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Development of a Data Acquisition System for Autonomous Vehicle Systems

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ABSTRACT:

A data acquisition system along with a sensor package was designed and installed on an existing mechanically-controlled system to gather more data on their usage patterns. The data collected through the developed system include GPS route, vehicle speed and acceleration, engine state, transmission state, seat occupancy, fuel level, and video recording. The sensor package was designed and integrated in a way that does not interfere with the driver's operation of the system. Cellular network connectivity was employed to retrieve sensor data so as to minimize human effort and maintain typical usage patterns of the outfitted systems. Testing and validation results showed that the developed system can correctly and effectively record data necessary for further analysis and optimization. The collected data will significantly promote system activity simulations in order to facilitate optimizing work flow at large industrial facilities and improving energy efficiency.

KEYWORDS:

Data acquisition system; Sensor package; Cargo tractor; Testing and validation

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1. Introduction

For operating a large number of cargo tractors at airports to haul heavy, containerized cargo to and from aircraft, in order to maintain high efficiency and reliability, the knowledge of all the basic parameters of the cargo tractor operating conditions is required at every instant so that the coordinator can monitor the usage patterns of those tugs. The collected data is also necessary for ensuring the safety of the driver and the Ground Support Equipment (GSE). To fulfil such requirements, a data acquisition (DAQ) system and a sensor package have to be designed and integrated into both older and newer model cargo tractors to enable these vehicles to gather useful data during operation. The technology advancement in sensor use experienced by the commercial vehicle market has not been carried over to GSE vehicular fleets. Based on subject matter expert (SME) feedback given by the engineers from the corporation participating in this study, the culture of manufacturing in GSE (most notably in cargo tractors) is even more seasonally driven than commercial vehicles.

The number of purchases for GSE equipment are much smaller in number and due to the high cost of the equipment (e.g. greater than $60,000 per new cargo tractor), most purchasers opt to maintain their GSE fleets for decades rather than replace them after they've been fully depreciated from a tax benefit perspective. Therefore, GSE and cargo tractor orders are often low in number and occur annually when the corporations receive their yearly equipment budget. Upon receipt of their budget amounts, these companies that often operate at airport ramps, place an order for their new equipment. The cargo tractor manufactures receive the order, staff up line worker staff accordingly, fulfil the orders making minimal, incremental changes with each yearly model in order to avoid increased complexity, and then lay off the line worker staff until the next order is received. This removes much of the experience gained on the part of the workers and all but eliminates continuity.

Another added complexity to this seasonal "ramp up, ramp down" staffing model is that the cargo tractor models built at the same time on the same manufacturing line by the same vendor, often differ in significant enough ways that new technology packages cannot be universally installed across the same model number. For instance, the wiring harness may be functionally the same but installed in different locations. Mounting brackets may be in different places. Simple gaps in space between components may differ, and so on. The engineers assisting with this research study explained that this manufacturing culture prevents creative advancements. Significant feature advancements often only occur when the company interested in more advanced features pays for the research and development (R&D) while allowing the cargo tractor or GSE manufacturer to retain the intellectual property rights to the technology installation thereby creating conflict between the vendor and the customer.

The least "painful" solution is to accept the incremental model changes and adjust the work and/or facility to account for the minimally advanced GSE feature set. Therefore, by adding a DAQ system and a sensor package, engineers responsible for making decisions about cargo tractors at airport ramps will be made to holistically understand the operational behaviour of the vehicle and to extract useful information for optimization of work flow and energy efficiency. In this study, such a DAQ system and a sensor package were designed, and integrated into a GSE vehicle to collect data on the usage patterns of cargo tractors, and were validated through field tests in live, production environments. Before launching this project, existing vehicle data acquisition systems developed by other investigators for different purposes had been reviewed to form a theoretical background for the present study. DiGenova et al. [1] designed, installed and tested an on board DAQ system in a 1991 Chevrolet Lumina to collect engine and vehicle operating data, including tailpipe pollutant concentrations.

