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Design of a GreenHouse Gas Reporting System for Package Delivery

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Abstract: In the United States, the majority of small packages are shipped using trucking transit cycles. These transit cycles are major carbon emission polluters leading to the transportation and logistics industry accounting for 29% of total carbon emissions in the United States. GreenHouse Gas (GHG) emissions estimates are based on emissions models that require tracking package location. Currently, eighty-five percent (85%) of packages are tracked with discrete event tracking (i.e., RFID or barcode). Discrete tracking results in under-reporting GHG emissions by at least 25% (depending on circumstances and conditions). A case study analysis of package delivery from warehouse in Atlanta to warehouse in Washington DC resulted in under-reporting on GHG emission from discrete methods by an average of 25%. An improved GHG reporting system for small packages was developed based on a mobile device to provide continuous tracking. In addition, an enhanced set of emission models are used along with a mobile package sensor that provides continuous package tracking to include data such as position, time, and velocity. With improved reliability of GHG emission inventory reporting a set of report regulations and standards were developed to methodize the processes of GHG reporting.

Keywords: Logistics, Optimization, Environment, GreenHouse Gas (GHG), Emissions, Continuous Tracking

1. Introduction

The logistics industry is responsible for ensuring a package is efficiently transported from manufacturer to consumer via warehouses, distribution centers, trucks, and alternate forms of transportation. In 2019 approximately 14.7 billion small packages and parcels were shipped within the United States alone (Mazareanu 2021). In the United States today, the majority of small packages are shipped primarily using trucking transit cycles. These transit cycles, especially on the national scale, are major carbon emission polluters. The transportation and logistics industry accounts for 29% of carbon emissions in the United States, making it the largest polluting industry (EPA 2021).

As governmental regulations and social expectations develop increasing concern for environmental protection, it is becoming critical for companies within the logistics industry to adopt technology and methodologies to accurately track and report fleet emissions. This research was crucial to identifying the underlying foundation and gaps in environmental reporting within the industry so that developed technologies may mitigate gaps and further existing operations.

2. Context Analysis

2.1 Stakeholder Analysis

Adopting environmental responsibility is a core business strategy. Environmentally friendly companies have an opportunity to set a positive example by their actions while garnering societal support. Unfortunately, implementing a green business model may not always be a quick and smooth transition for a company and its current employees. There are initial expenses and data risks to consider but most tensions fall secondary to the biggest tension. The biggest tension is that society as a whole wants to reduce CO2 emissions but how much is it going to cost. Our system will minimize both, providing a win-

win situation where we help the environment by reducing CO2 which reduces fuel burn, which reduces costs and benefits the company by increasing profits. In the long run there's no reason not to go green.

2.2 As-Is Process

To best understand the operational environment, the team studied current processes and technologies being utilized within the logistics industry. These documented As-Is processes included: logistics delivery, package tracking, emission generating, and GHG inventory reporting.

2.2.1 Logistics Delivery Process

The package delivery and logistics supply chain industry play an imperative role in both the work and lives of individuals throughout the country and even the entirety of the globe. The logistics industry, made up of both transportation and warehousing, alone made up 7.4% (approximately $1.56 trillion) of the United States gross domestic product in 2020 alone (Kearney 2021). The vast majority of individuals within the United States directly utilize or benefit from the logistics industry for their own personal ordering and shipping needs. A 2020 "Year-in-Review" report was released by the Department of Transportation (DoT), describing that in addition to wide general use, the transportation and logistics industry accounted for a total of 14.2 million labor workforce jobs (10% of the total US workforce) (DoT 2020). Therefore, the system's target enterprise directly impacts the work of 14.2 million logistic industry employees and indirectly to the remainder of the US population.

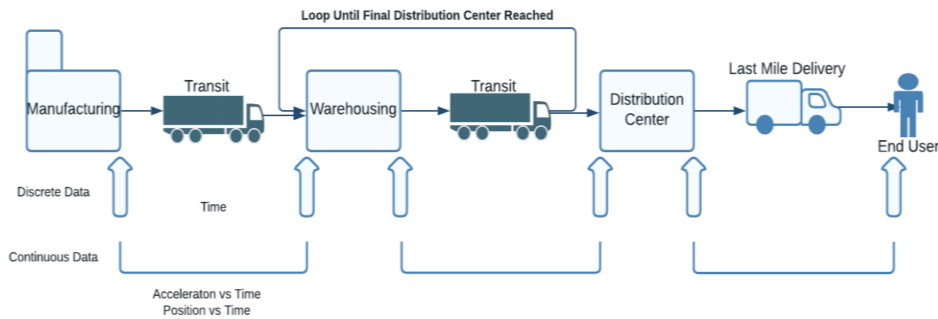


Figure 1. Logistics Delivery Process

As seen in figure one, the package travel cycle is a standard repetitive process that is carried out in a variety of interactions in order to transport a package from a manufacturer to an end user or customer. While the processes are standard, each parcel's travel is unique in the different amounts of wait time, loop repetition, and routes that it moves through. The polluting processes of interest in this cycle specifically are the transit processes. Transit develops into a shipping loop between warehousing and transit where packages are tracked and distributed until reaching a final destination.

