billion extra gallons of diesel fuel each year to support idling for power, costing $3 Billion and emitting 11 million tonnes of CO_2. [4] In addition, according to the Federal Motor Carrier Safety Administration (FMCSA) there are 8,746,518 single-unit trucks (straight trucks) and 2,752,043 combination trucks (tractor-trailers) which are also often challenged to meet EPA anti-idling laws while making deliveries, particularly in the urban core.[5] Idling also adds to noise pollution, additional fuel waste and engine wear and tear for fleets. Unnecessary idling can amount to as much as 2000 gallons of fuel and 17 tonnes of carbon per truck per year. [6] Clearly, the patchwork of anti-idling laws and regulations in the United States has failed to reduce carbon emissions and failed to support the comfort and wellness of essential professional drivers living and working on the road.

To reach goals laid out in The Paris Agreement, global emissions must limit warming to 2 degrees Celsius compared to pre-industrial levels. While there continues to be advances in electric truck technology which reduces tailpipe CO_2 emissions but currently increases overall global CO_2 emissions, electric trucks will not reduce emissions at the scale and speed necessary. Therefore, a multipronged strategy is required. Most industry and academic analyses find that given the importance and intensity of trucking within the North American economy alone, diesel trucking will be part of the industry well into 2050. In a 2019 report, Columbia University's Center for Energy Policy writes "Even in decarbonization scenarios, diesel is likely to remain the predominant fuel for trucks through 2040. A transition to a very low diesel-fuel world appears unlikely before at least 2050." [7]

Meanwhile, original equipment manufacturers and truck manufacturers continue to develop new technologies that require even more electric power: electric trucks, autonomous trucks, platooning sensors etc. A perennial issue plaguing these developments is the lack of available electricity. RelGen, hybrid charging, solves the issue on four key fronts: it electrifies existing diesel engines, supports driver health and wellness, decarbonizes the trucking industry faster and more affordably than anything else and provides the necessary power for future tech to be developed.

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[1] The North American Freight Efficiency Council, 2014, *Confidence Report: Idle Reduction Technologies,* from: https://nacfe.org/downloads/confidence-report-idle-reduction

[2] Kingston, John, 2018, "Retention: The benefits, the costs and why drivers are switching jobs," from https://www.freightwaves.com/news/driver-issues/how-to-retain-truck-drivers.

[3] United States Environmental Protection Agency, n.d., *Sources of Greenhouse Gas Emissions,* from https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

[4] U.S. Department of Energy, 2015, *Long-Haul Truck Idling Burns Up Profits*, from: https://afdc.energy.gov/files/u/publication/hdv_idling_2015.pdf

[5] U.S. Federal Motor Carrier Safety Administration, 2018, *Pocket Guide to Large Truck and Bus Statistics,* from: Federal Motor Carrier Safety Administration Pocket Guide to Large Truck and Bus Statistics 2018 (dot.gov)

[6] Argonne National Laboratory, 2016, *Idling Reduction for Long Haul Trucks: An Economic Comparison of On-Board and Wayside Technologies*, from https://publications.anl.gov/anlpubs/2016/10/130502.pdf

[7] Columbia University Center for Global Energy Policy, 2019, *Prospects for Global Truck Electrification and Autonomy and New Delivery Models*, from: https://www.energypolicy.columbia.edu/research/global-energy-dialogue/prospects-global-truck-electrification-and-autonomy-and-new-delivery-models

RelGen: Hybrid Charging

RelGen takes the best of regenerative braking and kinetic energy recovery to invent an entirely new category within transportation: Hybrid Charging.

RelGen is a clean energy solution that is 100% made in the United States. It generates as much as 5x the amount of electric power currently available on a commercial vehicle. The system consists of a proprietary center bearing with a pulley connected to the inner race of the bearing. The pulley is made of high-grade bearing steel machined in a series of compound, contoured curves that flute out from the inner race to surround the driveshaft tube while maintaining a consistent air gap between the pulley and the driveshaft tube. No rebalancing of the shaft or any change to power train geometry is required. This design feature makes installation fast and easy.

The pulley is connected via a belt to a high-efficiency power unit. The entire system is mounted behind the truck's transmission which allows RelGen to leverage torque. RelGen's multiplication and higher revolutions per minute allows it to produce energy that is consistently 30% higher than the amount produced by a system not located behind the transmission or driven by the crankshaft on an engine. The pulley turns the alternator's rotor shaft, which spins a set of magnets around a coil to generate electricity, which is stored for later use in auxiliary batteries.

In the RelGen Kinetic Energy Recovery System (KERS) model, the unit is controlled electronically by an electronic control unit (ECU) and a proprietary algorithm. The ECU connects the vehicle's controller area network (CAN) to the internet via a telematics unit. ECU monitors the truck's CAN bus for braking and slowing events. When the ECU's algorithm identifies a braking or slowing event, it turns on the power unit and begins to use the rotational force of the drive shaft to make electricity. As soon as the driver reapplies the accelerator, the ECU shuts off the power unit, returning it to a free-spinning, no-resistance state. The power unit remains at the free-spin state until the next braking or coasting event.

RelGen KERS works on the millisecond level, capturing valuable data about the vehicle's performance and broadcasting it over a wireless communications network to a fleet owner's operations center. Blackburn Energy's proprietary algorithm monitors data from the vehicle and battery performance data that is tracked and reported in real-time to the driver and fleet operators. This information helps operators optimize fleet performance, improving operating efficiency and saves fleet owner's money.

Blackburn's RelGen is a globally patented innovative and durable system that outperforms the industry standard truck alternator by up to 5x and outperforms alternative improvements such as higher amperage alternators and added solar panels by multiples in speed and charge capability.

RelGen can be configured in multiple voltages in either closed-loop or fully integrated configuration. In a closed loop configuration, RelGen is connected to the auxiliary batteries with an independent ground isolated from the truck's 12-volt electrical system, allowing the addition of 48-volt engine components and appliances to existing 12-volt vehicles. 48-volt is generally accepted as the power source of the future, but the transition is difficult and has yet to be accomplished. RelGen breaks that barrier and leads the path towards higher fuel economy by replacing parasitic mechanical engine components, such as pumps and fans, with electric ones. The capacity of smaller passenger automobiles allowed engine electrification which has driven increases in fuel economy over the past several decades. Blackburn is continuing to drive the electrification revolution forward in commercial vehicles.

University of Massachusetts, ECRL
Research and Analysis Methodology

Blackburn Energy contracted the Energy & Combustion Research Laboratory because of their unique qualifications and capability to perform the data analysis and process validation. The work effort was broken into three tasks:

Task 1:	Data Collection Procedures
Summary:	ECRL consults with Blackburn Energy regarding relevant data to collect when RelGen is deployed on a vehicle
Deliverable:	Recommendations as to what metrics and parameters are necessary to validate potential greenhouse gas reductions.
Task 2:	Data Analysis
Summary:	Perform independent analysis of data collected on instrumented vehicles.
Deliverable:	A report detailing conclusions, including greenhouse gas reductions, changes in fuel economy, and other performance metrics.
Task 3:	Reporting
Summary:	The research team will report findings.
Deliverable:	A detailed formal end-of-project report summarizing all experimental findings.

Over the course of 2020 UMass Lowell ECRL assisted in designing the data requirements for conducting the analysis, created the analytical tool to review the data, analyzed the data, provided periodic reports, and delivered a final project report that includes their findings. Two types of vehicles were involved in the research, class 7 delivery trucks with liftgates that are often used in the urban core where RelGen was operated continuously, and on long-haul class 8 sleeper cabs where RelGen was programmed to run in "Hybrid Mode" (charging when braking and gliding).

Blackburn's installation team severed the connection between the power liftgate and the sleeper cab's auxiliary batteries from the engine alternator. RelGen was installed to be the sole charging source for liftgates and the sleeper cab hotel load. The drivers were unaware of this new configuration during the research project.

In both cases ECRL was able to calculate the impact of RelGen on engine idling, fuel saved, and CO_2 emissions. The data used for analysis was collected by a combination of sensors on the liftgate and APU battery banks and an ECU connected to the truck's CAN bus which logs engine data. The algorithm developed by ECRL uses the data collected to identify the total time that the truck spends driving, idling, off and when the liftgate is in use. For the long-haul trucks, ECRL uses data to identify the total time that the truck spends driving, idling, off and when the hotel load is in use.

The report summary provides an overview of a truck's total potential fuel savings for one year. Following that is the description of the test results and an overview of the methodology. This study was developed to provide information to our current customer fleet owners to show them their savings and for prospective fleet owners to help them to identify fuel savings opportunities that can be implemented and established with the addition of RelGen on their trucks. We are also using this study to demonstrate RelGen's decarbonization capabilities to government regulators and policymakers such as the Environmental Protection Agency and the Department of Energy to help the US achieve Paris Agreement goals as fast as possible while supporting fleet profitability.

UMass Lowell ECRL Study Summary

UMass Lowell ECRL's study shows that hybrid charging is a cost-effective and productive tool to solve three interconnected crises for the $1.32 trillion global commercial vehicle market: (1) the lack of available electric power on commercial vehicles without running the engine; (2) rising carbon emissions because of engine idling; and (3) limited use of efficient electric components and accessories for commercial trucks due to the electricity barrier.

The Energy & Combustion Research Laboratory (ECRL) at the University of Massachusetts Lowell certifies that the fuel and emissions savings from this product were as described in the report.

ECRL examined the data from 2 trucks with Blackburn Energy's RelGen® installed. The first use case was for a truck with a power liftgate. The second use case was for a long-haul sleeper cab. Both trucks were in service with their respective fleets and were used without regard to the presence of RelGen.

This study informs fleet owners about the actual performance of the technology as they might use it to show them their potential savings and to help them identify fuel savings opportunities that can be achieved with the addition of RelGen on their trucks. The report summary provides an overview of a truck's total potential fuel savings for one year. Following that is the description of the test results and an overview of the methodology.

Key People

Professor Hunter Mack, PhD., Principal Investigator
Department of Mechanical Engineering & Energy Engineering Graduate Program
Dr. Mack joined the Department of Mechanical Engineering at the University of Massachusetts Lowell as an Assistant Professor in the Fall of 2014. His research focuses on the development of tools to rapidly evaluate novel fuels for use in existing and next-generation engines, both in transportation and stationary applications. Additionally, he is interested in renewable energy applications with respect to energy storage (like Blackburn Energy). Before joining the faculty at UMass Lowell, Dr. Mack was a Lecturer and Project Scientist at the University of California at Berkeley, where he also received his doctoral degree. After his completion of his Ph.D., he held a post-doctoral research position at UC Berkeley and worked at a successful solar energy start-up before returning to academia. He additionally holds a B.A. in Physics from Hendrix College (Conway, Arkansas) and a B.S. in Mechanical Engineering from Washington University (St. Louis, Missouri).

Samuel Burns, Student Assistant
Department of Mechanical Engineering
Projects have included "Evaluation of Microclimate Cooling Garments" for Military applications through designing and creation of a testing apparatus to determine the performance of current vests for further improvement. Utilizing artificial neural networks, combustion theory, reaction kinetics and machine learning to develop computational models to predict specific properties of alternative fuels and to develop next-generation biofuels. And applying computational models to evaluate the efficacy of a hybrid charging system.

Use Case: Truck with Liftgate

Test Summary

Based on data from a full month of usage, the test proves that RelGen always produced enough power for liftgate operation without needing to engine idle. At the end of each working day, the state of charge for the liftgate batteries never fell below 80% for the duration of the study. A delivery truck equipped with a liftgate and RelGen Hybrid Charging as the sole power source for liftgate batteries can potentially save **1,268 gallons of diesel**, **12.9 tonnes of CO_2,** and **$3,868** in fuel per year. Since a basic RelGen unit costs $3K, this results in a return of investment (ROI) of less than one year. Fuel and Emissions test results are shown below in Table 1.

Table 1: Total Potential Savings with RelGen

	Total Potential Savings		
	Gal/Year	**Annual Savings**	Tonnes CO_2/Year
RelGen	1,268.42	**$3,868.69**	12.91

Purpose of Test

This test was conducted to determine (a) the efficacy of RelGen as the only charging source for the liftgate batteries and (b) the total savings that can be realized by eliminating 100 percent of engine idling during deliveries.

Test Vehicle and Equipment

The truck analyzed is a 2018 Kenworth T-370 and 40’ van trailer equipped with a Maxon BMR-55 liftgate, four liftgate four batteries and the RelGen Hybrid Charging system. The liftgate battery bank consists of two trailer-mounted liftgate batteries connected in parallel via a dual-pole stinger cable to two tractor-mounted batteries. All four liftgate batteries are charged and maintained solely by Blackburn Energy’s RelGen system.

The truck’s engine alternator is completely disconnected from the liftgate charging circuit. Therefore, the engine alternator is incapable of contributing to the recharge of the liftgate batteries; engine idling has zero effect on the charge of the liftgate batteries.

Test Conditions

In order to isolate the effectiveness of the RelGen Hybrid Charging unit, the installation team severed the connection between the liftgate batteries and the engine alternator. The RelGen Hybrid Charging system was installed to be the sole charging source for liftgate operations. The drivers were unaware of this new configuration during the research project ensuring that there was no change in driver behavior, driving habits, or routes taken. Therefore, the actual idle time is not relevant to the test since the auxiliary batteries are not connected to the engine alternator. Any idle time stopped during deliveries would not have improved the performance of the liftgate and therefore was not necessary.

Detailed Summary of Final Results

The script written by ECRL to analyze truck data was developed in MATLAB. The purpose of the script is to identify the total potential savings based on the time spent making deliveries.

To determine the total potential savings, the total time that the truck spent stopped at deliveries is interpreted as total potential idle time, from which the total potential savings is calculated. The total potential savings is the maximum amount of savings for this fleet if the driver idled 100% of the time while making deliveries.

To arrive at this metric, the data collected from the battery sensors and the engine was analyzed to determine the state of the truck at each 10 second interval, i.e., driving, idling, off and/or accessory in use.

The sequence of these states was then used to identify time when the truck is either making a delivery or driving.

The data collected to determine fuel savings includes battery voltage, battery current, engine percent torque, accelerator pedal position, wheel speed, GPS speed, GPS Dilution of Precision (DOP), and number of satellites.

Table 2 breaks down the total time that the truck is in use, where:

- **In-Transit** consists of **Driving** time and **In-Traffic Idle** time, and
- **Stopped for Delivery** consists of the total time the truck is stopped for deliveries.

Table 2: Breakdown of time the truck spent in use, either driving or out for delivery

	Truck In-Use	
	%	**Time (hrs)**
In Transit	29.16	43.50
Stopped for Delivery	70.84	**105.70**

Table 3 uses the following calculations to determine the total potential savings in fuel and CO_2 emissions associated with the maximum amount of idle time while making deliveries. **Total Potential Fuel Savings** is calculated using the DOE published value of 1 gallon burned per hour of idling[8]. **Total Potential CO_2 Savings** are calculated using the EPA published value of 0.01018 metric tonnes of CO_2/gallon of diesel burned[8]. **Total Potential Dollar Savings** is calculated using the average cost of fuel in the U.S. during 2019, the year in which the data was captured[10].

Total Potential Fuel Savings *= Hours Stopped for delivery * 1 gallon/idle-hour*

Total Potential CO_2 Savings *= Total Potential Fuel Savings * 0.01018 tonnes CO_2/gal*

Total Potential Dollar Savings *= Total Potential Fuel Savings * $3.05/g***Table 3:** Total savings that can be achieved from 100% engine idle elimination.

	Total Potential Savings	
	1 Month (actual)	**1 Year (projected)**
Total Potential Fuel Savings	105.70 gal	**1,268.42 gal**
Total Potential CO_2 Savings	1.08 tonnes	**12.91 tonnes**
Total Potential Dollar Savings	$322.39	**$3,868.69**

Note that these savings were calculated for the truck under test. Depending on driver practices, environmental conditions and routes taken, actual savings for other trucks equipped with RelGen may be more or less.

[8] U.S. Department of Energy, 2011, *Vehicle Technologies Market Report*, from https://info.ornl.gov/sites/publications/files/Pub34442.pdf
[8] EPA, n.d., *Greenhouse Gases Equivalencies – Calculations and References,* from https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references#diesel
[10] U.S. Energy Information Administration n.d., *Petroleum & Other Liquids*, from https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=pet&s=emd_epd2dxl0_pte_nus_dpg&f=a

Conclusion: Liftgate Use Case

This test proved that Blackburn Energy's Hybrid Charging technology, RelGen, could have saved this truck approximately 105.7 gallons of fuel, 1.08 metric tonnes of CO_2, and $322.39 in the month of July 2019.

The yearly projection based on the monthly findings show that this truck has the potential to save up to 1,268.42 gallons of fuel, 12.91 metric tonnes of CO_2 and $3,868.69.

Beyond fuel savings, reduced maintenance costs, reduced breakdowns and jump starts, increased liftgate runtime and increased deliveries per day are additional benefits fleets experience by adding RelGen to their trucks. 100% idle elimination on class 7 trucks has important implications for reducing air pollution and emissions.

Use Case: Long-Haul Tractor Trailer

Test Summary

Based on data from a full month of usage, the test proves that RelGen always produced enough power for hotel load without needing to engine idle. At the end of each working day, the state of charge for the APU batteries never fell below 80% for the duration of the study. A long-haul tractor-trailer truck equipped with an electrified air conditioning unit and RelGen Hybrid Charging as the sole charging source for auxiliary batteries can potentially save **2,900 gallons of diesel**, **29 tonnes of CO_2,** and **$8,846** in fuel per year. This results in a return on investment of less than one year. Please note that the cost of the electrified air conditioning unit varies, and in many cases may already be installed.

Fuel and Emissions test results are shown below in Table 4.