The presented system measured and recorded manifold air pressure and temperature, vehicle speed and acceleration, gear changes, and pollutant concentrations in engine exhaust with the help of a portable gas analyzer. Zhao and Shibasaki [2] proposed a vehicle-borne system of measuring 3D urban data using single-row laser range scanners for measuring 3D urban scene. Through two single-row laser range scanners that were mounted on the roof of a vehicle, high accurate positioning was obtained and 3D reconstruction was accomplished based on the recorded vehicle horizontal and vertical range profiles. Wang et al. [3] developed a computer-controlled DAQ system using lab view to collect data of electromotor armature electric current, wheel speed and body work speed of the electric vehicle. Testing and experiments proved that the presented method could avoid the complicated computer program, shorten software-developing time, simplify the development process, and increase the application of agility. Zhao and Feng [4] achieved remote data acquisition using GPRS wireless network: a fast, reliable data transmission channel; such method is suitable for being used on watch stations for safety control and transportation monitoring.

In Alkar and Karaca's work [5], the researchers presented a low-operational-cost but flexible internet-based DAQ system which was built based on an embedded hardware running a scaled-down version of Linux. The application of GPRS for the embedded device communication made the collected data accessible from anywhere in the world through a Web server built into the embedded device. The system was demonstrated to be suitable for different embedded applications by attaching several real-time modules through appropriate interfaces. Kucera and co-workers developed a vehicle DAQ system for the car transport safety project which aims at reducing hazardous situations on the roads by analysing behaviour of the driver and identifying the degradation of driver's abilities [6].

Through the developed system, a publicly available data archive was taken from the operation of a real car under various real conditions of the driver and the road. Such data was then processed with the aim to analyze it and reveal changes in a driver's abilities and to eventually alarm the driver or passengers. Tsoumas et al. [7] designed a data acquisition and telemetry system and incorporated such system in a prototype solar vehicle. Practical results from the in situ operation of the data acquisition and telemetry system were also presented and discussed. Y. Wang and H. Wang [8] designed a temperature signal acquisition system to allow for remote fault diagnosis for a vehicle body system. Osman and Magdy [9] proposed a low cost and configurable DAQ system consisting of sensors, analogue to digital card and software package for acquisition and processing. Such system can be used to measure cylinder pressure, vibration of the cylinder block on 3D, different types of temperature, crank angle and engine's RPM.

2. Problem description

Fig. 1 displays a model of cargo tractor generally employed at various airports. Maximum speed of such a cargo tractor is approximately 13mph and its towing capacity is about 40,000 pounds. Those cargo tractors are typically equipped with either gasoline engines or diesel engines. A DAQ system was designed for the cargo tractors so as to create databases of the drive cycle information and fuel efficiency, which could be useful in future analysis and optimization efforts. It was decided that the designed system should be able to collect following data: fuel level, wheel speed, wheel angle, gear position, engine RPM, engine on/off status, seat occupancy, brake pressure, throttle position, GPS position, acceleration, start count, temperature/humidity, and video. Moreover, the entire DAQ system must be waterproof and be able to withstand a rugged, dirty environment along with wide ranges in temperature. The engineers from the corporation working with this study also desired that all components must be minimally visible to drivers and not affect driver performance. Based on these design requirements, individual components and instruments were determined and integrated into the system.

Fig. 1: Example of a cargo tractor model [10]

3. Design of the DAQ system

Hardware required to fully functionalize the DAQ system was first determined. A list of critical DAQ components are listed in Table 1 along with their functions and model numbers. The wheel speed sensor consists of a Hall-effect sensor and a magnetic drive shaft collar that is fastened to the drive shaft. The Hall-effect sensor detects magnets inside the split collar and sends digital signals to the controller. A vertical-mounted fuel level sensor FAST-A that sends analogue signal to controller will replace the current visual gauge. A rotary potentiometer is used for detecting gear position and wheel angles, which sends an analogue signal to the controller based on output voltage changes. The Influx Rebel LT data logger has 12 digital channels, ± 30V input measurement range, and up to 15 universal analog sensor inputs, which can be accessed remotely and share data through emails or FTP servers. This data logger is configured using software "Dialog", which enables users to convert raw data into csv file that can be easily read into spread sheet for further data processing.

The selected camera is a HD backup camera for capturing ambient conditions of the cargo tractor, and video is recorded using a dash cam DVR. Memory cards and screen videos can be retrieved to reconstruct ambient conditions of the cargo tractor. A USB slot for data transferring and an Ethernet port for communication with a PC is available on the data logger. The driver presence sensor Interlink Electronics RB-int-04, is very thin and can be easily cut into different sizes to be fit for any space. All the sensors listed in Table 1 and the cargo tractor's CAN bus are connected to a Parker Raptor controller, in which the sensor signals (analogue and digital) and CAN bus will be converted into a CAN message that is recorded by the data logger (Fig. 2).