2.2.2 Package Tracking Processes

The logistics process of tracking and tracing packages is generally broken down between two different methods, known as Discrete and Continuous (Hillbrand et al, 2007). Discrete tracking systems, such as the use of barcodes and RFID, are leveraged to alert the arrival and departure of cargo at designated locations. These systems are limited to only tracking shipments that reach a predefined location and are equipped with the proper technological functionality. Continuous tracking on the other hand, leverages technologies such as GPS and Global System for Mobile Communications (GSM). Continuous solutions leverage methodologies to localize an accurate location of a package at any and all times. These methods are used to both record full length route paths and when possible, share current movement and position with available logistic networks (Kandel et al, 2011).

2.2.3 Emissions Generating and GHG Reporting

Current methods of estimating carbon emissions that are reliant on discrete package tracking take assumptions and generalizations into the equations leveraged. Discrete data does not collect data such as acceleration and velocity so equations are reliant on an assumption of constant acceleration and fuel burn which would never be accurate within the operational environment. Current emission estimates only rely on three factors that include: total distance traveled, weight of the shipment, and general emission factor. The emission factor used is a constant derived from laboratory engine testing and the average factor used for transport trucks is 161.8 grams per ton mile. In the operational environment the emissions factor would change due to acceleration, incline, temperature, and other performing factors for which discrete methods cannot account (Mathers 2015).

Continuous methods on the other hand leverage remote sensing emission estimation methods that use continuously collected instantaneous route data (such as acceleration, time, position, and velocity). From that point piecewise functions (as seen in the equations section) are leveraged to calculate a vehicle's specific power, fuel consumption, and specific distance based emissions factor for each instance. Combined with the distance traveled GHG values are generated for each instance and can be summed together for a total route emission estimation (Davidson et al, 2020).

As for GHG inventory reports, analysis of top logistics companies within the United States clarified two facts. The first, that there were no official regulations for carbon emission reporting by a government or corporate body. The second being that there were no standards established for what these GHG inventories should contain. Companies often only reported environmental roadmaps and no statistical emission data.

2.3 Need Statement

There is a need to develop a GHG reporting system to improve logistic GHG inventory reporting standards and accuracy. This must be done through the development of a mobile continuous package tracking device, GHG analytic support tool, and criteria for GHG inventory reporting. The tracking device must accurately collect real rojute data (time, position, and velocity) when paired with a package. The support tool must leverage high fidelity emission estimation equations through the use of collected route data. GHG reporting must display yearly critical GHG information according to a company, its fleet, and high polluting sectors.

3. Design Solution

3.1 Concept of Operations (ConOps)

The ConOps for the GHG Reporting System follows the high-level flow diagram seen in figure 2. A package is paired with a mobile tracking device. The package then travels normally through its trucking transit cycle. During this phase the mobile device is continuously collecting instantaneous route data (such as time, position, acceleration, and velocity). Once the device is retrieved from the package the corresponding data can be uploaded to the GHG Analytic Support Tool. Here high-fidelity emissions equations are used in conjunction with the continuous data to generate GHG estimates, visualizations, and route optimization analysis. Together these outputs are used to populate a GHG Inventory Report which can consist of different routes, fleets, packages, and other shipping factors.