Table 4: Total Potential Savings with RelGen

	Total Potential Savings		
	Gal/Year	**Annual Savings**	Tonnes CO_2/Year
RelGen	2,900.47	**$8,846.44**	29.53

Purpose of Test

This test was conducted to determine (a) the efficacy of RelGen as the only charging source for the APU batteries and (b) the total savings that can be realized by eliminating 100 percent of engine idling during rest periods.

Test Vehicle and Equipment

The truck analyzed is a 2016 Mack Pinnacle equipped with a Bergstrom NITE SSI electrified air conditioning unit. The SSI is powered by four tractor-mounted auxiliary batteries connected in parallel. All four batteries are charged and maintained solely by Blackburn Energy's RelGen system, completely isolated from the starter batteries.

The truck's engine alternator is disconnected from the electric APU battery charging circuit. Therefore, the engine alternator is incapable of contributing to the recharge of the auxiliary batteries; engine idling has zero effect on the charge of the auxiliary batteries.

Test Conditions

In order to isolate the effectiveness of the RelGen Hybrid Charging unit, the installation team severed the connection between the electric APU batteries and the engine alternator. RelGen Hybrid Charging system was installed to be the sole charging source for the sleeper cab hotel load. The drivers were unaware of this new configuration during the research project ensuring that there was no change in driver behavior, driving habits, or routes taken. Therefore, the actual idle time is not relevant to the test since the auxiliary batteries are not connected to the engine alternator. Any overnight idle time would not have improved the performance of the electric APU and therefore was not necessary.

Detailed Summary of Results

The script written by ECRL to analyze truck data was developed in MATLAB. The purpose of the script is to identify the total potential and savings based on the time spent using the hotel load overnight.

To determine total potential savings, the total time that the truck spent overnight using the hotel load is interpreted as total potential idle time, from which the total potential savings is calculated. The total potential savings is the maximum amount of savings for this fleet if the driver idled 100% of the time while using the hotel load overnight.

To arrive at metric, the data collected from the battery sensors and the engine was analyzed to determine the state of the truck at each 10 second interval, i.e., driving, idling, off and/or accessory in use. The sequence of these states was then used to identify time when the truck is either using the hotel load overnight or driving.

The data collected to determine fuel savings includes battery voltage, battery current, engine percent torque, accelerator pedal position, wheel speed, GPS speed, GPS Dilution of Precision (DOP), and number of satellites. **Detailed methodology available upon request.**

Table 5 breaks down the total time that the truck is in use, where:

- **In-Transit** consists of **Driving** time and **In-Traffic Idle** time, and
- **Stopped Overnight** consists of the total time the truck is stopped with hotel load use.

Table 5: Breakdown of time the truck spent in use, either driving or stopped with hotel load use

	Truck In-Use	
	%	**Time (hrs)**
In Transit	51.27	254.35
Stopped Overnight	48.73	**241.71**

Table 6 uses the following calculations to determine the cost in fuel and CO_2 emissions associated with the maximum amount of idle time while using the hotel load overnight. **Total Potential Fuel Savings** is calculated using the DOE published value of 1 gallon burned per hour of idling[11]. **Total Potential CO_2 Savings** is calculated using the EPA published value of 0.01018 metric tonnes of CO_2/gallon of diesel burned[12]. **Total Potential Dollar Savings** is calculated using the average cost of fuel in the U.S. during 2019, the year in which the data was captured[13].

Total Potential Fuel Savings *= Hours Stopped Overnight * 1 gallon/idle-hour*

Total Potential CO_2 Savings *= Total Potential Fuel Savings * 0.01018 tonnes CO_2/gal*

Total Potential Fuel Savings *= Total Potential Fuel Savings * $3.05/gal*

Table 7 describes the **Total Potential Savings** – the total savings that is possible when using RelGen to power electric APUs and hotel loads.

Table 7: Total savings that can be realized if engine idling is 100% eliminated:

	Total Potential Savings	
	1 Month (actual)	**1 Year (projected)**
Total Potential Fuel Savings	241.71 gal	**2,900.47 gal**
Total PotentialCO_2 Savings	2.46 tonnes	**29.53 tonnes**
Total Potential Dollar Savings	$737.21	**$8,846.44**

Note that these savings were calculated for the truck under test. Depending on driver practices, environmental conditions and routes taken, actual savings for other trucks equipped with RelGen may be more or less.

[11] U.S. Department of Energy (2011) *Vehicle Technologies Market Report*, from https://info.ornl.gov/sites/publications/files/Pub34442.pdf

[12] EPA, n.d., *Greenhouse Gases Equivalencies – Calculations and References,* from https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references#diesel

[13] U.S. Energy Information Administration, n.d. *Petroleum & Other Liquids*, from https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=pet&s=emd_epd2dxl0_pte_nus_dpg&f=a

Conclusion: Long-Haul Tractor Trailer Use Case

This test proved that Blackburn Energy's Hybrid Charging Technology, RelGen, could have saved this truck approximately 241.71 gallons of fuel, 2.46 metric tonnes of CO_2, and $737.21 in the month of July 2020.

The yearly projection based on the monthly findings show that this truck has the potential to save up to 2,900.47 gallons of fuel, 29.53 metric tonnes of CO_2 and $8,846.44.

Beyond fuel savings, reduced maintenance costs, reduced breakdowns, increased runtime for electric APU's and other appliances, idle time warranty impact is eliminated, less DEF use, and potentially lower driver turnover are additional benefits fleets experience by adding RelGen to their trucks.

Furthermore, according to the EPA's statistics, 100% engine idle elimination on long haul trucks also serves to annually eliminate:

- 1 billion gallons of fuel consumption
- 11 million tonnes of carbon dioxide (CO_2)
- 180,000 tonnes of nitrogen oxides (NO_x)
- 5,000 tonnes of particulate matter (PM)[14]

[14] Environmental Protection Agency, n.d., *Learning About Idling Reduction Technologies (IRTs) for Trucks and School Buses*, from: https://www.epa.gov/verified-diesel-tech/learn-about-idling-reduction-technologies-irts-trucks-and-school-buses

UML ECRL: Raw Data Analysis and Methodology for Liftgate Truck with RelGen

Project:	**Efficacy Test for Variable Uses of Blackburn RelGen**
PI:	**Prof. John Hunter Mack**
Student:	**Samuel Burns**
Date:	**April 12, 2021**

1.0 Executive Summary

This report lays out the current work that has been performed for Blackburn Energy by the University of Massachusetts Lowell under the direction of the principal investigator (Prof. John Hunter Mack, Department of Mechanical Engineering).

Task:	Data analysis of new data provided
Summary:	Using MATLAB, the data received (LKnifeTruck71_2019.11.01-2019.11.30 - GPS.csv), was analyzed with the expanded upon methods utilized in past reports to deduce the truck status. The fuel and CO_2 saved/emitted were calculated for the liftgate truck.
Outcome(s):	Generated a plot depicting the current status of the truck at each time instance. Obtained the percentage and length of time for which the truck was in each status condition. Using the amount of time, the amount of fuel and CO_2 saved/emitted was deduced.

2.0 Approach

This report contains new additions that were added to the data analysis process that were not present in the original reports. The original process is detailed in section 2.1 with the additions detailed in 2.2. The most notable addition was adding new status conditions to better represent the idle and off conditions.

2.1 Approach from prior Reports with edits

For this section, the overall methodology remained consistent, the notable change was for the current limit check which was changed to -3 amps for the liftgate truck. This was changed from -2 amps and was done as in analyzing the data it was noticed that certain events were being misidentified. What follows is the original process with the modified current threshold.

To understand and analyze the provided data it was decided to look at what status the vehicle was in at each time instance. With an understanding of what the data in each column of the provided data set displayed three columns were utilized for determining the vehicle status:

B12_Actual_Engine_Percent_Torque (%),
B10_Wheel_Based_Vehicle_Speed(mph)
B07_Battery_Current(A).

The three chosen variables depicted if the engine was on/off, if the vehicle was in motion and if power was being drawn from the batteries (only the negative values for Battery Current were used to denote power draw as the positive displayed the batteries were charging via Blackburn Energy's alternator). These three variables were chosen to understand when the truck was idle and when power was being drawn. The ideal case is when power is being drawn while the engine is off thus indicating the truck is not idle.

All work for the data analysis was done using MATLAB code. The analysis was based on basic threshold values to determine which of seven potential statuses the truck was in at any moment in time. Five of the statuses are tied directly to truck operation while the remaining two are for error checking and removing invalid data. The thresholds set for the torque and speed were both zero while for current it was set to -3. For any situation where the speed was over zero, assuming there was no error or invalid data, the condition would be deemed as driving. The next check was if the accessory were being used, determined if the current were less than -3 it would indicate the accessory was being utilized. Last is to determine if the truck were off or idle, done by checking the torque where if torque were greater than zero the vehicle would be deemed idle else off.

With knowledge on when the vehicle was in each status condition, a plot was generated to represent the data. A mixture of stair plots and area plots were utilized to obtain a graphical representation of the time in which the vehicle was in each condition. As well pie charts were generated to better display the percentages within each status.

An additional aspect was added in the determination of the fuel saved/consumed and the CO_2 saved/emitted while within the Idle status with accessory usage. The calculations and values utilized to make the determination were obtained via the Code of Federal Regulations 40 CFR 600.114-12 - Vehicle-specific 5-cycle fuel economy and carbon-related exhaust emission calculations (September 2011) [1].

2.2 Expanded Methodology

With the data obtained through the process detailed in section 2.1, a secondary pass on the data was performed with new checks. The new checks served to check for specific patterns, and when a certain pattern appeared to make appropriate status adjustments. In addition, new statuses were utilized for this secondary check to better compare the results before and after the alterations.

New status conditions were created to generate a better representation of the final data after the secondary check process. The first status was called Unnecessary Idle which is the condition that is desired to occur as little as possible as the liftgate battery is charged solely with the Rel-Gen product, yet they are running idle. This condition corresponds to the original IdleAcc status. Another is the Eliminated Idle status; this is the condition that is sought to exist thanks to the usage of the Rel-Gen product, and it corresponds to the original OffAcc status. The last new status is labeled as In-Traffic Idle, which serves as the remaining instances when the truck is simply running idle with no accessory usage.

As new statuses are being utilized with the expanded checking, an initial status setting was performed for the new statuses. Any instance originally deemed as IdleAcc was also set to be the Unnecessary Idle condition, as these are the avoided cases. Similarly, any original instance of OffAcc was also set to Eliminated Idle, as these are targeted conditions.

The first set of checks were labeled as Pre-Idle with accessory usage and Pre-Off with accessory. In these instances, the pattern of being in the Idle/Off status before the IdleAcc/OffAcc was checked. This pattern exists right after a truck stops to start the delivery process. When this pattern was found, and so long as the time duration of the Idle/Off event was under a threshold of one hour. This was done to capture the entire delivery time while using the liftgate and not just instances solely where the accessory is used. Any cases which met the conditions had the duration of the Idle/Off status swapped to the Unnecessary Idle/Eliminated Idle cases, respectively.

Similarly, a second of pattern checks serve to check the statuses when the delivery has completed, and the driver is headed out. This case checks two patterns. The first being when an IdleAcc event is followed by an Idle event than a driving event. The second is when an OffAcc event is followed by an Off event than an Idle or driving event. For these cases when the Idle/Off component is under the same threshold of one hour, then the component is swapped to the Unnecessary Idle/Eliminated Idle cases, respectively.

The last check is based on the amount of time permitted to run idle in several states. Based on the Compendium of Idling Regulations, an average idle time of 5.546875 minutes is allowed [2]. Thus, for any instance where an idling event exceeded this time, the duration which exceeded the limit was set to Unnecessary Idle.

With the checks and any instances swapped, a last pass was performed to classify any other remaining conditions into the newly created statuses. Thus, any case in which the vehicle was deemed Idle and not Unnecessary Idle, it was set to the status of In-traffic Idle. Likewise, any instance of the vehicle being Off and not in Eliminated Idle would be classified within the status of Inactive as nothing is occurring.

3.0 Results

Utilizing the generated data detailed in section 2.0, Table 1 was compiled. Data was derived from "LKnifeTruck71_2019.11.01-2019.11.30 - GPS.csv " which contained data for 30 days (11/01/19 – 11/30/19).

Table 1. Cumulative Results after performing Secondary Checks on the Data

Truck In-Use	%	Time (hrs.)
In Transit	29.16	43.49985056
Stopped for Delivery	70.84	105.7020167

Stopped for Delivery	%	Time (hrs.)
Unnecessary Idle	71.21	75.26923639
Eliminated Ide	28.79	30.43278028

Unnecessary Idle Cost - 1 month	
Fuel Consumed (Gal)	75.26923639
CO2 Emitted (tonnes)	0.766240826
Dollars Spent	$ 229.57

Eliminated Idle Savings - 1 month	
Fuel Saved (Gal)	30.43278028
CO2 Saved (tonnes)	0.309805703
Dollars Saved	$ 92.82

Unnecessary Idle Cost Projections - 1 year	
Fuel Consumed (Gal)	903.2308367
CO2 Emitted (tonnes)	9.194889917
Cost Projections	$ 2754.85

Eliminated Idle Savings Projections - 1 year	
Fuel Saved (Gal)	365.1933633
CO2 Saved (tonnes)	3.717668439
Savings Projection	$ 1113.84

Total Potential Fuel Savings (Gal) -1 year	1268.4242
Total Potential CO2 Savings – 1 year	12.91 tonnes
Total Potential Savings - 1 year	$ 3868.69

*10,180 grams CO_2 / gallon [1], $1*10^6$ g = 1 tonne

** $ 3.05/ gallon of Diesel in the U.S. in 2019 [3]

Table 1 presents the culminated results from the process detailed in section 2.0. The first portion labeled Truck In-Use details two sets of statuses. The condition of In-Transit makes up the statuses of Driving and In-Traffic Idle while the Stopped for Delivery condition is made up of the Unnecessary Idle and Eliminated Idle conditions. The results present a percentage and the total time in each condition, where the percentage is the amount of time spent in each respective condition for the total time the truck was in use.

An important piece to note is that for the RelGen system, the battery used for the liftgate is solely charged by the product. As such idling is not needed for the liftgate operation. As well, the combination of the unnecessary idle and eliminated idle conditions sum to the total savings from RelGen as both have the liftgate being used from power generated by the product.

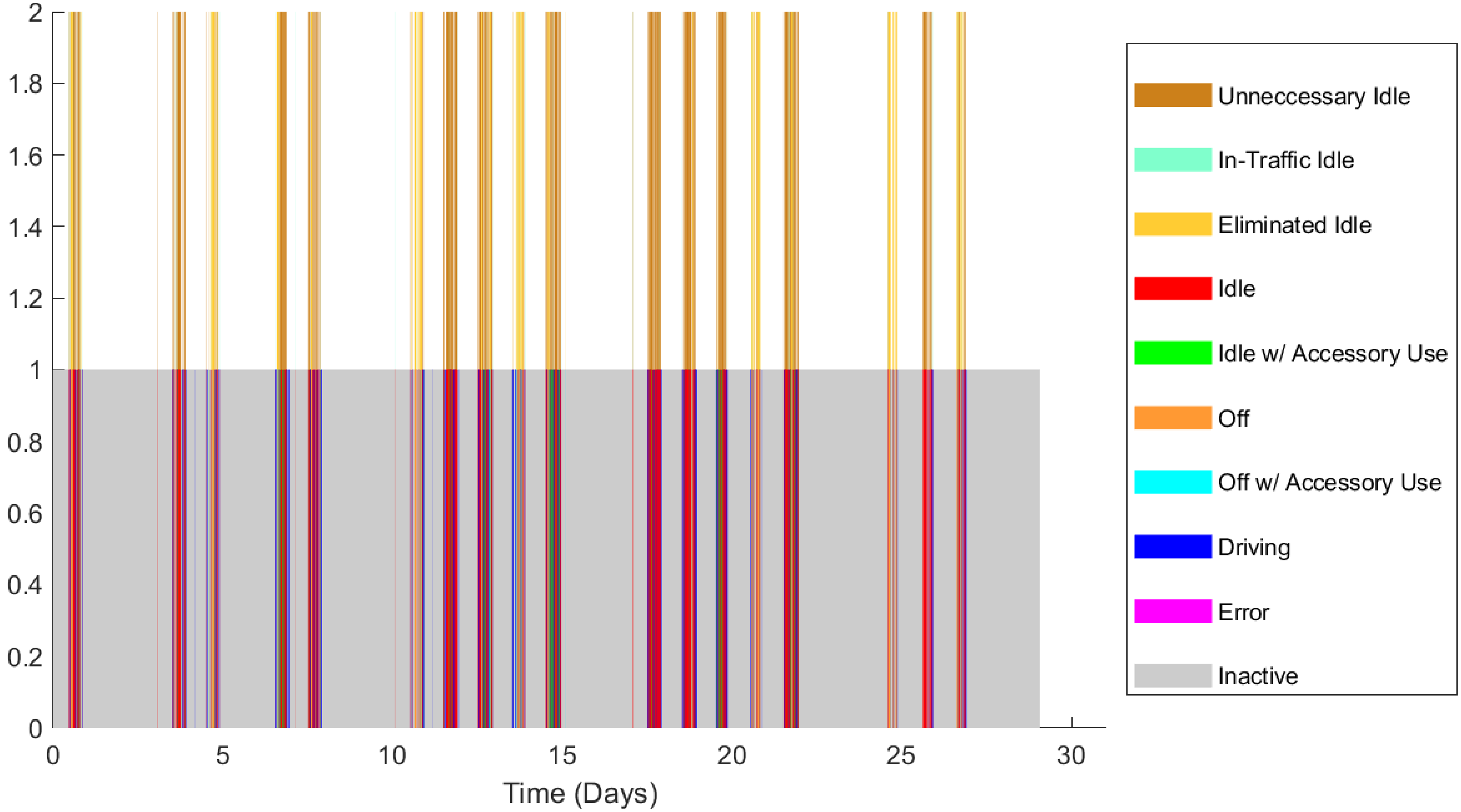
From the initial portion, the Stopped for Delivery condition is expanded to present a breakdown of the Unnecessary Idle and Eliminated Idle conditions. The respective time spent in each condition and the percentage as a function of the total amount of time within the Stopped for Delivery condition is displayed as well. In this case, the Unnecessary Idle condition is seeking to be minimized while the Eliminated Idle wants to be maximized through the usage of the Rel-Gen product.