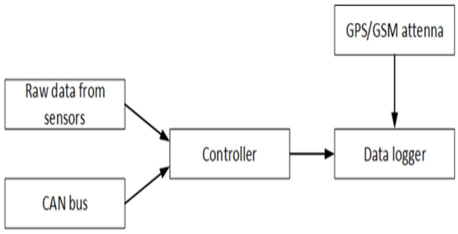

Fig. 2: Hardware integration

Table 1: Hardware components for the DAQ system and their functionalities

Components	Model numbers	Functions
Driver presence sensor	Interlink Electronics RB-Int-04	A pressure sensitive strip to measure pedal forces applied by the driver so as to evaluate the situation and performance of the driver
Seat switch	John Deere AM124426	Binary control to monitor seat occupancy
Weather proof fuel gauge	Wema USA SSS/SSL 04.0	Display the fuel level of the cargo tractor
Wheel speed sensors	Honeywell – 1GT101DC	Measure wheel speed
Brake pressure sensor	AiM 2000 psi	Measure brake pressure
Wheel angle & gear position sensor	ACDelco 22666955 rotary potentiometer	Detect the wheel angles and gear position
Data logger	Influx Rebel LT	A data collector to send and receive all data collected from the cargo tractor
Camera	A universal rearview backup camera	Monitor road and ambient conditions for the cargo tractor
Video recorder	A two-channel digital video recorder	Monitor road and ambient conditions for the cargo tractor
Thermocouple data logger	Omega OM-62	Measure ambient temperature and relative humidity
Voltage regulator	KEEDOX DC/DC converter	Regulate voltage from 12 V to 5V and supplies up to 3A
Storage case	Battery box	Store all sensors and hardware components
Fuel level sensor	FAST-A	Provides fuel level signal

4. Prototype

A retrofitted cargo tractor model was then prototyped by implementing the designed DAQ system and installing all the listed hardware components. In order to ease the installation process, mounts for installing sensors and camera were first designed using CAD; and then either fabricated or 3D printed based on their complexity. A universal rear-view backup camera with 170° view angle and 720 × 480 resolution and infrared night vision was mounted to the cargo tractor model. Two versions of camera mounts were designed. A two-channel digital video recorder (DVR) was mounted in a separate enclosure in the front of the cargo tractor. The camera was wired to the DVR to jointly record and monitor road and other ambient conditions for the cargo tractor. Likewise, gear position lever arms were designed for installing the gear position sensor. The gear position sensor was installed between the gear shifter mount and the designed lever arm assembly. The same rotary potentiometer used for detecting the gear position is also used to capture the wheel angles.

In installation, the wheel angle sensor is screwed into a wheel angle insert. Through the wheel angle sensor, the angles of wheels could be detected, based on which the instantaneous direction of the cargo tractor is decided. The wheel angle insert, mount, and position locator were specifically designed for the purpose of installing the wheel angle sensor. The existing cargo tractor model does not provide space for installing wheel speed sensors, therefore an adjustable wheel speed bracket was fabricated. To install the brake pressure sensor, a custom T fitting was added to minimize total number of fittings used. A brake pressure sensor was then screwed into the T fitting and wired to the controller. A weather proof fuel gauge was mounted near the fuel tank cover to detect the fuel level and facilitate the fuel usage analysis. Two seat switches, one at the center of the driver's side and another of the passenger's side were integrated into the seats of the cargo tractor and fastened. These seat sensors would detect the seat occupancy of the cargo tractor.

Finally, a data logger, which receives and sends all data collected from the installed sensors about the cargo tractor, was fastened to an electronics cover and attached to inside of the battery box. All the installed sensors and hardware components were wired to the data logger for data transferring and sharing. Finally, a detailed installation manual was created during the initial prototyping. The manual includes instructions for installing each DAQ component, maintenance plans, and instructions to restore the enhanced cargo tractor to its original version by removing all DAQ units.