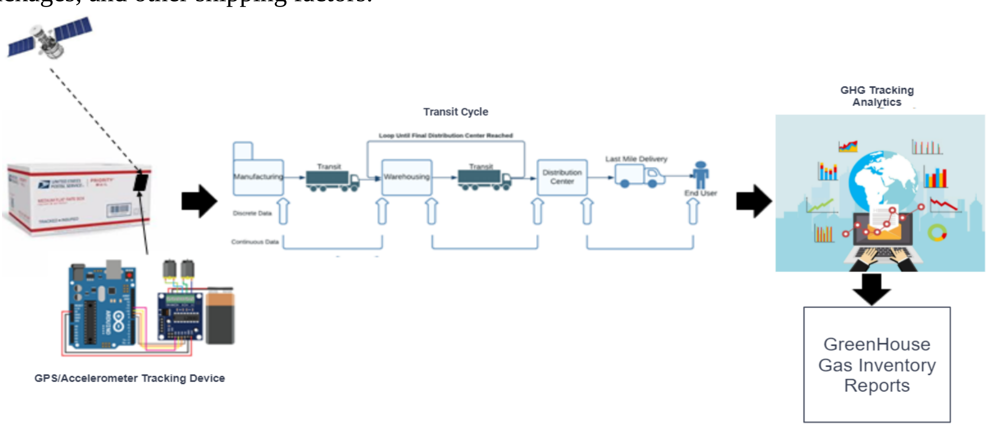


Figure 2. ConOps

3.2 GHG Tracking Device and Analytic Support Tool

The implementation for the mobile device of the GHG Reporting System is the Sten-SLATE Experimenters Kit Arduino board. Components include: MPU-6050 6 Axis IMU, Neo-6M GPS, and a Micro SD Card adapter.

The GHG Package Reporting System processes are decomposed into specific workflow processes as seen in figure 3. The high-level action diagram depicts all major stages that occur within the system. These stages include mobile sensor data collection, data extraction, data parsing, route visualizations & optimizations, and most importantly emission estimation processes. From the high-level action diagram view three processes are decomposed to depict specific cycles of these processes. These decomposed processes include sensor data collection, raw data parsing and emission estimation.

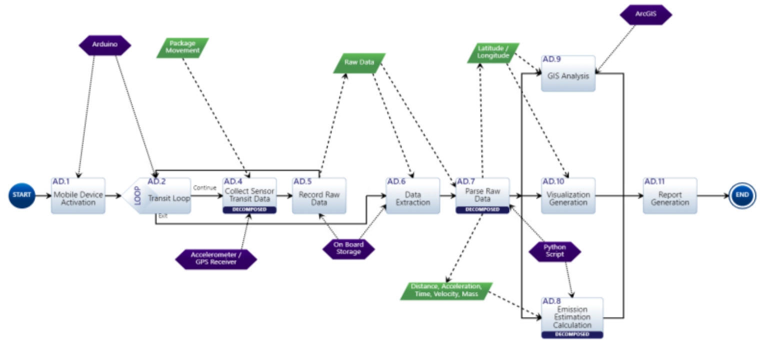


Figure 3. GHG Reporting System Workflow

3.3 Equations for Estimating GHG Emissions

$$VSP = \frac{2500+\left(R_o*v+R_1*v^2+C_d*A*0.5*\rho*v^3\right)*1.08}{m*1000} + v*1.08*(1.04*a+g*Grad) \quad (1)$$

Vehicle Specific Power (Kilowatts per ton: kW/t), used to measure the instantaneous power demand of the vehicle over its mass.

$$FC_{gh} = (M*VSP+C)*m \qquad FC_{gkm} = \frac{FC_{gh}}{v*3.6} \quad (2)$$

Fuel Consumption (Grams per hour: g/h to Grams per kilometer: g/km), used to measure the fuel consumed during a specific time/distance. It is then converted to fuel consumed in grams per kilometer traveled.

$$EF_{gkm} = EF_{gkg} * \frac{FC_{gkm}}{1000} \quad (3)$$

Distance Emission Factor (Grams per kilometer: g/km) which combines average fuel-based emission factor with derived fuel consumption for a distance-based emission factor. For each instance where distance-based emission factor is calculated it is then combined with the distance traveled in that instance to generate GHG produced at that given instant. These are summed at the end to find a total route emission estimation (Davidson et al, 2020).

4. Testing

4.1 Verification

Verification testing of the mobile device has passed accuracy testing for acceleration and velocity at a 90% confidence interval for true values. Results of testing on board GPS receivers matched the hardware specified sensor accuracy rates for an expected 2.5 meters of error. Currently, independent battery life of the mobile device has been recorded to remain operational for approximately 200 hours with the opportunity for the use of a 26,800 mAh external battery reserves all error rates and confidence intervals are then accounted for during data parsing and processing.