The subsequent table components break out the Fuel consumed/saved, CO_2 emitted/saved and Dollars Spent/Saved between the Unnecessary Idle and Eliminated Idle statuses respectively for the duration of the data set (approximately one month). The fuel consumed/saved was calculated by the conversion of 1 gallon per hour idle. The units presented for the CO_2 saved/emitted are in tonnes of CO_2 acquired by two conversion factors: 10,180 grams CO_2 / gallon [1] and $1*10^6$ g = 1 tonne. The dollars spent/saved was determined by obtaining the average cost of diesel in the United States during the time of operation for this dataset. Based on the values found the amount of fuel and CO_2 saved was less than what was emitted/used while in the respective states, however, the values are relatively close to counteracting the impact of the other

With the results from the data set for the month, the results were extrapolated up to a year timeframe to provide projected Costs and Savings.

The last component of the table displays the net savings for fuel, $CO_{2,}$ and money based on the yearly projected costs and savings. These were obtained by adding consumed/emitted/spent value from the respective saved value. These values are added together to calculate the total potential savings from the usage of RelGen.
Figures 1-12, presented below, display the graphical representation (odd Figures) and pie charts (even Figures) for the truck statuses. Figures 1 and 2 cover the total dataset period while the subsequent figures are one week within the overall set to provide finer detail.

Figure 1. Truck Status for Entire Time range (11/01/2019 – 11/30/2019)



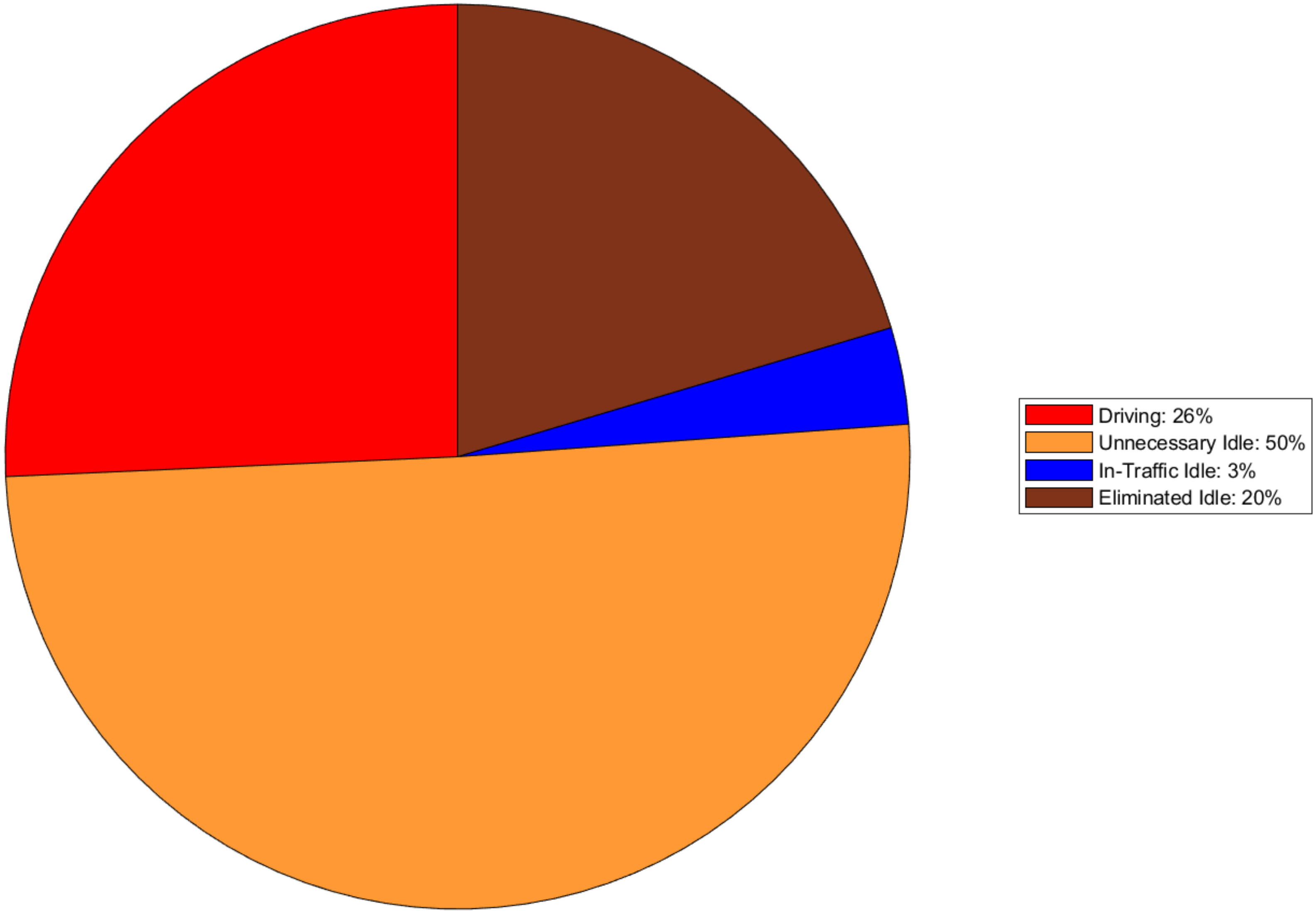
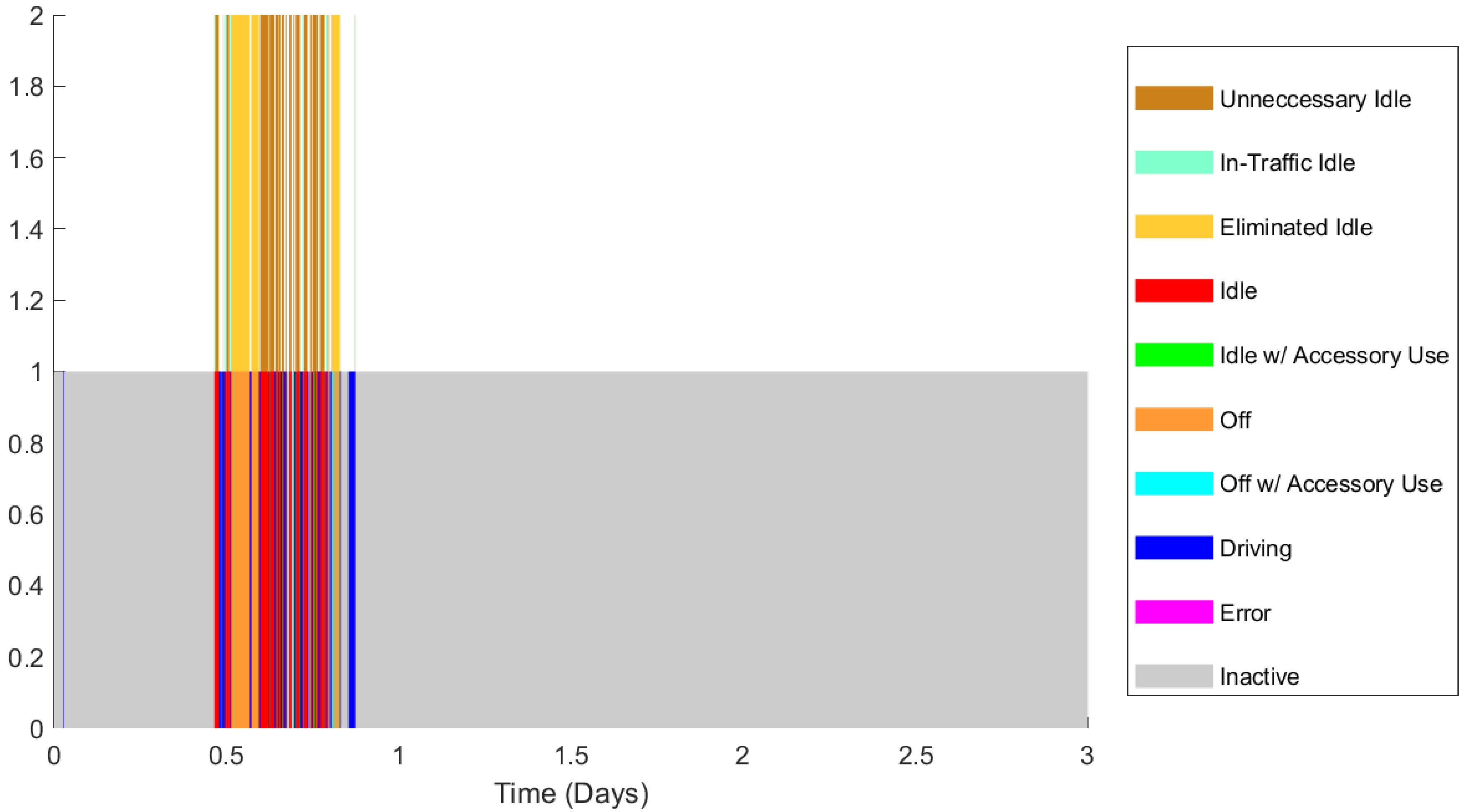


Figure 2. Pie Chart of Truck Status for Entire Time range (11/01/2019 – 11/30/2019)

Figure 3. Truck Status for Week 1 (11/01/19 - 11/03/19)



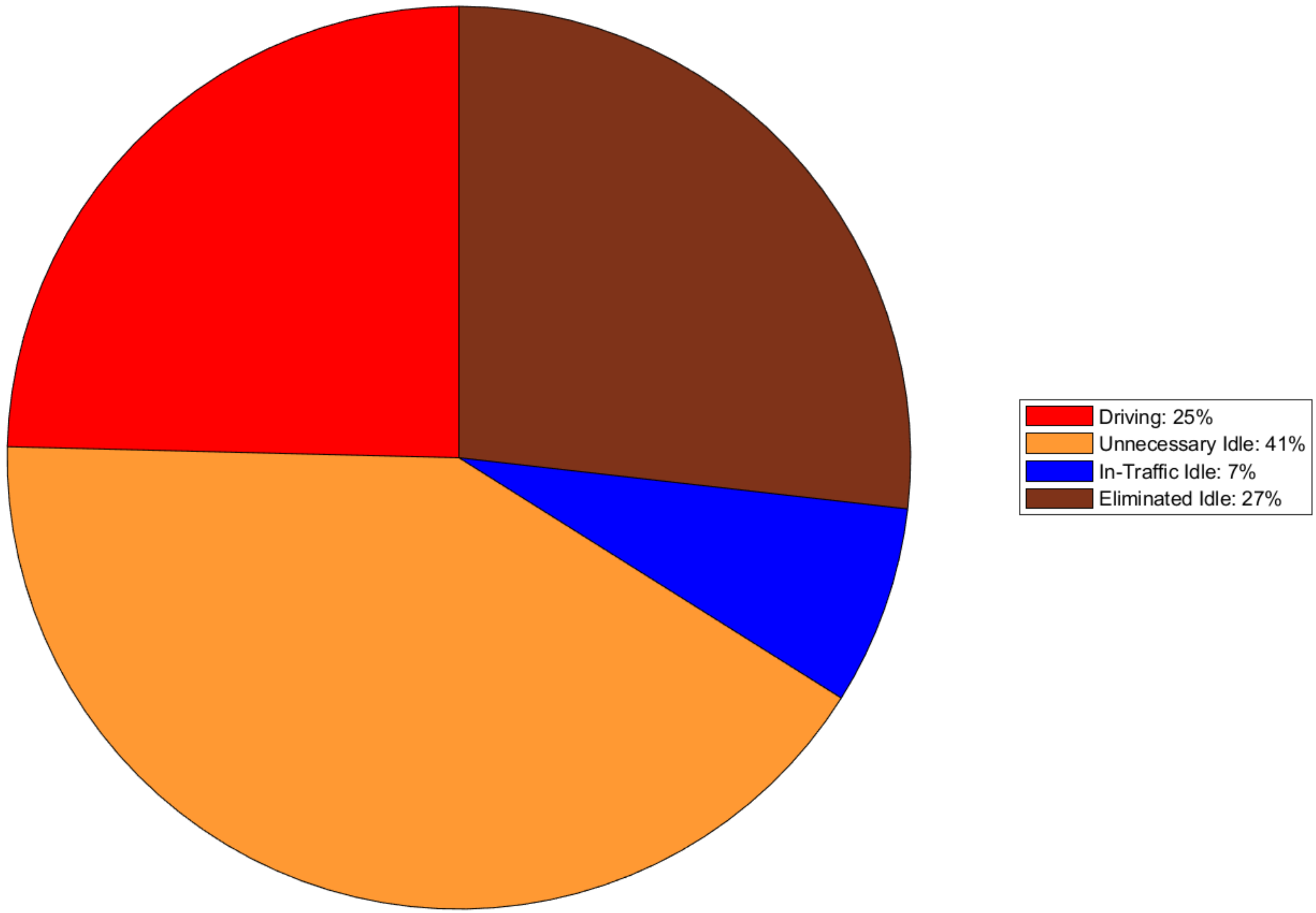
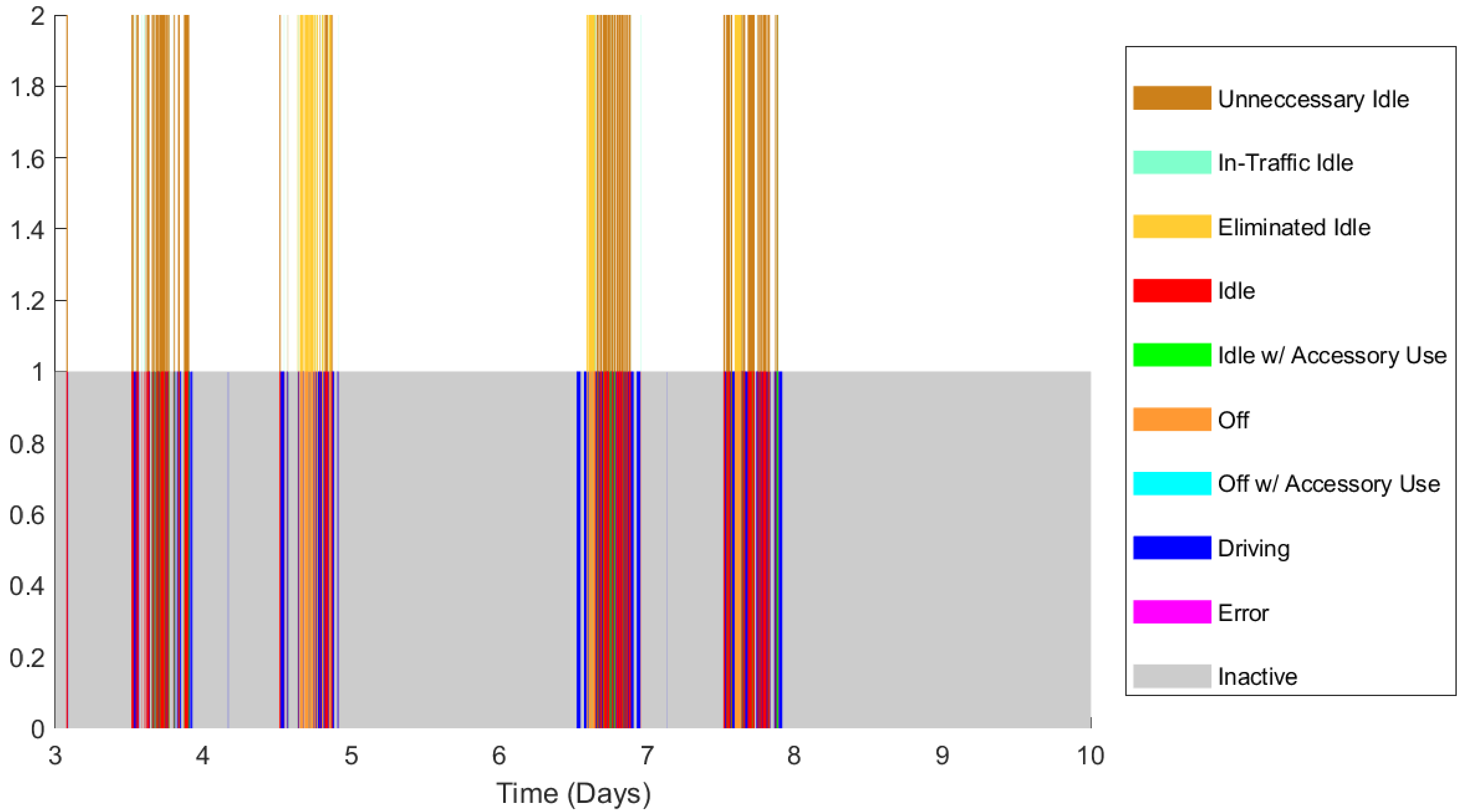


Figure 4. Pie Chart of Truck Status for Week 1 (11/01/19 – 11/03/19)

Figure 5. Truck Status for Week 2 (11/03/19 – 11/10/19)