5. Testing and validation

After installing the DAQ system onto a cargo tractor, the vehicle was driven along different paths and all sets of data collected by the DAQ system were reviewed to validate this system. Some example data is presented here. Fig. 3 displays the temperature and humidity data and curves recorded by the thermocouple data logger. Figs. 4 and 5 show the speed and path of the cargo tractor, which were tracked by the data logger. Afterwards, a sky rotor equipped with a high resolution camera (Fig. 6) was employed to take photographs for the moving cargo tractor at a frequency of 1 frame per second to capture its instantaneous directional angles. The angles measured from the photographs were compared with the cargo tractor angles recorded by the data logger and shown in Fig. 7.

Samp	Temp (F)	Hum (%RH)	Dew Point (F)	Date	Time
1	70.66	50.73	51.52	12/9/2015	1:52:45 PM
2	70.66	50.73	51.52	12/9/2015	1:52:46 PM
3	70.66	50.73	51.52	12/9/2015	1:52:47 PM
4	70.74	50.74	51.59	12/9/2015	1:52:48 PM
5	70.74	50.74	51.59	12/9/2015	1:52:49 PM
6	70.74	50.71	51.58	12/9/2015	1:52:50 PM
7	70.74	50.67	51.56	12/9/2015	1:52:51 PM
8	70.74	50.67	51.56	12/9/2015	1:52:52 PM
9	70.74	50.67	51.56	12/9/2015	1:52:53 PM
10	70.74	50.67	51.56	12/9/2015	1:52:54 PM
11	70.74	50.64	51.54	12/9/2015	1:52:55 PM
12	70.74	50.64	51.54	12/9/2015	1:52:56 PM
13	70.74	50.61	51.52	12/9/2015	1:52:57 PM
14	70.74	50.58	51.51	12/9/2015	1:52:58 PM
15	70.74	50.54	51.49	12/9/2015	1:52:59 PM
16	70.74	50.58	51.51	12/9/2015	1:53:00 PM
17	70.74	50.54	51.49	12/9/2015	1:53:01 PM
18	70.74	50.54	51.49	12/9/2015	1:53:02 PM
19	70.74	50.54	51.49	12/9/2015	1:53:03 PM
20	70.74	50.51	51.47	12/9/2015	1:53:04 PM
21	70.74	50.54	51.49	12/9/2015	1:53:05 PM
22	70.74	50.48	51.45	12/9/2015	1:53:06 PM
23	70.81	50.48	51.52	12/9/2015	1:53:07 PM
24	70.74	50.48	51.45	12/9/2015	1:53:08 PM
25	70.81	50.48	51.52	12/9/2015	1:53:09 PM
26	70.81	50.48	51.52	12/9/2015	1:53:10 PM
27	70.81	50.48	51.52	12/9/2015	1:53:11 PM
28	70.74	50.41	51.42	12/9/2015	1:53:12 PM
29	70.81	50.45	51.51	12/9/2015	1:53:13 PM
30	70.74	50.45	51.44	12/9/2015	1:53:14 PM
31	70.81	50.42	51.49	12/9/2015	1:53:15 PM
32	70.81	50.45	51.51	12/9/2015	1:53:16 PM
33	70.81	50.42	51.49	12/9/2015	1:53:17 PM
34	70.81	50.42	51.49	12/9/2015	1:53:18 PM
35	70.81	50.39	51.47	12/9/2015	1:53:19 PM
36	70.81	50.42	51.49	12/9/2015	1:53:20 PM
37	70.81	50.39	51.47	12/9/2015	1:53:21 PM
38	70.81	50.39	51.47	12/9/2015	1:53:22 PM
39	70.81	50.35	51.45	12/9/2015	1:53:23 PM
40	70.81	50.35	51.45	12/9/2015	1:53:24 PM
41	70.81	50.32	51.43	12/9/2015	1:53:25 PM
42	70.81	50.32	51.43	12/9/2015	1:53:26 PM
43	70.81	50.32	51.43	12/9/2015	1:53:27 PM