Trial	Start Position (°)	Stop Position (°)	Distance (m)
1	38.83332,-77.31612	38.83406,-77.31602	82.74
2	38.83331,-77.31613	38.83404,-77.31602	81.73
3	38.83330,-77.31609	38.83405,-77.31601	83.68
4	38.83332,-77.31609	38.83405,-77.31602	81.4
5	38.83331,-77.31612	38.83405,-77.31603	82.65
6	38.83334,-77.31611	38.83410,-77.31601	84.95

alpha	0.01
n	6
m(true)	84.39
m(experimental)	82.858
S^2	1.701
S	1.304
df	5
Critical T Value	4.032
2 Tailed T-Test	3.79
p-value	0.0128
Fail to reject H0	
% Error	1.8

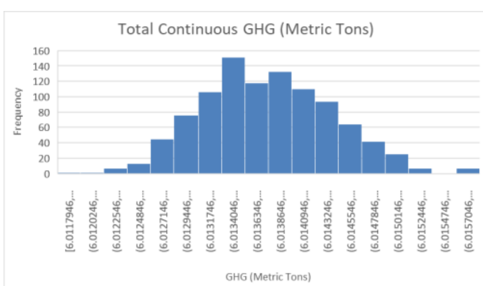
Figure 5. Dynamic Position Test

4.2 Simulation Case Study

A simulation was created to test both the accuracy of the analytic support tool and to evaluate the effectiveness of continuous tracking on logistics package emission estimations. The simulation operates using processes and equations outlined within the design solution section. However, latitude and longitude positional data is pulled from an online database instead of being gathered directly. Theoretical travel time from origin to destination is used and velocity is randomized according to the triangular distribution recorded from an initial shipping trial and follows the distribution of tri (.2, 10, 15).

A simulation, consisting of 1000 independent trials, was conducted between the locations of Fiarfax and Atlanta. Imputed values included a theoretical travel time of 600 minutes, shipment mass of 20 metric tons, and a recorded latitude and longitude position file from Fairfax to Atlanta.

The null hypothesis: mean GHG emissions reporting from discrete tracking methods is equal to that of the mean GHG emissions reported from continuous tracking. Alternative hypothesis: the results of the mean discrete GHG reporting would be less than the mean GHG reported from continuous tracking. In this case study, there was a mean 6.01 metric tons of CO2 emissions using the continuous tracking method and a mean 4.80 metric tons using the discrete. This case results in a 25% difference between continuous. From the 1000 simulated trials, the derived critical values are shown below. With a corresponding p-value less than .00001 we reject the null hypothesis and state that, in this case, the mean GHG results of continuous tracking is greater than that of discrete tracking.



H0: m(Discerete) = m(Continuous)	
Ha: m(Discerete) < m(Continuous)	
aplha = 0.05	
n	1000
m(Discerete)	4.7991839
m(Continuous)	6.0138582
S^2(Discrete)	0
S^2(Continuous)	4.133E-07
S(Discrete)	0
S(Continuous)	0.000642889
df = v	999
Critical T value	1.65
1 Tail T-Test	5.975E+04
p < .00001 - Reject H0	

Figure 6. Fairfax x Atlanta simulation results

Analyzing the trends between both the instantaneous and cumulative GHG emissions over distance provided a tool for further analysis on continuous and discrete tracking (as seen in figure 11). Viewing small distances, discrete and continuous methods behave similarly in their trends of increasing GHG. However, it is apparent in the differences in the estimated GHG emissions at larger distances where fuel consumption varies the output. The simplistic linear relationship of discrete tracking is not representative of accurate GHG emissions produced.

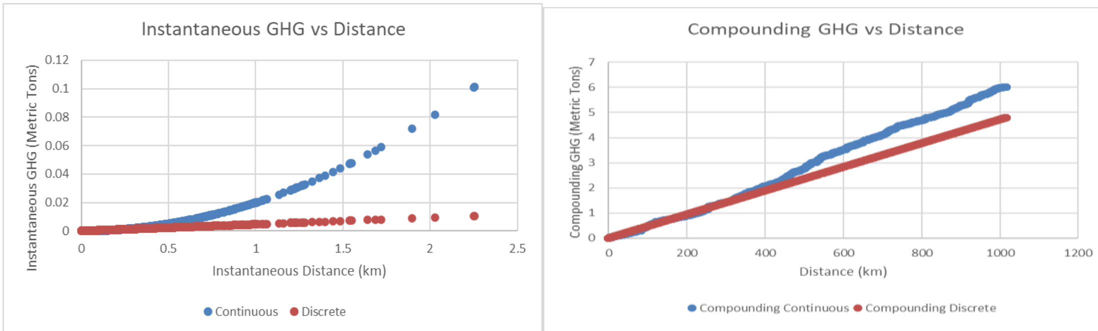


Figure 7. GHG vs Distance

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