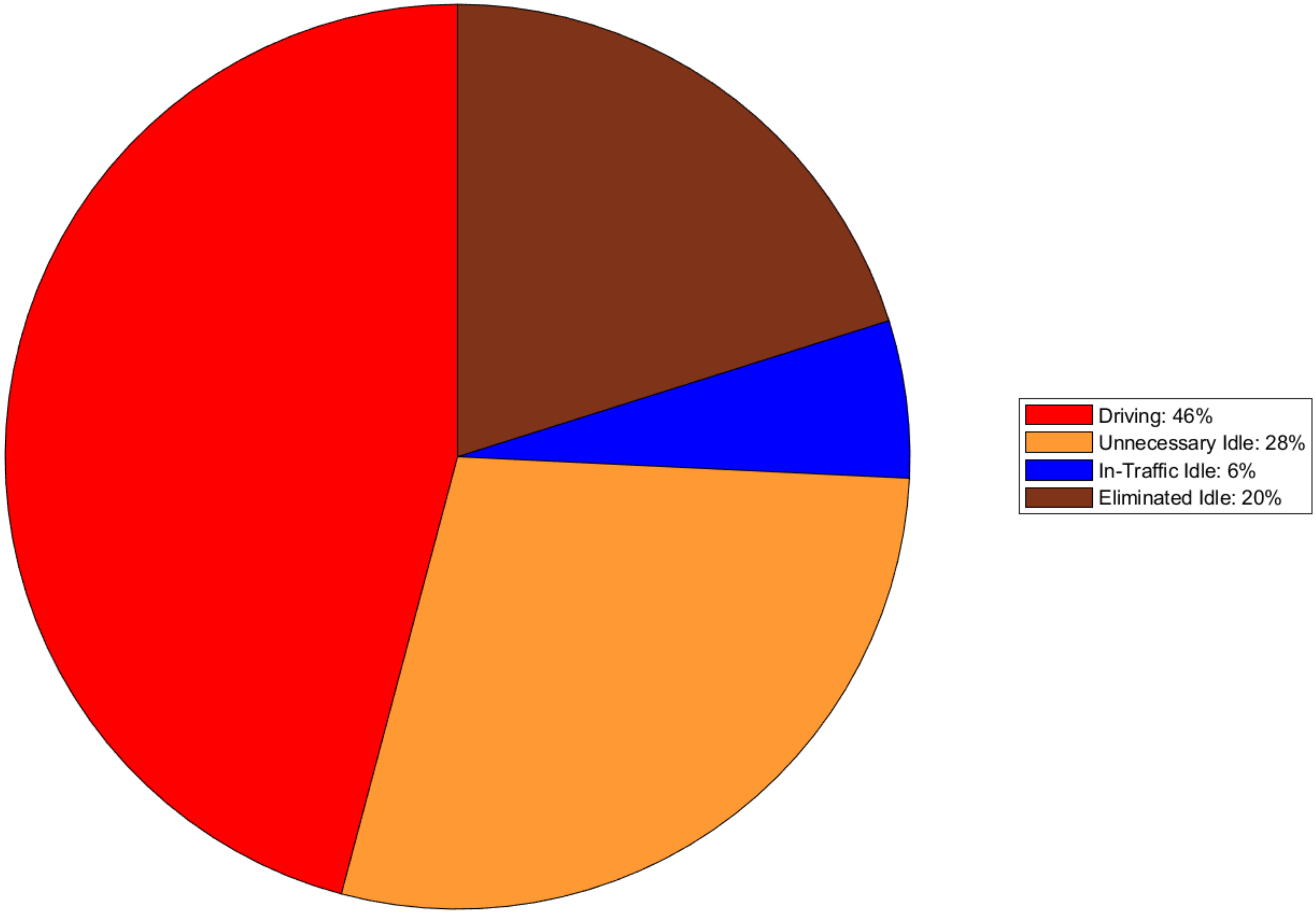
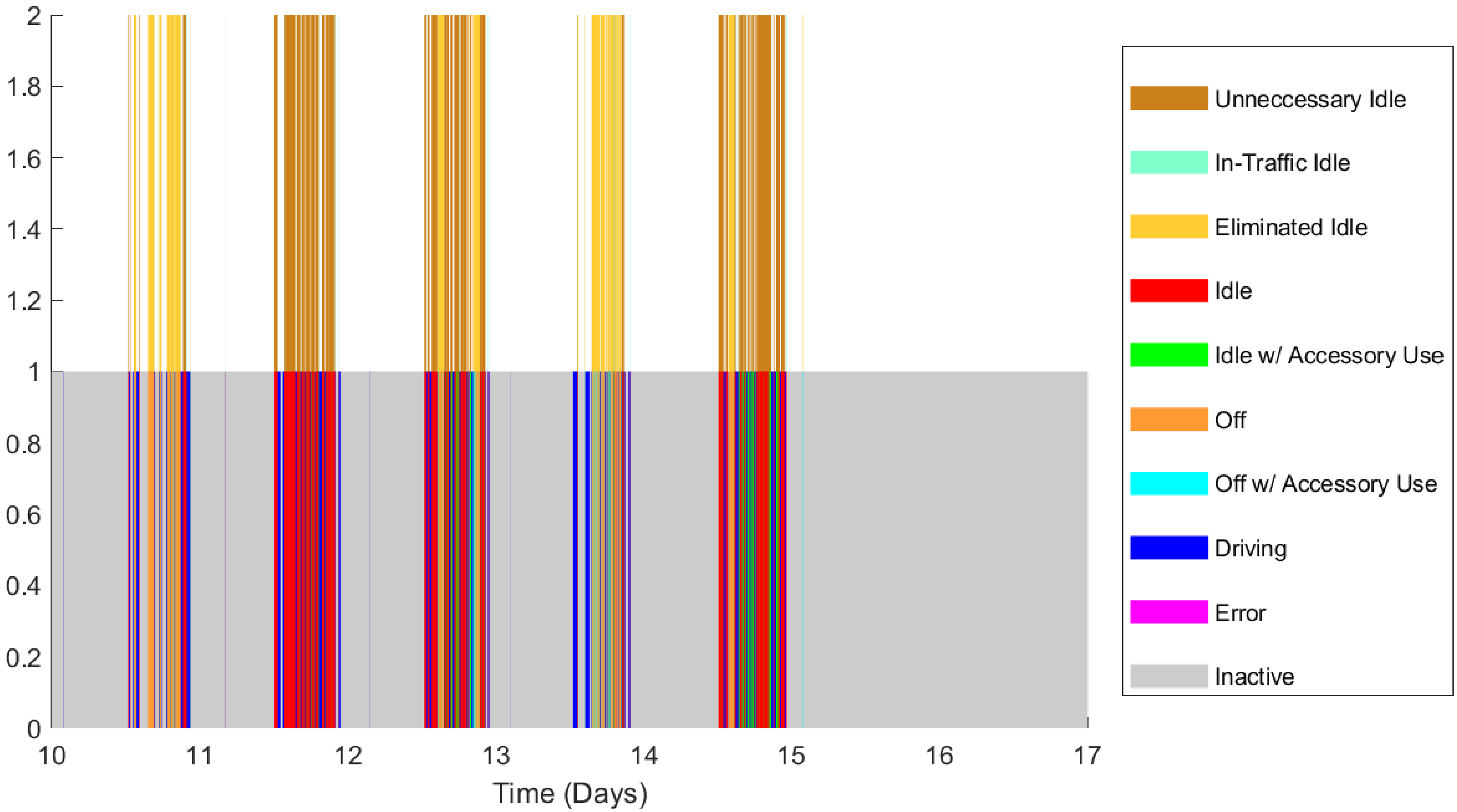


Figure 6. Pie Chart of Truck Status for Week 2 (11/03/19 – 11/10/19)

Figure 7. Truck Status for Week 3 (11/10/19 – 11/17/19)



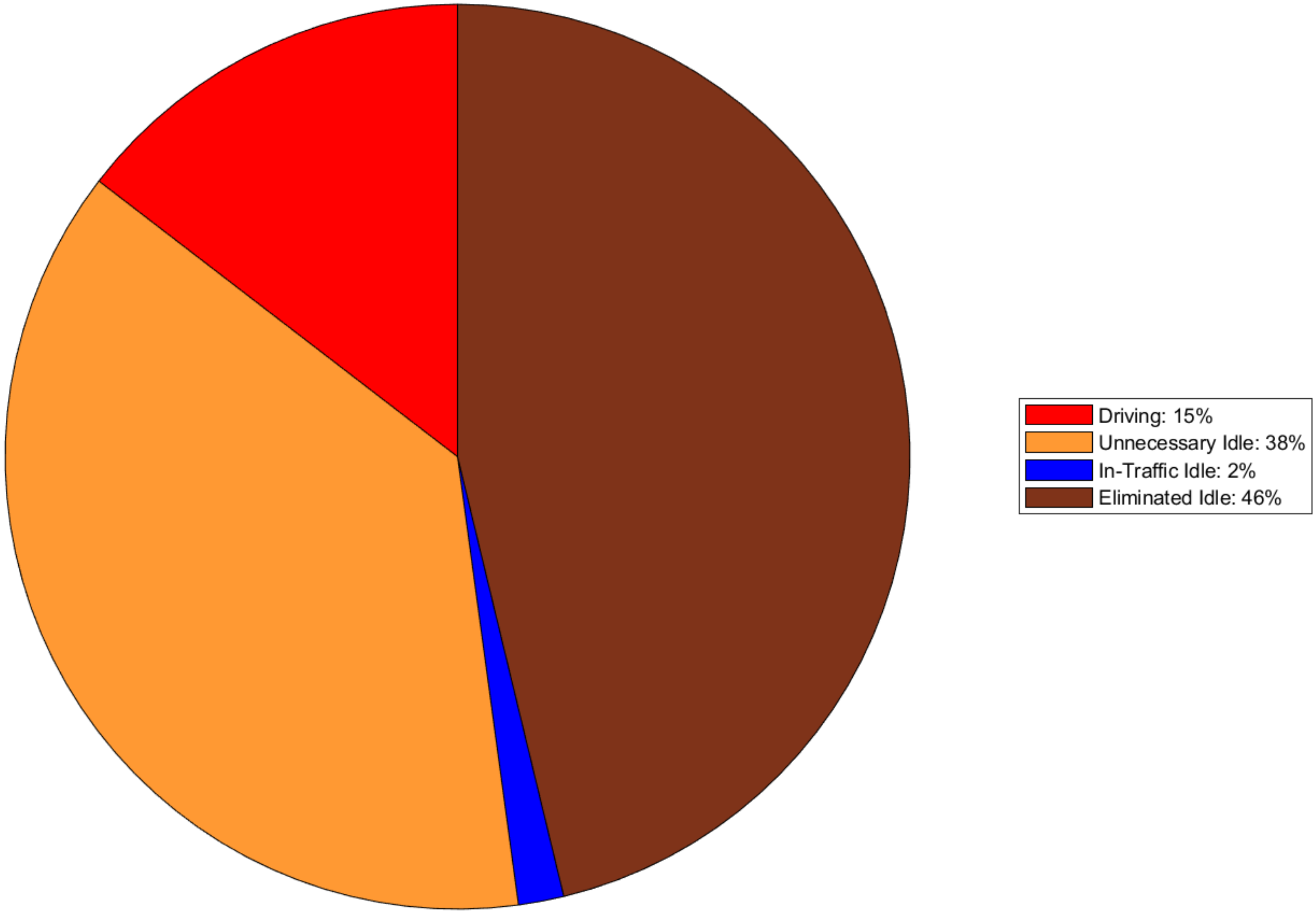
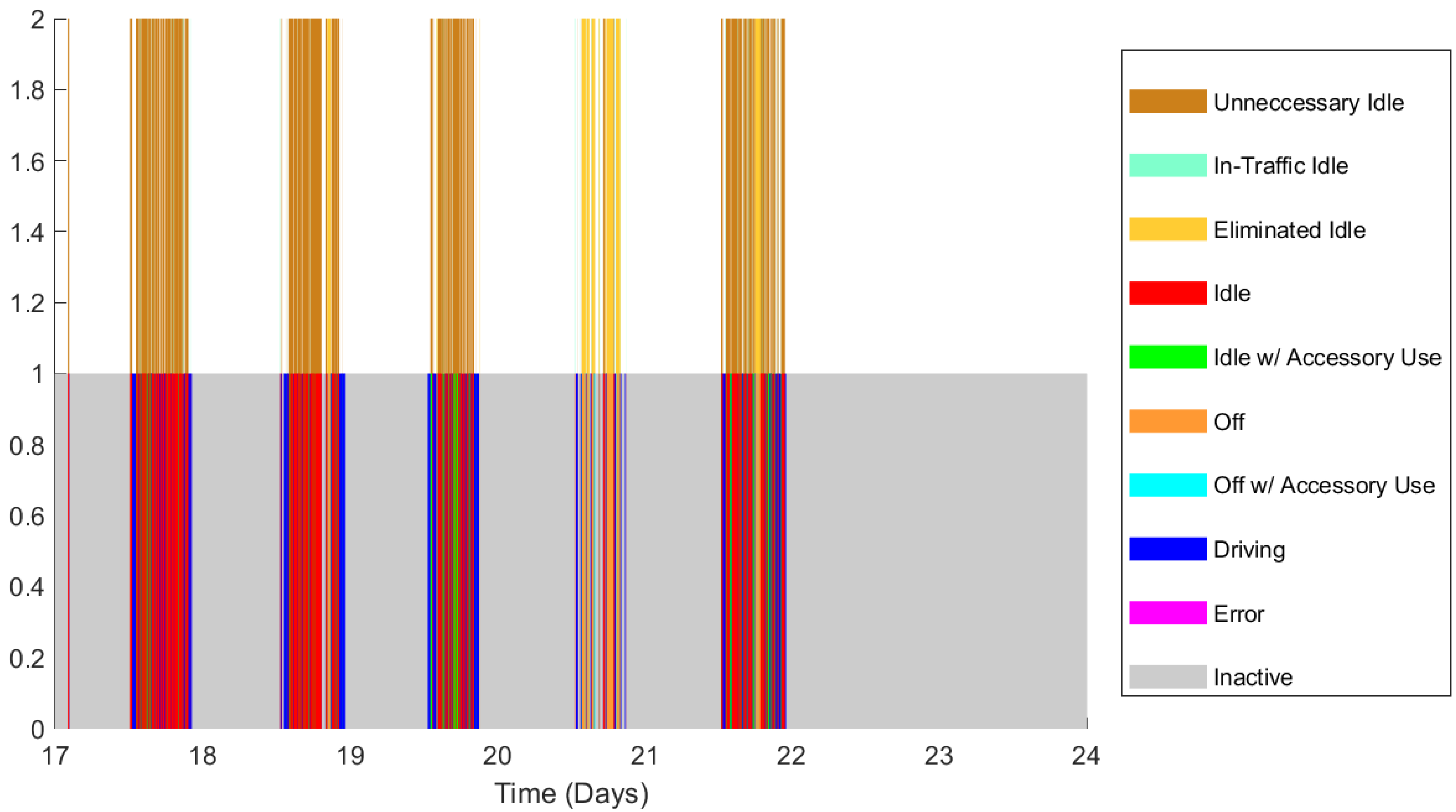


Figure 8. Pie Chart of Truck Status for Week 3 (11/10/19 – 11/17/19)

Figure 9. Truck Status for Week 4 (11/17/19 – 11/24/19)