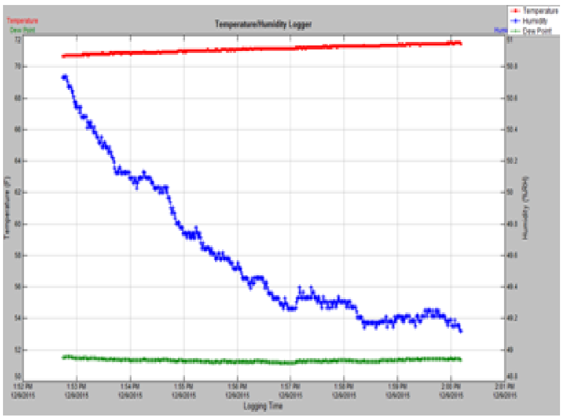

Fig. 3: Temperature and humidity data (top) and histories (bottom) readings from the csv file output from the thermocouple Omega-OM 62

As illustrated in Fig. 7, it can be seen that the values retrieved from the data logger precisely reflected the real directional angles of the cargo tractor. Finally, it was proved that when driving the modified cargo tractor, the driver's operation was exactly the same as that of the original cargo tractor, with no interference from this integrated DAQ system. The majority of data were retrieved via a cellular network so that minimum human effort was needed in data collection. The test results showed that the developed DAQ system is highly reliable, all the components function properly in that system to provide real-time data for the users to monitor the situation of a driving cargo tractor under different circumstances. Each component can be easily installed and removed, which means that the maintenance expense of this system is low.

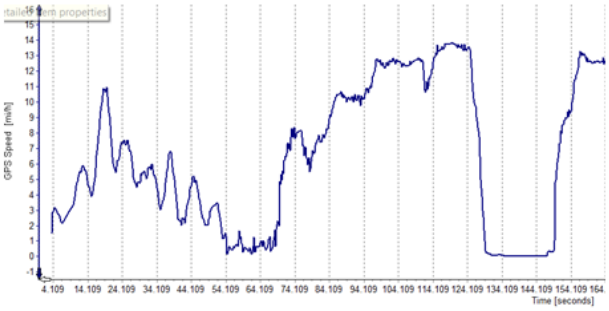

Fig. 4: GPS speed of the cargo tractor

Fig. 5: GPS route the cargo tractor tracked by the data logger

Fig. 6: Sky rotor used for photographing

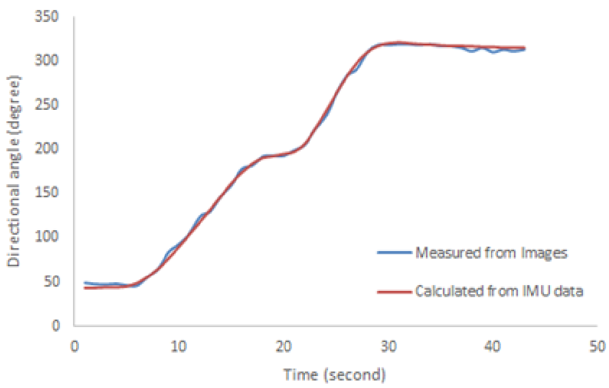

Fig. 7: Comparison of the cargo tractor angles recorded by the data logger with the angles measured from photographs

6. Fuel usage analysis

Fuel consumption was recorded by analyzing total fuel used over total distance driven for the length of the test. Fuel fill-ups were determined by mining the data log for events where the fuel level increased significantly in a short period of time. The data was then filtered to remove false positives caused by sloshing of the fuel in the tank as a result of road-induced disturbances or sudden starts/stops. This was done by removing data points where the vehicle was moving, as determined by a 3-second rolling average. The resulting filtered data corresponds to the total fuel added to the fuel tank over the course of the trial. Vehicle fuel usage was also measured using a Froude-Consine eddy current chassis dynamometer. A drive cycle was developed using sample data from the vehicle data logs (see Fig. 8). The drive cycle was 16.1 km long, took 150 minutes, and included 552 stops. The test was performed using the maximum possible simulated vehicle weight, which corresponds to the actual vehicle weight plus a simulated towing load of 7400 lb. At the beginning of the test, the engine was at operating temperature. Fuel consumption on the chassis dynamometer was measured by mass. The fuel was commercially available 87 octane fuel (no certification available.) The fuel mass was measured immediately before and immediately after the test to minimize effects of evaporative fuel loss. The test setup is shown in Fig. 9.