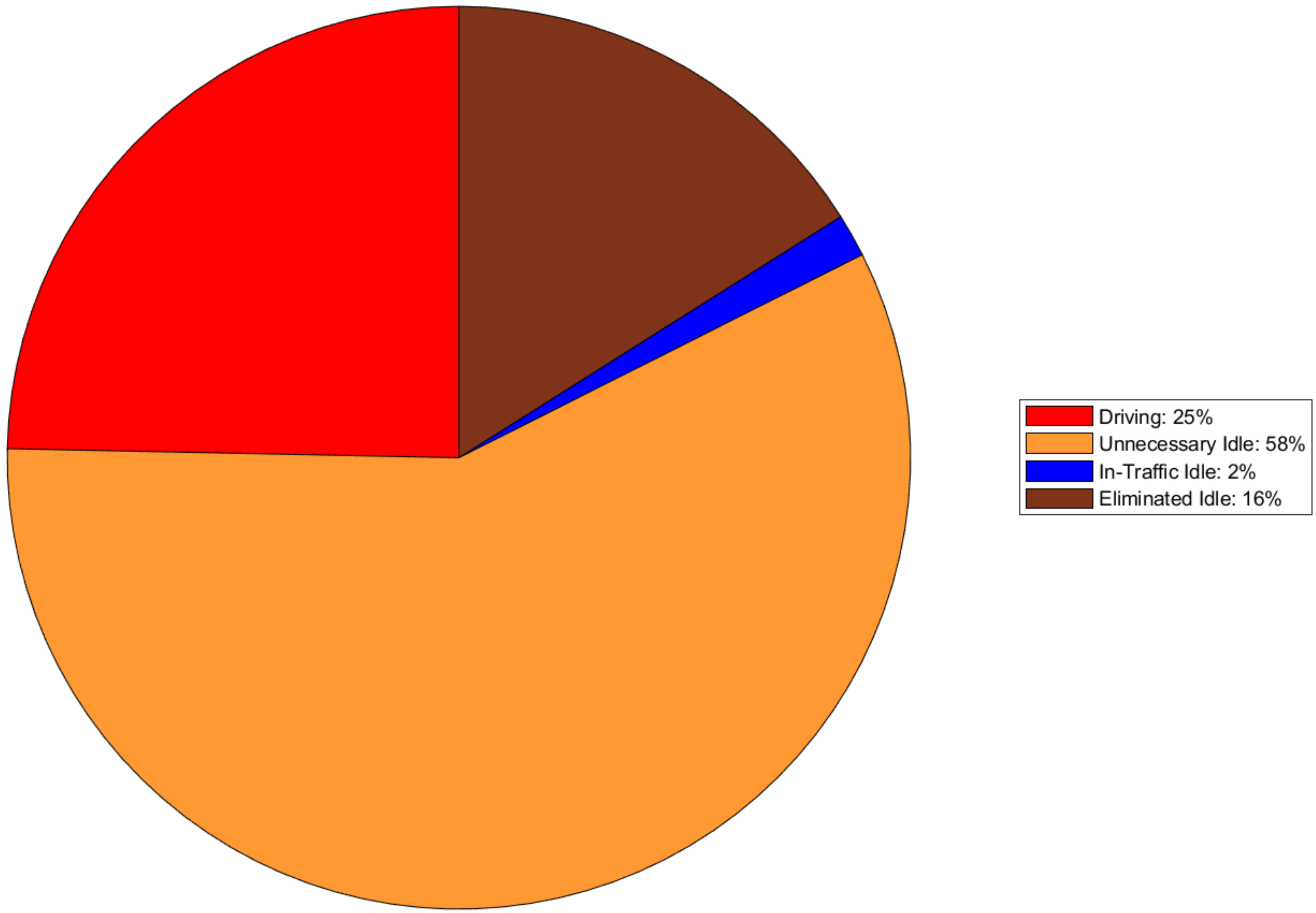
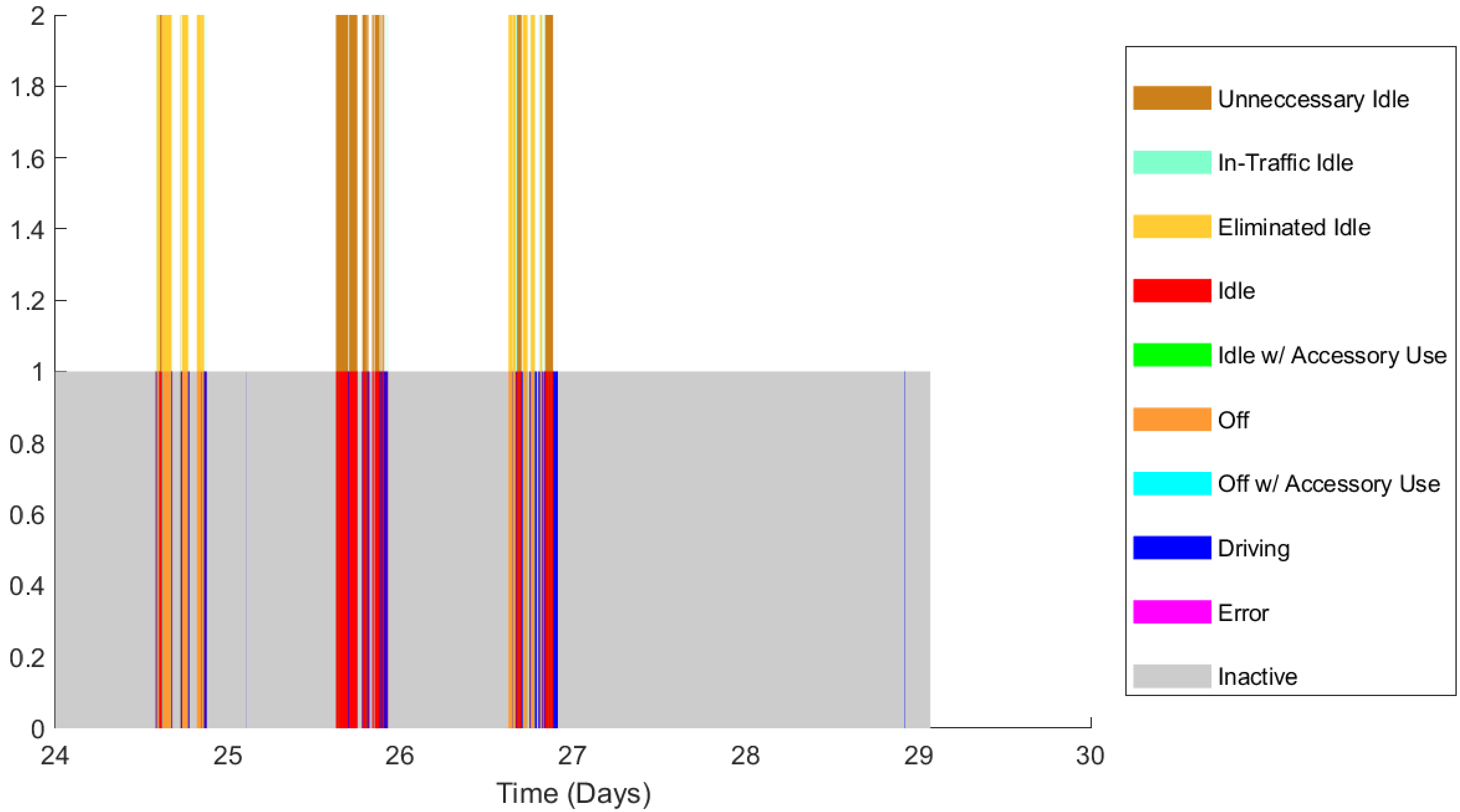


Figure 10. Pie Chart of Truck Status for Week 3 (11/17/19 – 11/24/19)

Figure 11. Truck Status for Week 5 (11/24/19 – 11/30/19)



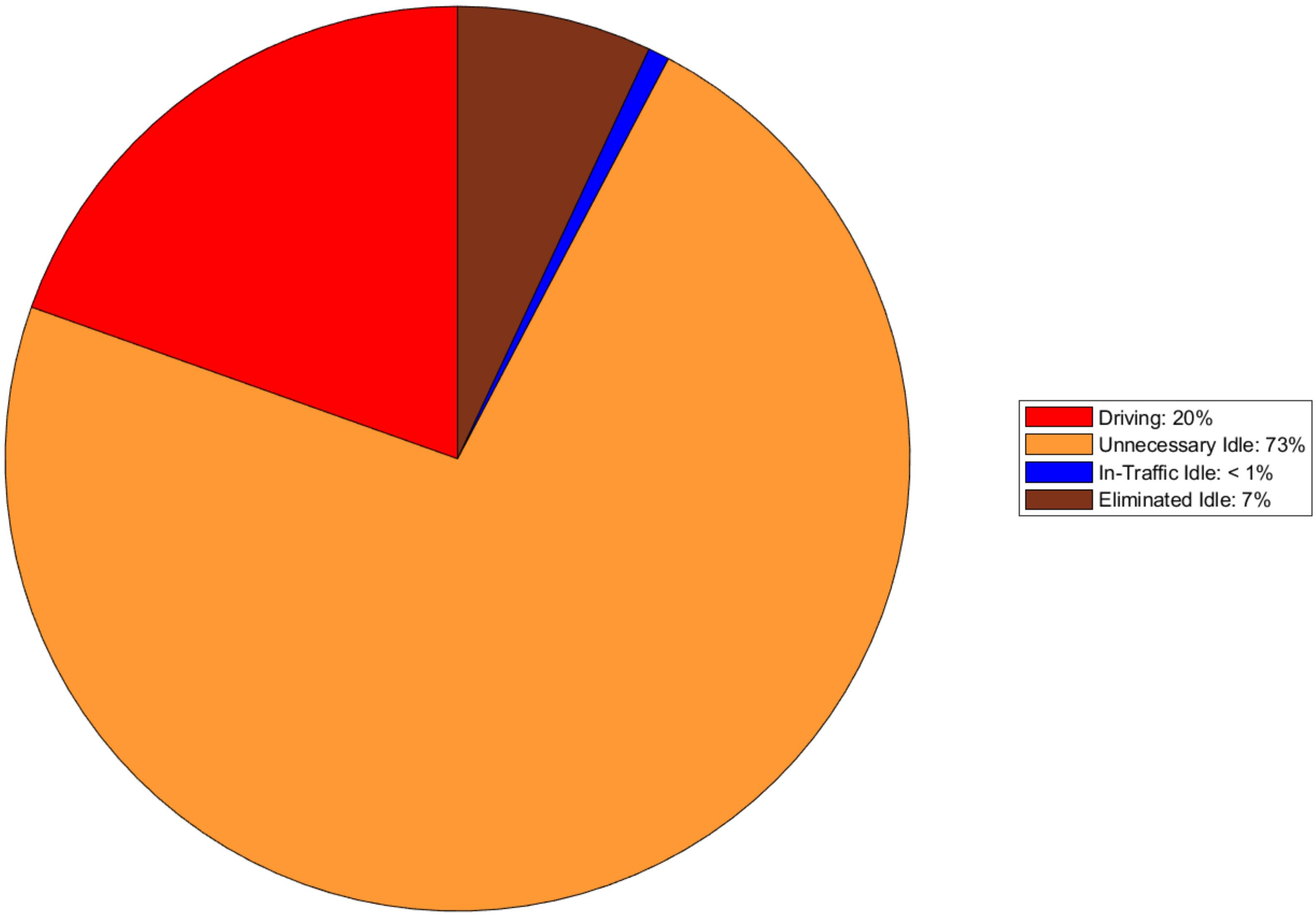


Figure 12. Pie Chart of Truck Status for Week 5 (11/24/19 – 11/30/19)

5.0 Summary

From the analysis of the dataset, "LKnifeTruck71_2019.11.01-2019.11.30 - GPS.csv", the truck was found to operate in the undesirable status of Unnecessary Idle more than the target condition of Eliminated Idle. Indicating that when the liftgate was in use, on average the engine was running Idle. As the battery used for the liftgate operation is being solely charged by the RelGen product any idling while using the accessory should be able to be prevented or mitigated. The script created in MATLAB allows for the data file to be imported and generate the presented plots.

As seen in all prior reports gaps in data exist, classified as Inactive time. This inactive time is caused by the control module shutting off after 3 hours of the engine is off. With the modifications implemented, Inactive was also classified as instances in which the vehicle was off with no actions being taken.

The results found that RelGen allowed the driver to operate the liftgate while not Idle for some time. This enabled approximately 365.19 Gal per year of fuel to be saved overall and prevented approximately 3.72 tonne CO_2 per year from being released. Overall, with the power generated by RelGen a total potential savings of 1268 Gal per year, 12.91 tonnes of CO_2 and $3868.69 per year could be saved if idling were prevented while operating the liftgate.

6.0 References

[1] Vehicle-specific 5-cycle fuel economy and carbon-related exhaust emission calculations, 40 CFR 600.114-12 (2011).

[2] COMPENDIUM OF IDLING REGULATIONS. (2020, March). Retrieved from https://truckingresearch.org/wp-content/uploads/2020/06/2020-ATRI-IdlingCompendium-March.pdf.

[3] Gasoline and Diesel Fuel Update - U.S. Energy Information Administration (EIA). (2020, August 17). Retrieved August 21, 2020, from https://www.eia.gov/petroleum/gasdiesel/

UML ECRL: Raw Data Analysis and Methodology for Sleeper Cab with RelGen

Project: Efficacy Test for Variable Uses of Blackburn RelGen
PI: Prof. John Hunter Mack
Student: Samuel Burns
Date: April 12, 2021

3.0 Executive Summary

This report lays out the current work that has been performed for Blackburn Energy by the University of Massachusetts Lowell under the direction of the principal investigator (Prof. John Hunter Mack, Department of Mechanical Engineering).

Task: Data analysis of new data provided

Summary: Using MATLAB, the data received (NTSTruck373_2020.07.01-2020.07.31 – GPS.csv), was analyzed with the expanded upon methods utilized in past reports to deduce the truck status. The truck detailed utilized RelGen for the sleeper cab/APU, for heating and cooling needs. Due to certain variables being unavailable in this dataset workarounds were added to produce similar results regardless of methodology. The fuel and CO_2 saved/emitted were calculated for the truck.

Outcome(s): Produced two workaround techniques in the event of the speed variable being unavailable for analysis. Generated a plot depicting the status of the truck at each time instance. Obtained the percentage and length of time for which the truck was in each status condition. Using the amount of time, the amount of fuel and CO_2 saved/emitted was deduced.

4.0 Approach

This report contains new additions that were added into the data analysis process that were not present in the original reports. Within this dataset, the B10_Wheel_Based_Vehicle_Speed(mph) variable does not exist, as such a workaround was introduced in the prior reports and had slight alterations in this revision. The original methodology is detailed in section 2.1 and the additional workaround is detailed in section 2.2 with the newly added elements. Lastly, section 2.3 contains details of the additional checks performed after the initial pass on the data.

2.1 Approach from Original Reports with edits

To understand and analyze the provided data it was decided to look at what status the vehicle was in at each time instance. With an understanding of what the data in each column of the provided data set displayed three columns were utilized for determining the vehicle status:

B12_Actual_Engine_Percent_Torque (%),
B10_Wheel_Based_Vehicle_Speed(mph)
B07_Battery_Current(A).

The three chosen variables depicted if the engine was on/off, if the vehicle was in motion and if power was being drawn from the batteries (only the negative values for Battery Current were used to denote power draw as the positive displayed the batteries were charging via Blackburn Energy's alternator). These three variables were chosen to understand when the truck was idle and when power was being drawn. The ideal case is when power is being drawn while the engine is off thus indicating the truck is not idle.

All work for the data analysis was done using MATLAB code. The analysis was based on basic threshold values to determine which of seven potential statuses the truck was in at any moment in time. Five of the statuses are tied directly to truck operation while the remaining two are for error checking and removing invalid data. The thresholds set for the torque and speed were both zero while for current it was set to -2. For any situation where the speed was over zero, assuming there was no error or invalid data, the condition would be deemed as driving. The next check was if the accessory were being used, determined if the current were less than -2 it would indicate the accessory was being utilized. Last is to determine if the truck were off or idle, done by checking the torque where if torque were greater than zero the vehicle would be deemed idle else off.

With knowledge on when the vehicle was in each status condition, a plot was generated to represent the data. A mixture of stair plots and area plots were utilized to obtain a graphical representation of the time in which the vehicle was in each condition. As well pie charts were generated to better display the percentages within each status.

An additional aspect was added in the determination of the fuel saved/consumed and the CO_2 saved/emitted while within the Idle status with accessory usage. The calculations and values utilized to make the determination were obtained via the Code of Federal Regulations 40 CFR 600.114-12 - Vehicle-specific 5-cycle fuel economy and carbon-related exhaust emission calculations (September 2011) [1].

2.2 Workaround utilized when lacking the Speed variable

To accommodate not possessing the B10_Wheel_Based_Vehicle_Speed(mph) variable two workarounds were generated. Two workarounds were produced to attempt and future proof the code should other data not be available. Regardless of what data is available, in the current model both the Torque and Current variables are required for every model utilized to determine the states. Likewise, error checks for variables with error codes were implemented for the speed, torque, and pedal position variables.

2.2-A Workaround 1: GPS data

The first check is using GPS data. Several new variables were utilized:

GPS Speed(km/h)
GPSValid(bool)
B11_Accel_Pedal_Position (%)
B06_Battery_Voltage(V)
NumSatellites(ct)
HDOP (ct)
PDOP (ct)
VDOP (ct)

The key variable is GPS Speed(km/h) which is being used as an alternative to the B10_Wheel_Based_Vehicle_Speed(mph) variable. In conjunction with the GPS Speed, the NumSatellites(ct) is used as well. These two variables are checked together with a few varying bounding conditions. The conditions are shown in Table 1. Various conditions were checked as when fewer satellites were observed, the data was far more erratic and less accurate. Thus, combining and checking the variables together produced more accurate results.

Table 1. Bounding conditions for GPS Speed(km/h) and NumSatellites(ct)

Condition	GPS Speed(km/h)	NumSatellites (ct)
1	<= 1	>= 7
2	<= 2	= 6
3	<= 3	= 5

This new method uses GPS which does not always function some checks were put into place to ensure the validity. GPSValid(bool) is a simple check that notes if it is recording valid numbers.

Next was to ensure the GPS data was accurate. This was done by checking the DOP (Dilution of Precision) using the HDOP, VDOP, and PDOP variables. The margin for DOP was set to under 5 as values under that are within a good accuracy rating. Each of the variables was checked for being less than 5 if they were than the GPS data was deemed valid.

Lastly, as an additional check, three other variables were checked which help in indicating when driving versus other statuses. B11_Accel_Pedal_Position (%) provides how much the accelerator is being pressed, anything over zero is an indication of driving. B06_Battery_Voltage(V) which should be under 13.8 while not charging, and thus not driving. The last variable checked in this workaround was the Current. In this current check, an upper bound on the current is assigned, being zero amps (0 amps), in checking the statuses. The original check assigns a lower current bound of -2 amps, with this adding an upper limit in assigning statuses.

2.2-B Workaround 2: No Speed variable or GPS data

In the event neither speed nor GPS data is available the last resort would be to utilize three variables presented in the last section:

B11_Accel_Pedal_Position (%)
B06_Battery_Voltage(V)
B07_Battery_Current(A).

These variables are utilized in the same manner as the last section as together they provide a means to identify the events enough, but with less accuracy given the limited amount of data.

With the addition of the NumSatellites(ct) variable in workaround 1, this variable was also added to this workaround version. In events where NumSatellites was < 5, the GPS was still valid, and the DOP was checked as well. This was added for events where the number of satellites was too few to produce accurate results.

2.3 Expanded Methodology

With the data obtained through the process detailed in sections 2.1 and 2.2, a secondary pass on the data was performed with new checks. The new checks served to check for specific patterns, and when a certain pattern appeared to make appropriate status adjustments. Also, new statuses were utilized for this secondary check to better compare the results before and after the alterations.

New status conditions were created to generate a better representation of the final data after the secondary check process. The first status was called Unnecessary Idle which is the condition that is desired to occur as little as possible as the sleeper cab battery is charges solely with the Rel-Gen product, yet they are running idle. This condition corresponds to the original IdleAcc status. Another is the Eliminated Idle status; this is the condition that is sought to exist thanks to the usage of the Rel-Gen product, and it corresponds to the original OffAcc status. The last new status is labeled as In-Traffic Idle, which serves as the remaining instances when the truck is simply running idle with no accessory usage.

As new statuses are being utilized with the expanded checking, an initial status setting was performed for the new statuses. Any instance originally deemed as IdleAcc was also set to be the Unnecessary Idle condition, as these are the avoided cases. Similarly, any original instance of OffAcc was also set to Eliminated Idle, as these are targeted conditions.

The first set of checks were labeled as Pre-Idle with accessory usage and Pre-Off with accessory. In these instances, the pattern of being in the Idle/Off status before the IdleAcc/OffAcc was checked. This pattern exists right after a truck stops to start the delivery process. When this pattern was found, and so long as the time duration of the Idle/Off event was under a threshold of two hours. This was done to capture the entire delivery time while using the sleeper cab/APU and not just instances solely where the accessory is used. Any cases which met the conditions had the duration of the Idle/Off status swapped to the Unnecessary Idle/Eliminated Idle cases, respectively.

Similarly, a second of pattern checks serve to check the statuses when the delivery has completed, and the driver is headed out. This case checks two patterns. The first being when an IdleAcc event is followed by an Idle event than a driving event. The second is when an OffAcc event is followed by an Off event than an Idle or driving event. For these cases when the Idle/Off component is under the same threshold of two hours, then the component is swapped to the Unnecessary Idle/Eliminated Idle cases, respectively.

The last check is based on the amount of time permitted to run idle in several states. Based on the Compendium of Idling Regulations, an average idle time of 5.546875 minutes is allowed [2]. Thus, for any instance where an idling event exceeded this time, the duration which exceeded the limit was set to Unnecessary Idle.

With the checks and any instances swapped, a last pass was performed to classify any other remaining conditions into the newly created statuses. Thus, any case in which the vehicle was deemed Idle and not Unnecessary Idle, it was set to the status of In-traffic Idle. Likewise, any instance of the vehicle being Off and not in Eliminated Idle would be classified within the status of Inactive as nothing is occurring.

3.0 Results

Utilizing the generated data detailed in section 2.0, Table 2 was compiled. Data was derived from "NTSTruck373_2020.07.01-2020.07.31 – GPS.csv" which contained data for 31 days (7/01/20 –7/31/20).

Table 2. Cumulative Results after performing Secondary Checks on the Data

Truck In-Use	**%**	**Time (hrs.)**
In Transit	51.27	254.3541442
Stopped & In-Use	48.73	241.7059278

Stopped Overnight	**%**	**Time (hrs.)**
Unnecessary Idle	68.69	166.0255733
Eliminated Ide	31.31	75.68035444

Unnecessary Idle Cost - 1 month	
Fuel Consumed (Gal)	166.0255733
CO2 Emitted (tonnes)	1.690140337
Dollars Spent	$ 506.38

Eliminated Idle Savings - 1 month	
Fuel Saved (Gal)	75.68035444
CO2 Saved (tonnes)	0.770426008
Dollars Saved	$ 230.83

Unnecessary Idle Cost Projections - 1 year	
Fuel Consumed (Gal)	1992.30688
CO2 Emitted (tonnes)	20.28168404
Cost Projections	$ 6076.54

Eliminated Idle Savings Projections - 1 year	
Fuel Saved (Gal)	908.1642533
CO2 Saved (tonnes)	9.245112099
Savings Projection	$ 2769.90

Total Potential Fuel Savings (Gal) -1 year	2900.471133
Total Potential CO2 Savings – 1 year	29.53 tonnes
Total Potential Savings - 1 year	$ 8846.44

*10,180 grams CO_2 / gallon [1], $1*10^6$ g = 1 tonne

** $ 3.05/ gallon of Diesel in the U.S. in 2019 [3]

Table 2 presents the culminated results from the process detailed in section 2.0. The first portion labeled truck In-Use details two sets of statuses. The condition of In-Transit makes up the statuses of Driving and In-Traffic Idle while the Stopped Overnight condition is made up of the Unnecessary Idle and Eliminated Idle conditions. The results present a percentage and the total time in each condition, where the percentage is the amount of time spent in each respective condition for the total time the truck was in use.

An important piece to note is that for the RelGen system, the battery used for the sleeper cab/APU is solely charged by the product. As such idling is not needed for the usage of the sleeper cab/APU. As well, the combination of the unnecessary idle and eliminated idle conditions sum to the total savings from RelGen as both have the sleeper cab/APU being used with a battery whose power was generated by the product.

From the initial portion, the Stopped Overnight condition is expanded to present a breakdown of the Unnecessary Idle and Eliminated Idle conditions. The respective time spent in each condition and the percentage as a function of the total amount of time within the Stopped Overnight condition is displayed as well. In this case, the Unnecessary Idle condition is seeking to be minimized while the Eliminated Idle wants to be maximized through the usage of the Rel-Gen product.

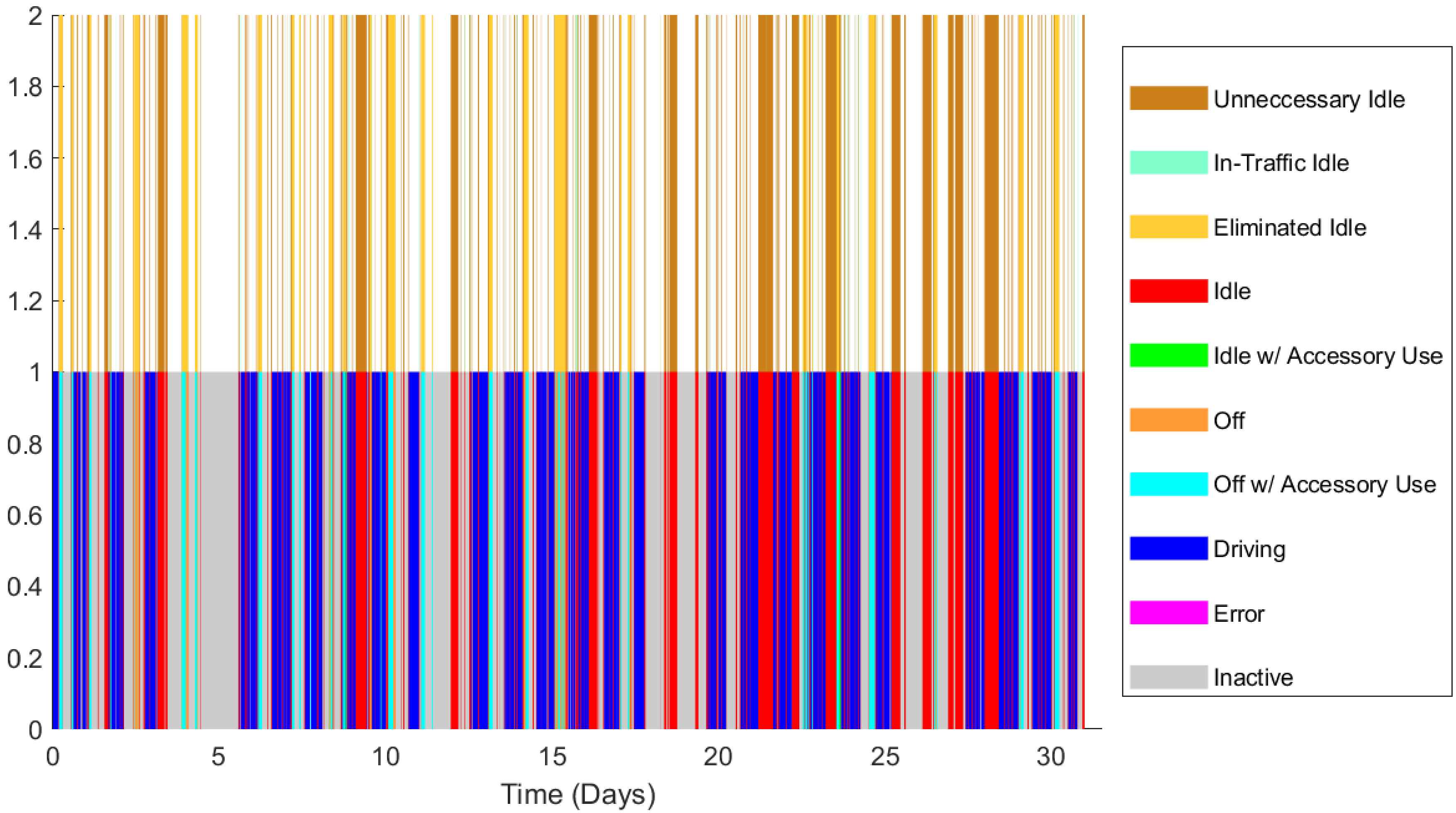
The subsequent table components break out the Fuel consumed/saved, CO_2 emitted/saved and Dollars Spent/Saved between the Unnecessary Idle and Eliminated Idle statuses respectively for the duration of the data set (approximately one month). The fuel consumed/saved was calculated by the conversion of 1 gallon per hour idle. The units presented for the CO_2 saved/emitted are in tonnes of CO_2 acquired by two conversion factors: 10,180 grams CO_2 / gallon [1] and $1*10^6$ g = 1 tonne. The dollars spent/saved was determined by obtaining the average cost of diesel in the United States during the time of operation for this dataset. Based on the values found the amount of fuel and CO_2 saved was less than what was emitted/used while in the respective states, however, the values are relatively close to counteracting the impact of the other

With the results from the data set for the month, the results were extrapolated up to a year timeframe to provide projected Costs and Savings.

The last component of the table displays the net savings for fuel, $CO_{2,}$ and money based on the yearly projected costs and savings. These were obtained by adding consumed/emitted/spent value from the respective saved value. These values are added as it the estimated savings with idling being eliminated through the usage of RelGen.

Figures 1-12, presented below, display the graphical representation (odd Figures) and pie charts (even Figures) for the truck statuses. Figures 1 and 2 cover the total dataset period while the subsequent figures are one week within the overall set to provide finer detail.

Figure 1. Truck Status for Entire Time range (7/01/2020 – 7/31/2020)



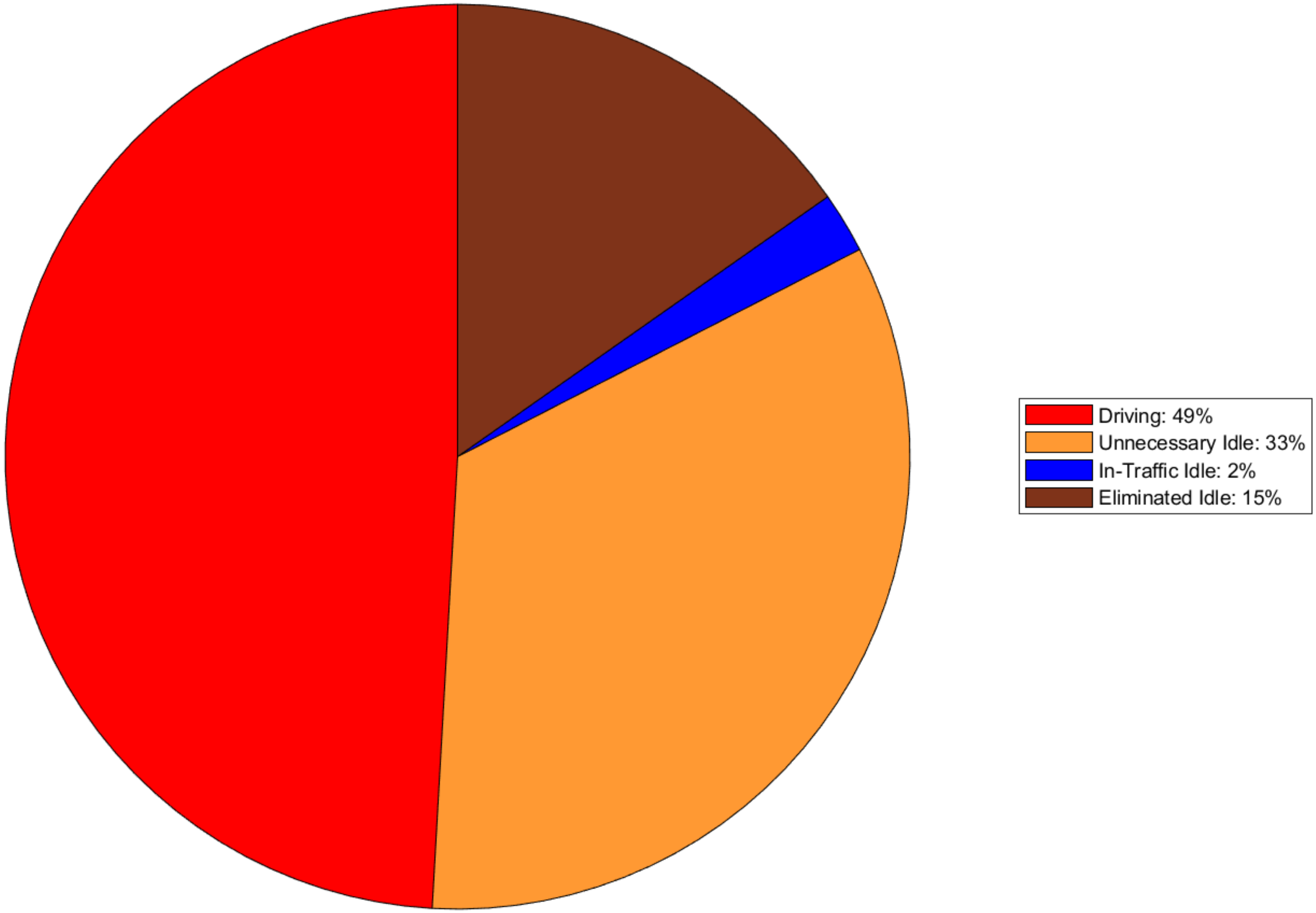
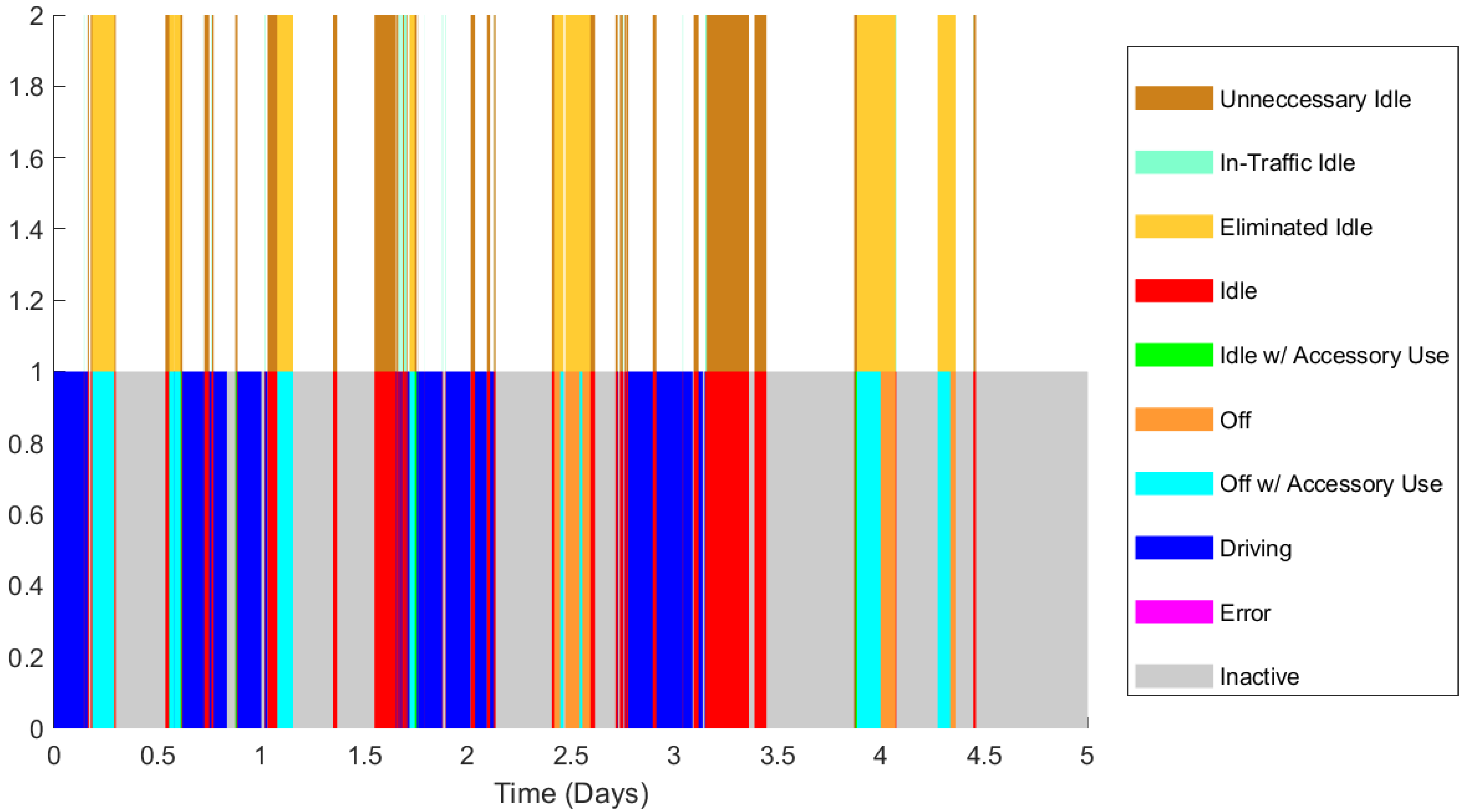


Figure 2. Pie Chart of Truck Status for Entire Time range (7/01/2020 – 7/31/2020)

Figure 3. Truck Status for Week 1 (7/01/2020 – 7/05/2020)