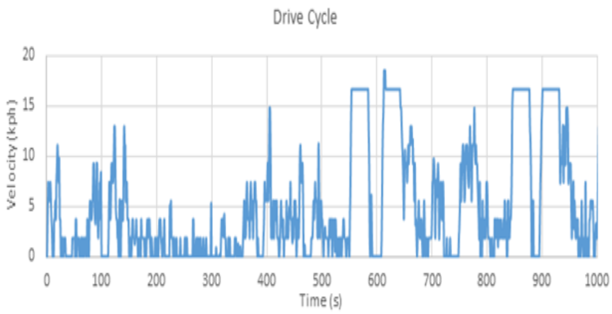

Fig. 8: Cargo tractor drive cycle

Fig. 9: Chassis dynamometer test setup

During the test, the average fuel efficiency of the vehicle was measured as 4.93 mpg (miles per gallon). While a good correlation is demonstrated with the real-world logged fuel economy (3.94 mpg), deviation possibly resulted from a mismatch of towing loads between the chassis dynamometer and the real-world test data. The chassis dynamometer did not allow for towing loads as high as are often seen in the application environment. It is shown, however, that the data collected during the three-month trial is reasonable based on an empirical validation test method.

7. Discussion

The ability to modify an existing and, in many cases, an aging fleet of cargo tractors used at an airport ramp for data collection is an important lesson learned for this project. Not only did this effort provide a blueprint for how additional fleets of cargo tractors across all makes, models and brands could be upgraded to quantify operational behaviour assessments, but this study provided insight that all aging GSE fleets of vehicles (e.g. forklifts, push-back tractors, belt loaders, security carts, people transporters, etc.) could be modified for data collection as well. For airport ramps and the companies who work at these ramps with limited equipment budgets looking to make operational decisions about the current state of their cargo tractor fleets, their options are limited outside of funding R & D work on the part of the cargo tractor manufacturer. This aim of this study was to provide another proven option.

While the goal of this study is to show that refitting existing equipment with a DAQ system and a sensor package could be achieved, from a business perspective, the data provided as a result of this research is the true values add. A common model found in the material handling and logistics industries (which are often co-located at airport ramps) is to "do more with less". This includes taking current equipment and facility assets and finding ways to push more volume in less time. Increasing optimization increases profits and decreases waste, therefore, awareness into what exactly the biggest fleet of GSE vehicles is doing allows for engineers to build highly precise models for tweaking operational flow. True quantified decisions about fuel burned, distance travelled, and general wear and tear can be made about these pieces of equipment allowing for preventative maintenance instead of reactionary maintenance. The decisions to refurbish existing equipment versus purchasing new ones can be made now based upon simple concepts like fuel economy or average repair and replacement lifecycles.

Accurate depreciation and equipment usage assessments can more effectively be "numbers justified" instead of relying on assumptions or the experience of mechanic staff who may be retiring soon. Further still, decisions regarding the corporate safety culture (or perhaps lack thereof) can be properly assessed leading to the prevention of serious accidents and a more progressive training (and re-training) program. The ability to do more and make better decisions with less is achievable when actionable data is consistently collected and this is the ultimate goal achieved in this research. Nowadays, with the rapid advancement of smartphone technology, the signals measured by the data logger can also be recorded using a variety of apps in smartphones, which these days are equipped with different types of sensors. This means that drivers can use their smartphones as a data logger to measure all the signals. However, the developed DAQ system still can find a wide range of applications in industry such as distribution centers for large companies because a number of companies are restricting or even banning cell phones in their workplaces.

8. Conclusions

A sensor package and DAQ system was designed for cargo tractors, through which important data on their usage patterns can be gathered, such as GPS route, vehicle speed, engine state, transmission state, seat occupancy, fuel level, and video recording. The data collected using the DAQ system will support development of cargo tractor activity simulations, which can be used to optimize work flow and energy efficiency. Different mounts for installing the sensors and other components onto the cargo tractor were designed and fabricated to facilitate the integration of this DAQ system. Field testing results showed that the designed system can effectively collect the cargo tractor data and the integrated system will not alter the driver's manner in driving the cargo tractor. The data collected by sensors are converted into csv files through a data logger, which can be easily read into spread sheets for further processing and analysis.

Future research includes taking the blueprint for a DAQ refit outlined in this research and applying it to additional vehicle types similar to cargo tractors in comparable "sandbox" environments like airport ramps where many of the variables are within the control of the facility. Forklifts within a material handling warehouse are another example where this methodology could be applied where the resulting data would further benefit a corporation that is heavily reliant upon operational optimization.

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