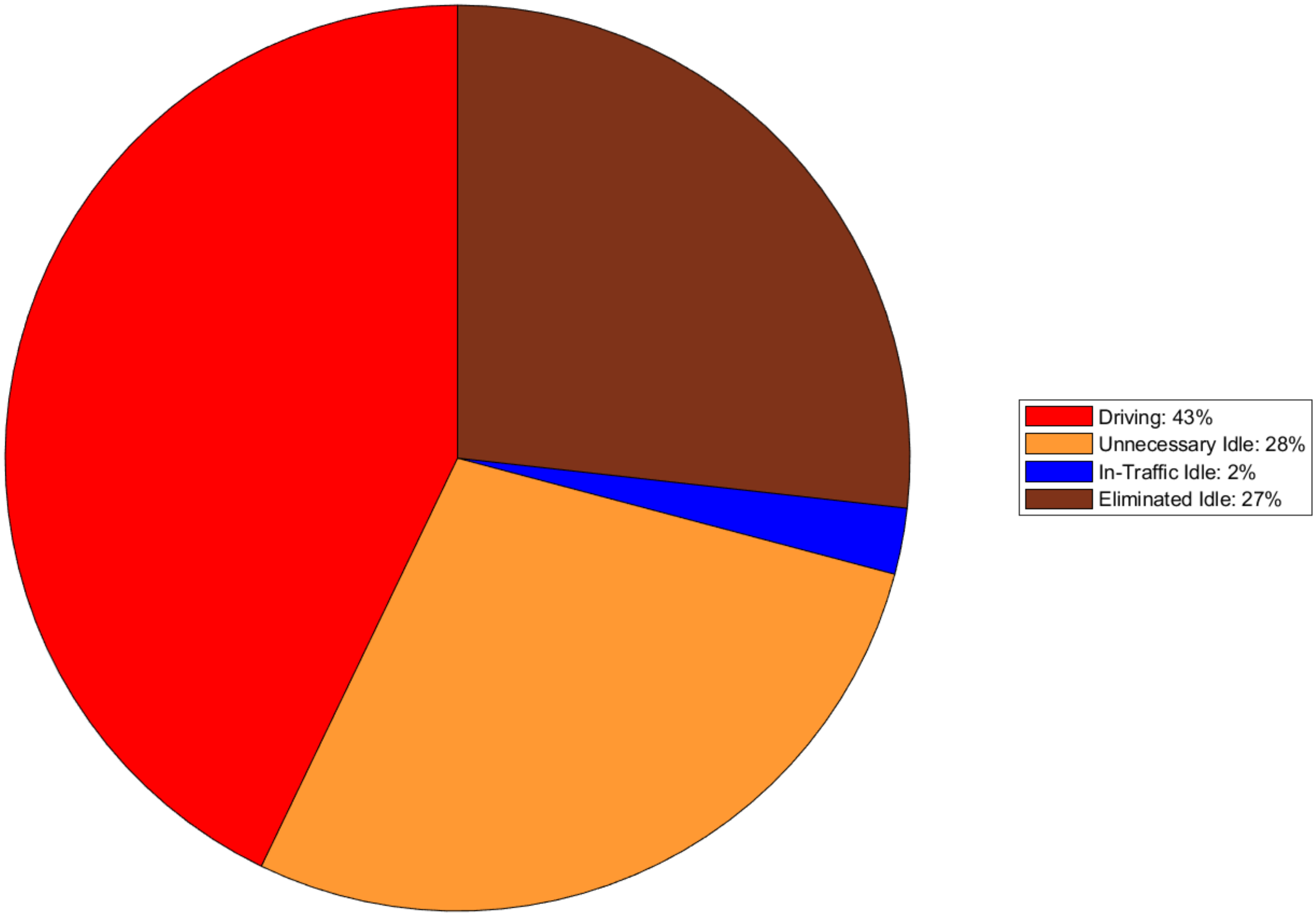
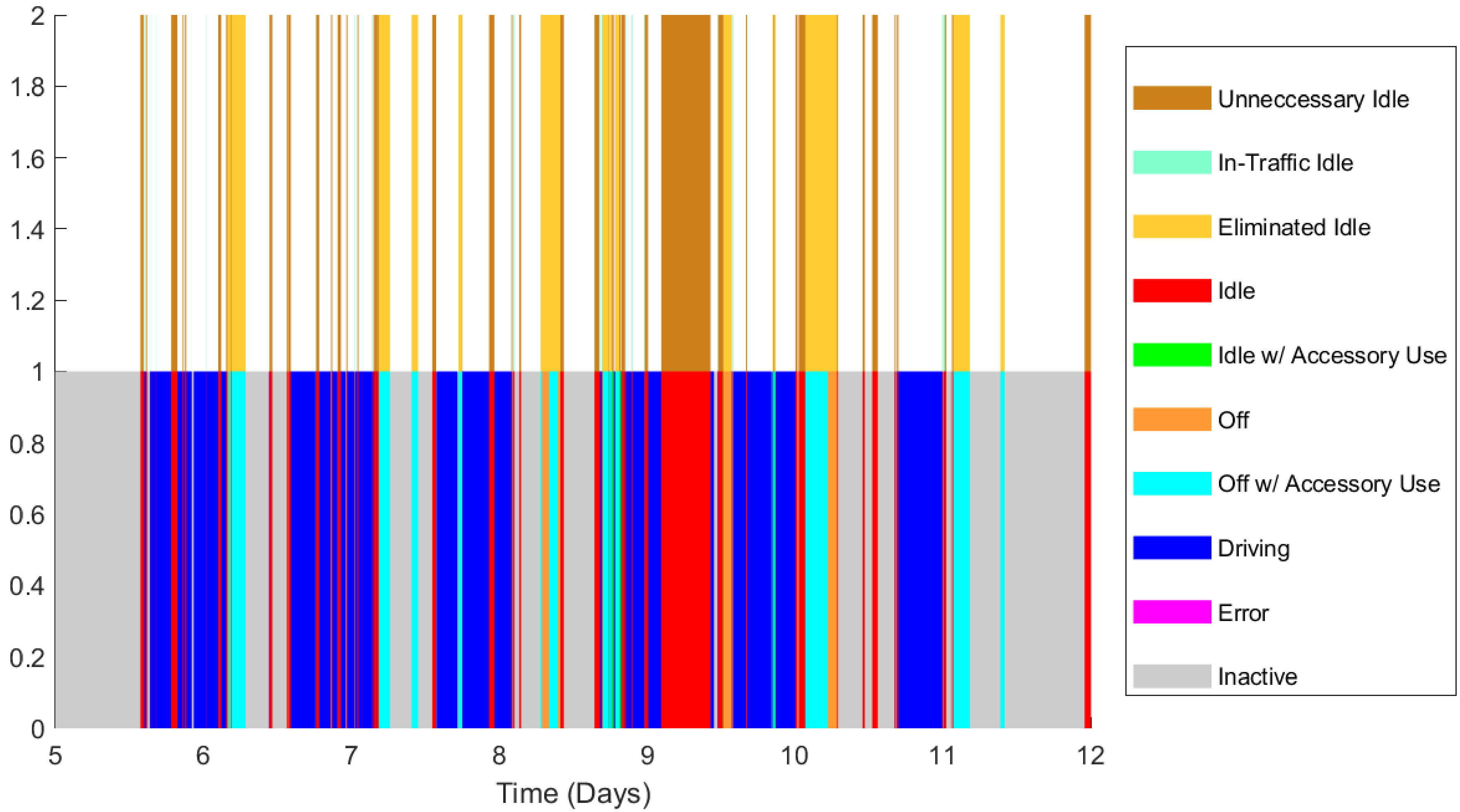


Figure 4. Pie Chart of Truck Status for Week 1 (7/01/2020 – 7/05/2020)

Figure 5. Truck Status for Week 2 (7/05/2020 – 7/12/2020)



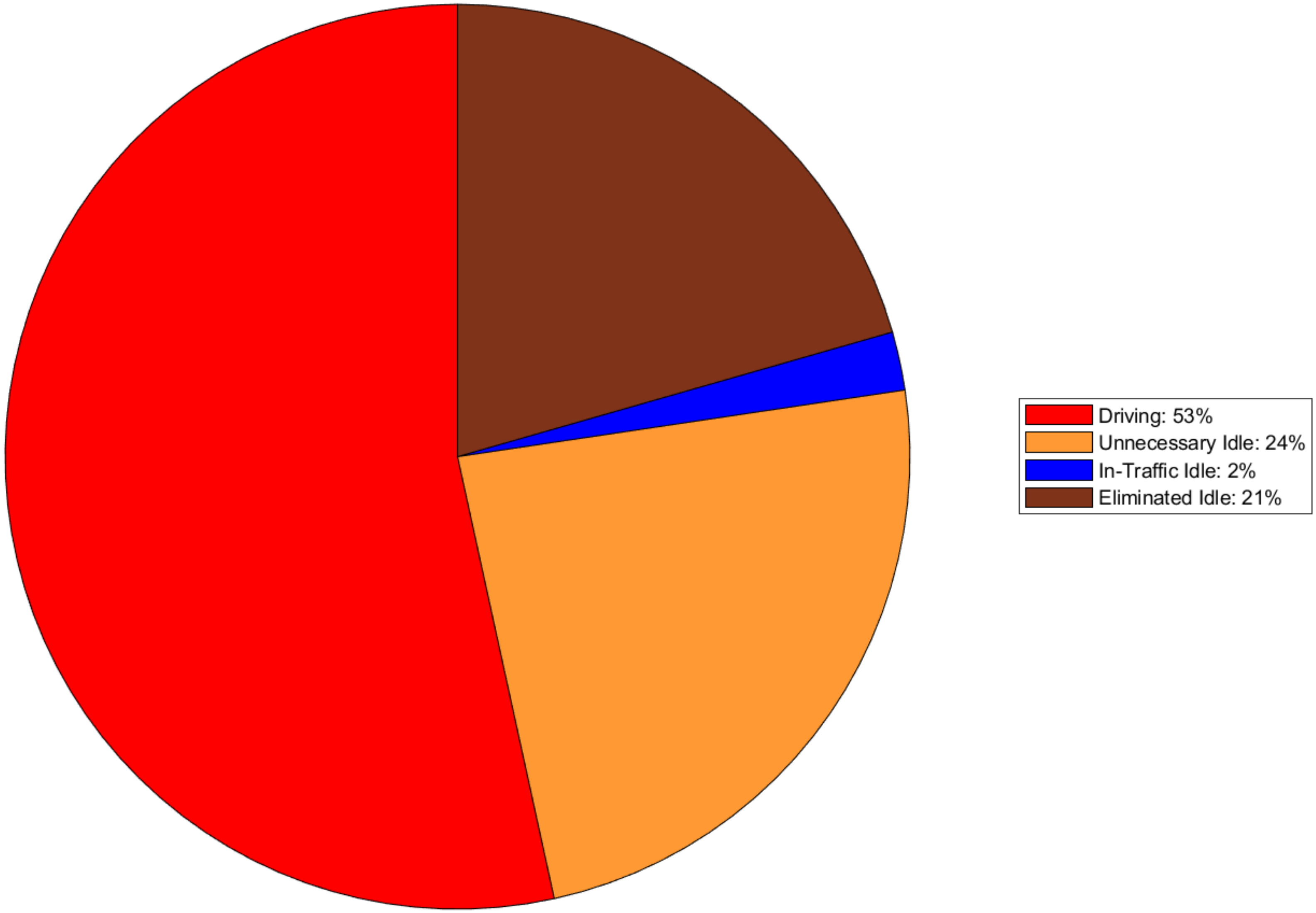
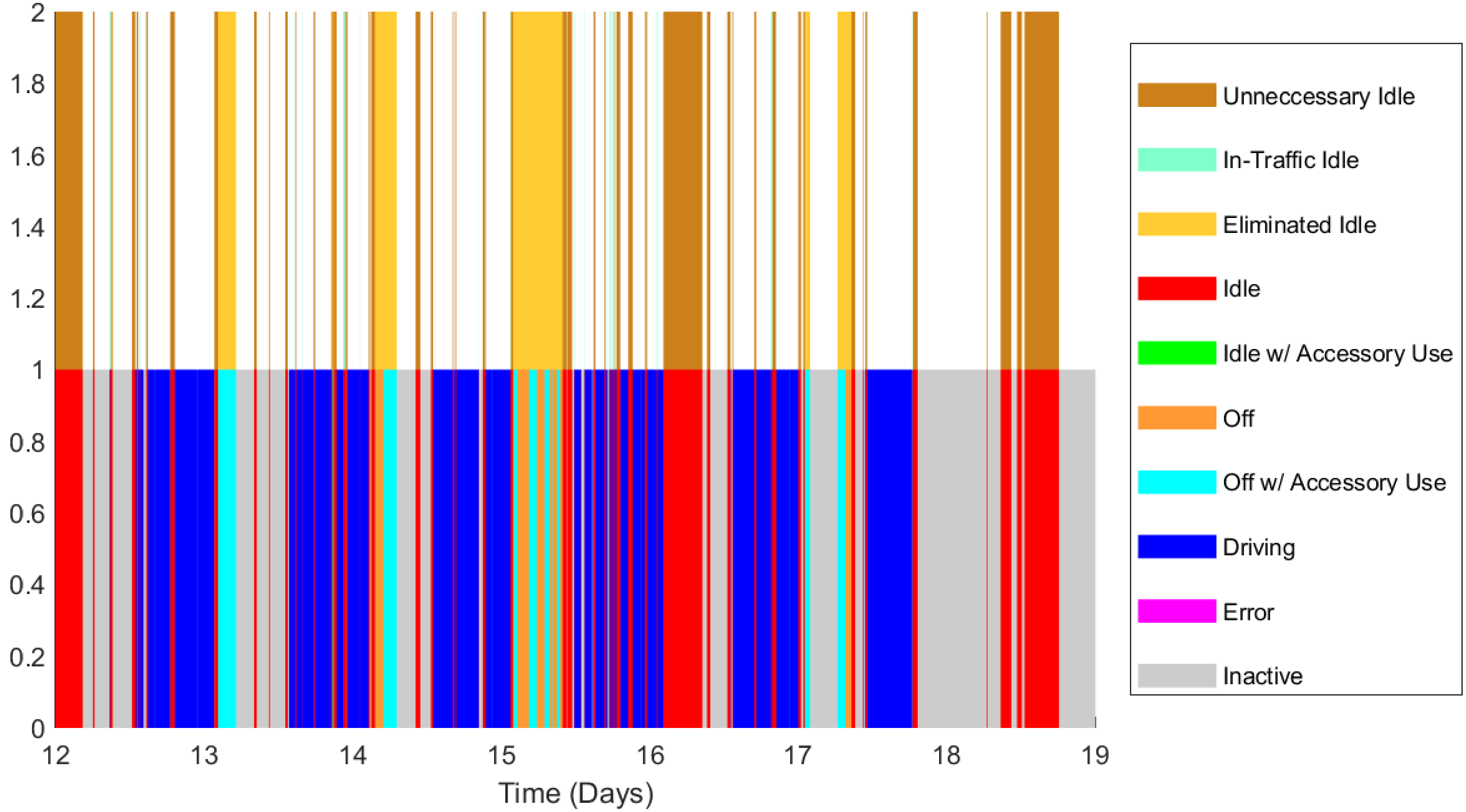


Figure 6. Pie Chart of Truck Status for Week 2 (7/05/2020 – 7/12/2020)

Figure 7. Truck Status for Week 3 (7/12/2020 – 7/19/2020)



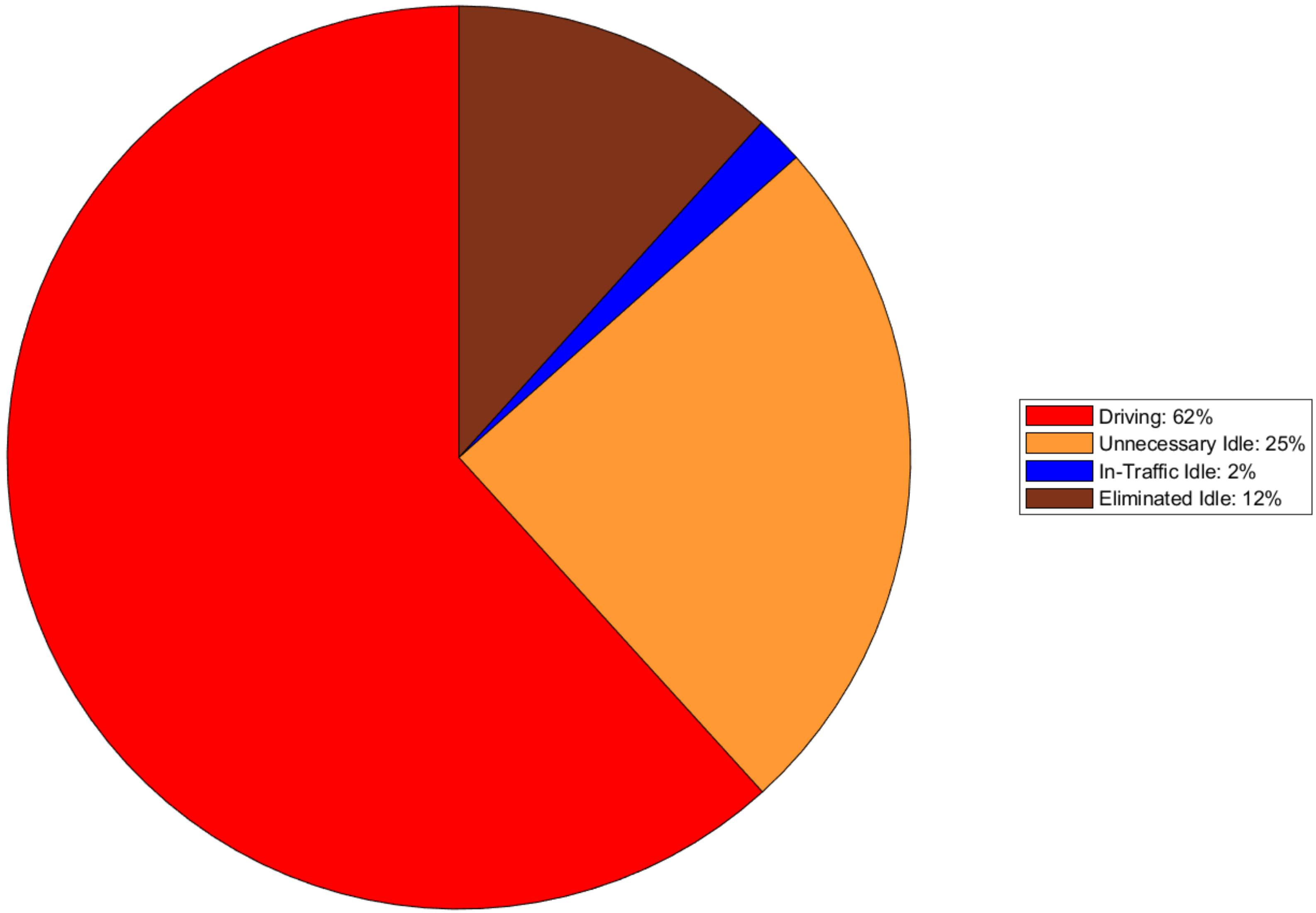
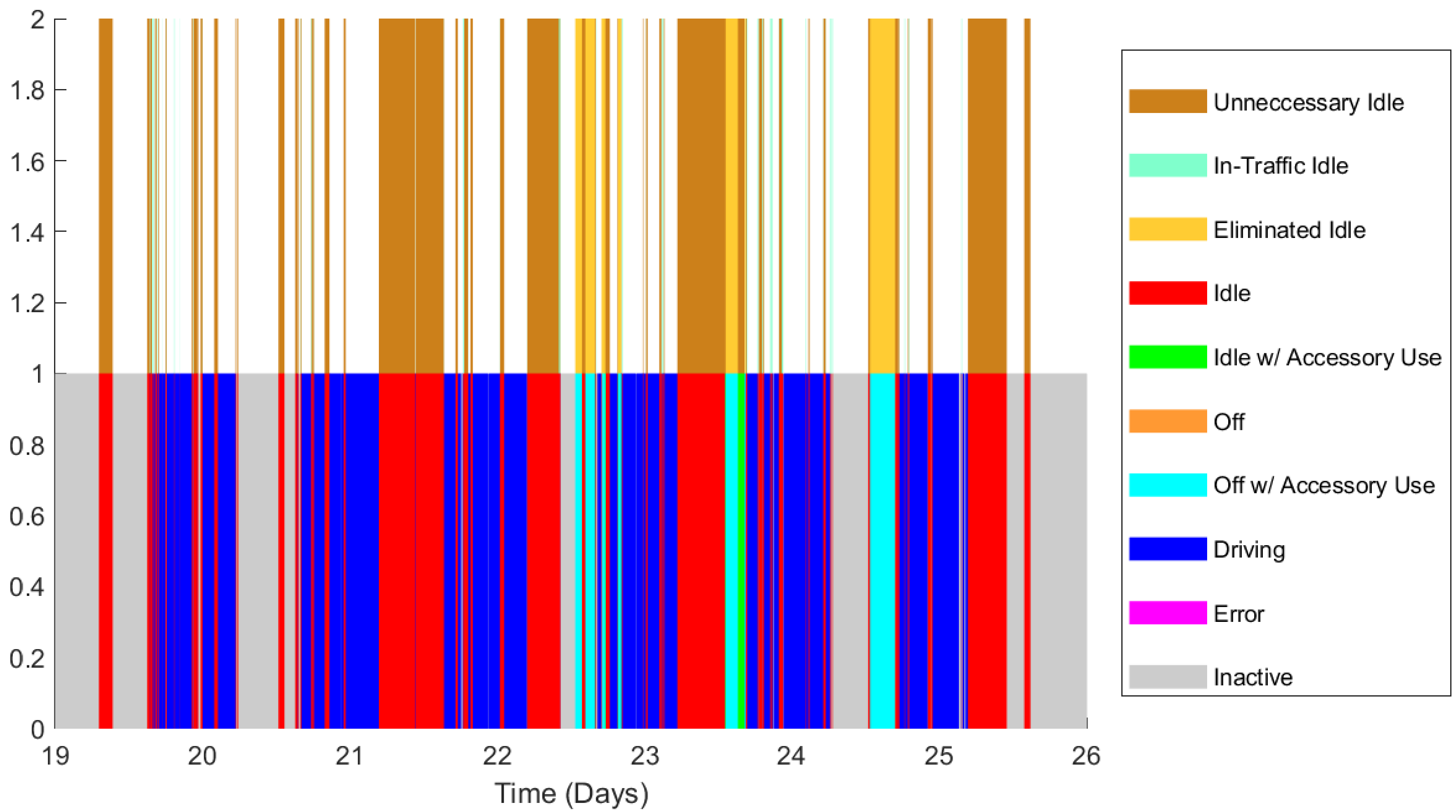


Figure 8. Pie Chart of Truck Status for Week 3 (7/12/2020 – 7/19/2020)

Figure 9. Truck Status for Week 4 (7/19/2020 – 7/26/2020)



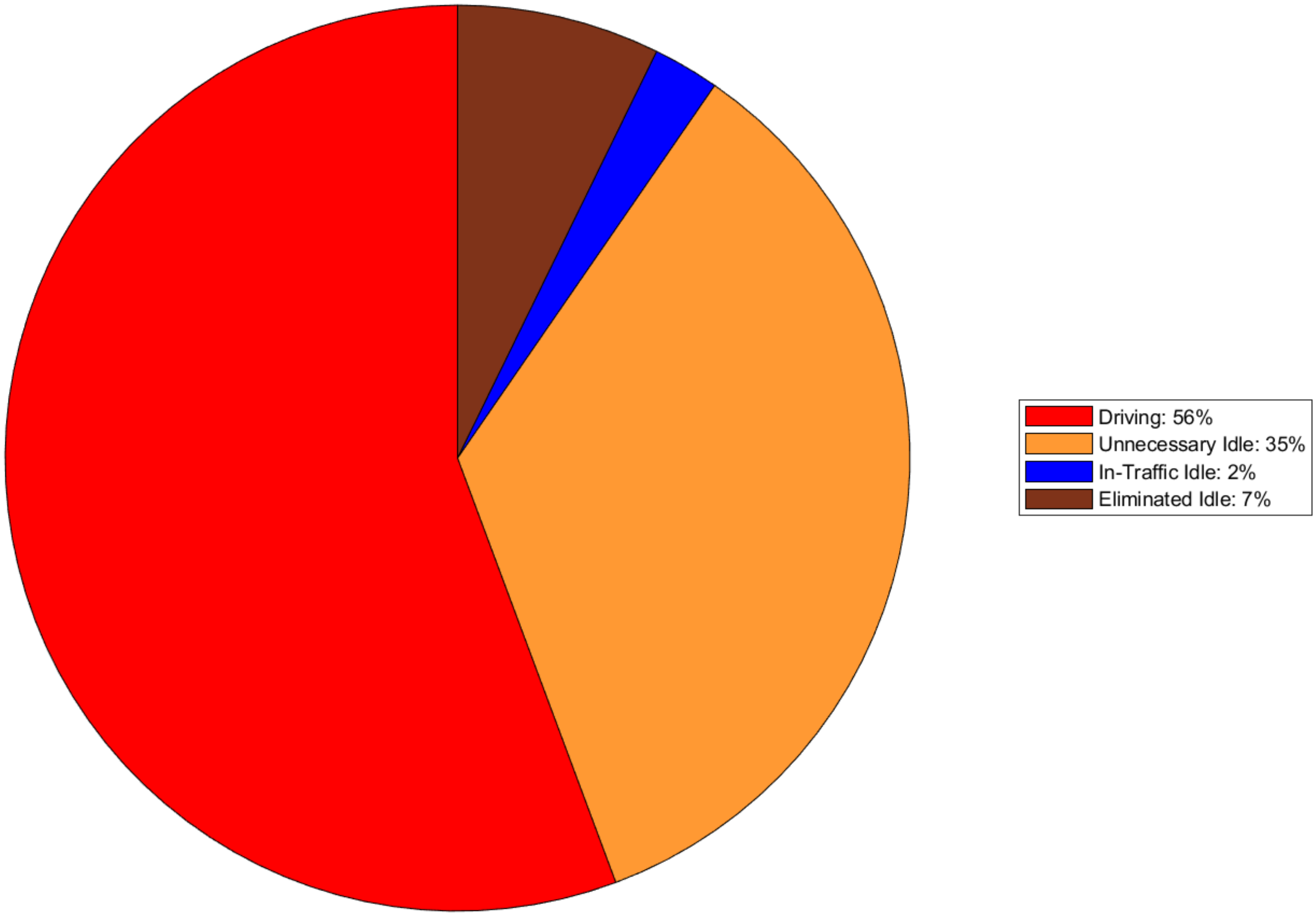
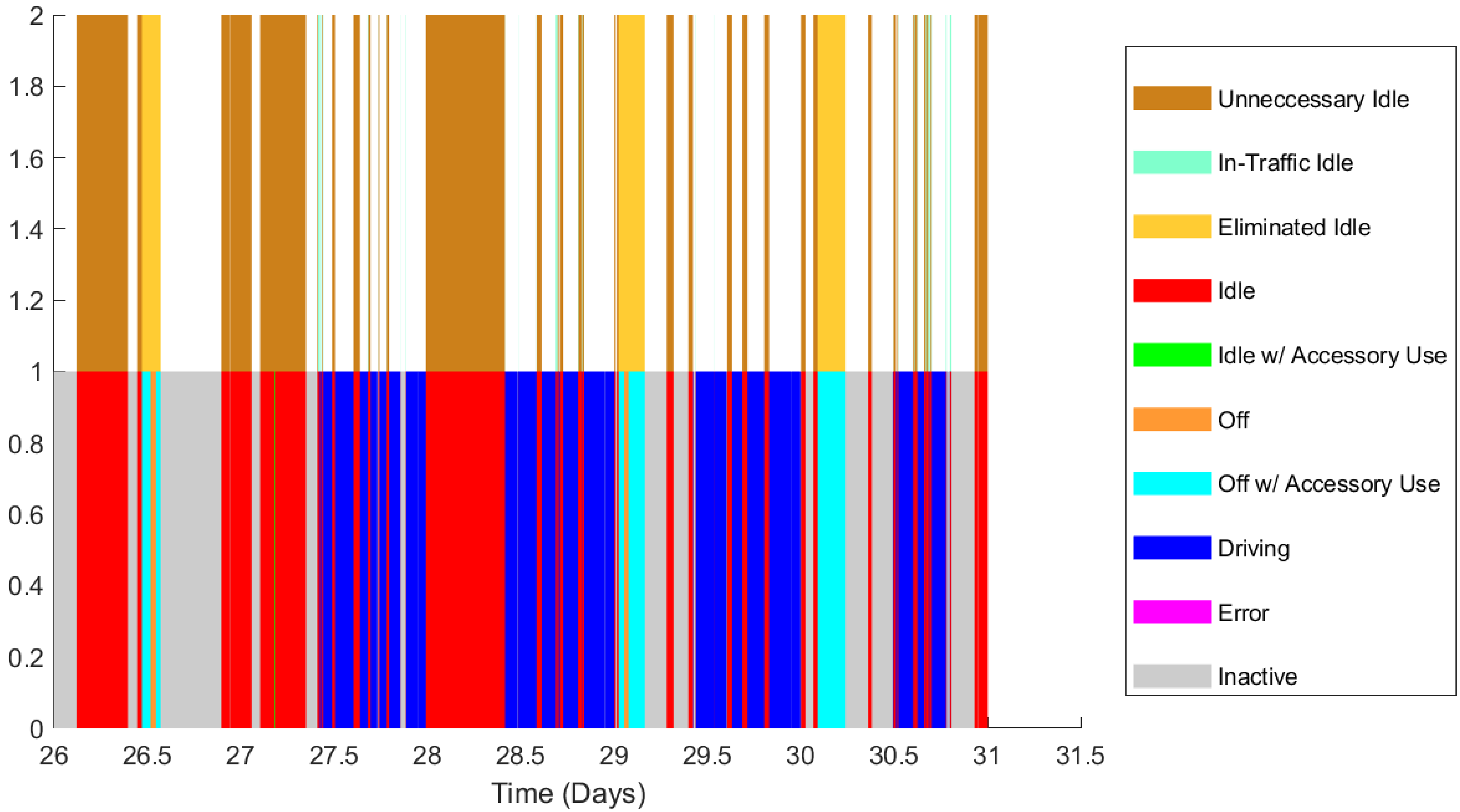


Figure 10. Pie Chart of Truck Status for Week 3 (7/19/2020 – 7/26/2020)

Figure 11. Truck Status for Week 5 (7/26/2020 – 7/31/2020)



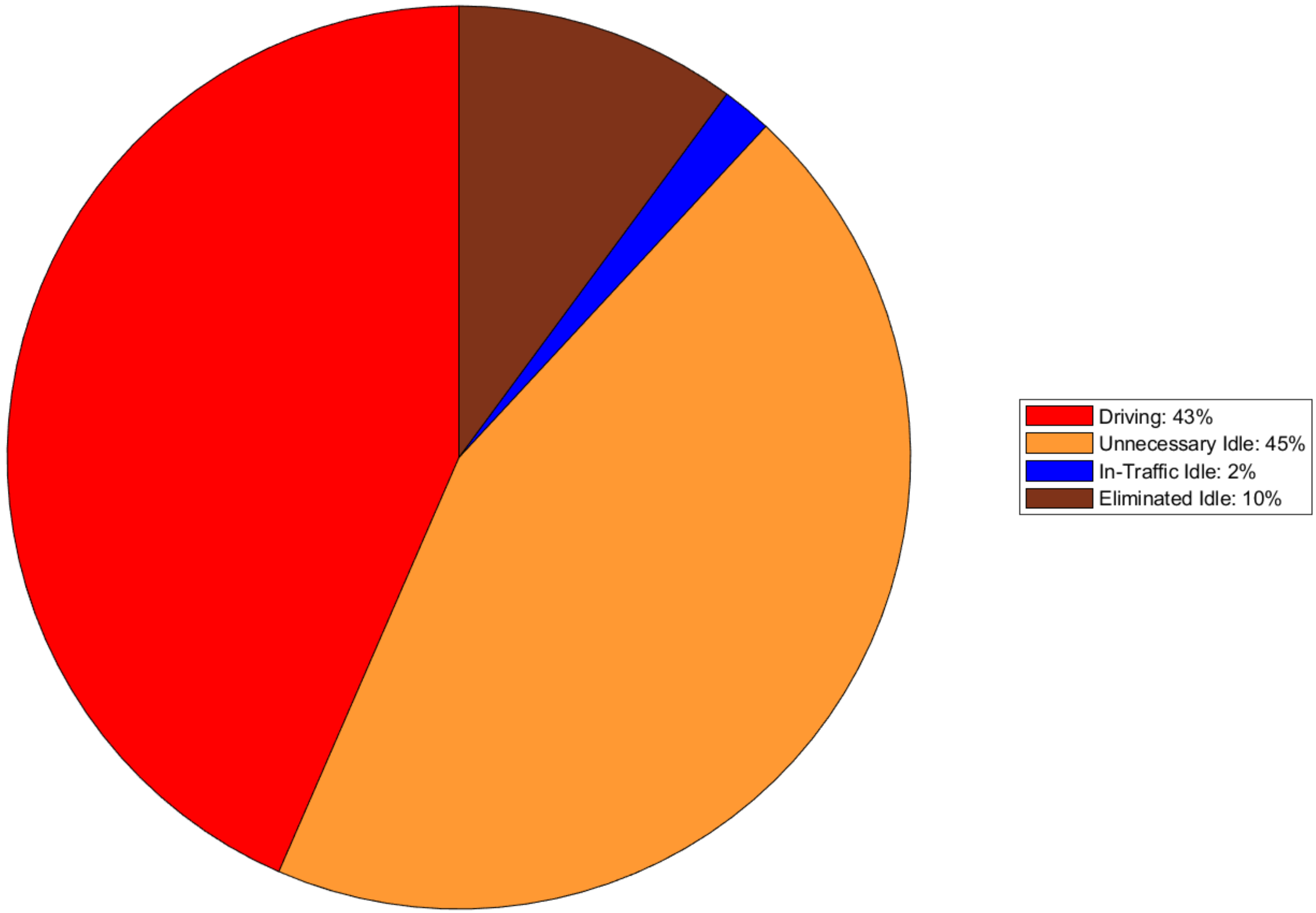


Figure 12. Pie Chart of Truck Status for Week 5 (7/26/2020 – 7/31/2020)

5.0 Summary

From the analysis of the dataset, "NTSTruck373_2020.07.01-2020.07.31 – GPS.csv", the truck was found to operate in the undesirable status of Unnecessary Idle more than the target condition of Eliminated Idle. Indicating that when the heating/cooling in the sleeper cab was in use, on average the engine was running Idle. As the battery used for the sleeper cab is being solely charged by the RelGen product any idling while using the accessory should be able to be prevented or mitigated. The script created in MATLAB allows for the data file to be imported and generate the presented plots.

As seen in all prior reports gaps in data exist, classified as inactive time. This inactive time is caused by the control module shutting off after 3 hours of the engine being off. With the modifications implemented, Inactive was also classified as instances in which the vehicle was off with no actions being taken.

These results have found that RelGen allowed the truck to utilize the heating/cooling of the sleeper cab while not Idle for some time. This enabled approximately 908.16 Gal per year of fuel to be saved overall and prevented approximately 9.25 tonne CO_2 per year from being released. In addition, with the power generated by the RelGen product a total potential savings of 2900 Gal per year, 29.53 tonnes of CO_2 and $8846.44 per year could be saved if idling while the sleeper cab is in use was prevented.

6.0 References

[1] Vehicle-specific 5-cycle fuel economy and carbon-related exhaust emission calculations, 40 CFR 600.114-12 (2011).

[2] COMPENDIUM OF IDLING REGULATIONS. (2020, March). Retrieved from https://truckingresearch.org/wp-content/uploads/2020/06/2020-ATRI-IdlingCompendium-March.pdf.

[3] Gasoline and Diesel Fuel Update - U.S. Energy Information Administration (EIA). (2020, August 17). Retrieved August 21, 2020, from https://www.eia.gov/petroleum/gasdiesel/