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MODELLING THE CARBON FOOTPRINT OF NON-OPTIMAL ECOMMERCE LAST MILE DISTRIBUTION

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ABSTRACT

The topic of sustainability is now a top priority for business strategy, consumer discretion, and government aid. Sustainability's mass adoption comes from the issues arising from climate change and the ability to use metrics to tell what actions are primarily contributing to the increase in emissions. The top contributors of GHG emissions are large companies conducting business. The largest proponent of climate change for a business, making up ninety percent of the GHG emissions, is related to a company's supply chain. Since business is a top contributor to emissions, companies are now investing heavily in technology to reverse or minimize their environmental harm.

One way a business can look at sustainability is through a carbon footprint or carbon dioxide equivalent (CO2e) calculator. These calculators allow the business to view its emissions from the tasks the calculator is considering. This research partners with a Software-as-a-Service (SaaS) provider specializing in network optimization to build a carbon footprint modelling tool. The research investigated potential emission savings from perfect inventory placement, simplified ways to portray emission metrics, and financial savings related to transportation with perfect inventory placement.

It was found that there is potential for a business to save 35.5 percent of total emissions related to last mile transportation if it has perfect last mile inventory placement. In addition to the emission savings, seventeen different ways to portray tons of carbon dioxide equivalent (tCO2e) emission metrics were gathered in Table 5. Finally, it was found that annual savings in total transportation costs are $5,763,963.53 by evaluating tractor trailer and last mile delivery van fuel and labor costs.

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Finally, I would like to display my gratitude to the members of the Software-as-a-Service company who had a large role in the development of this research. The supply chain SaaS company was generous enough to provide the data used in the following research and worked closely with me over the past year to execute the methodology and analysis. Specifically, I wish to recognize Michael the CEO and Co-Founder for their continual support throughout the project. It has truly been a pleasure working with him and his team. I hope this research remains useful to the company in the future.

Chapter 1

Introduction

Climate change refers to long-term shifts in temperatures and weather patterns. An increase in temperature at Earth's surface, rising sea levels, shrinking ice caps, rampant wildfires, and extremes in precipitation events around the world are all proven and researched scientific discoveries relating to climate change. The primary cause of this climate change comes from fossil fuel combustion created through human activity which emits greenhouse gases (GHG) into the ozone layer of Earth's atmosphere. Humans are producing these heat trapping GHG's at a faster rate than the Earth is capable of processing them, leading to a forty percent increase occurring over the industrial era (U.S. Global Change Research Program, n.d.).

This spike in GHG emissions occurred during the industrial era because businesses began to grow at a much faster rate. This growth in business led to an increase in transportation and industry which, according to the Environmental Protection Agency, equate to relatively fifty percent of greenhouse gasses in the United States today (Environmental Protection Agency, 2022). It is commonly known by the public that business creates a large portion of GHG emissions contributing to global warming. Due to this knowledge, public pressure has encouraged companies to investigate which sectors are causing most of this issue. It has been found that an organization's supply chain is the culprit for more than ninety percent of GHG emissions when looking into their company's overall impact on the climate. Over the past two decades, many efforts have been made by government entities and leading organizations to reduce Scope 1 and 2 GHG emissions (Environmental Protection Agency, 2023).

One of the main government entities involved in regulating and advocating against climate change is the Environmental Protection Agency (EPA). There are many different responsibilities of the EPA. Some of these responsibilities include national environmental enforcement, waste and chemical management in the environment, water management, climate science, and environmental monitoring (Environmental Protection Agency, 2023). The EPA also has many different certifications and programs that industry leading companies in sustainability take part in. The EPA's SmartWay program helps companies improve their supply chain's sustainability through measuring, benchmarking, and improving freight transportation efficiency (Environmental Protection Agency, 2022).

SmartWay is a voluntary public-private program that was launched in 2004 to advance sustainable transportation in supply chains. The SmartWay program accomplishes this goal through many different activities. It provides a well-recognized system for tracking, documenting, and sharing information. Also, it helps companies identify and select efficient freight carriers, transport modes, equipment, and operational strategies to improve supply chain sustainability and lower costs. Additionally, it supports global energy security, advocates for advanced fuel-saving technologies, and is massively supported across the world by environmental groups, industries, and the corporate community. Logistics companies, freight shippers, carriers, and other stakeholders' partner with the EPA SmartWay program to measure, benchmark and improve their operations and reduce environmental impact (Environmental Protection Agency, 2022).

Companies that wish to implement an environmental sustainability strategy must measure their organization's environmental impact. A carbon footprint calculation is the standard way for companies to understand the impact that different sectors of their business have on the environment (IBM Corporation, 2020). Carbon footprint calculations can investigate operational activities including transportation, manufacturing waste, facility energy use, and more. This research is centered around the creation of a carbon footprint calculator for a Software as a Service (SaaS) company that specializes in small parcel, direct to consumer (D2C), last mile distribution and will be focused on transportation. This research investigates last mile mileage as the total distance the parcel travels after the customer places an order. Using UPS as an example, once an order is placed the software looks at the distance from the UPS origin terminal to last mile center, in addition to the small vehicle, such as a brown UPS package car, route travelled to the customer's house. This carbon calculator will aid the company in offering a new tool for visibility in sustainable supply chain metrics to their customers.

Direct to consumer, small parcel delivery has become more prevalent in organizations' supply chains due to ecommerce's fast growth. The global ecommerce growth rate for 2023 is forecasted at 10.4 percent making worldwide sales $6.3 trillion (Gaubys, 2023). This massive sector is expected to continue to grow, which makes research in it increasingly important. A study from MIT's Center for Transportation & Logistics showed that ecommerce's growth can lead to positive contributions regarding sustainability by creating supply chain efficiencies (Sparkman, 2020). The three supply chain efficiencies considered in this paper are: ideal inventory placement, distributed order management, and cartonization. These efficiencies are considered important to understand as they play a role in the data collected for this research.

There are a plethora of different practices and resources available to aid in calculating carbon footprint around transportation and logistics. The methodologies and resources in practice for this research are based on the United States Environmental Protection Agency's SmartWay program and leverage the company's proprietary dataset to develop meaningful outputs. There are many other organizations involved in providing detailed and accurate information regarding climate change and carbon emissions calculation, including: The Intergovernmental Panel on Climate Change (IPCC), The Environmental Defense Fund (EDF), and the United Nations Framework Convention on Climate Change (UNFCC). These organizations along with others have committed research to the topics looked at in this paper and their methodologies may be drawn on to finalize this modeling tool.

The structure of this research will be the following: background, methodology, analysis, and results, conclusion and recommendation. The background will provide a brief history of indicators of climate change, how businesses supply chains impact the environment, the standard practices for measuring carbon footprint, and finally how ecommerce supply chain efficiencies can help reduce carbon footprint. The methodology section will explain the process, step-by-step, that was used in the creation of the carbon emissions modelling tool. It will detail the selection process of constants, the metrics used, how each metric is used in the calculations, and the reason each metric is utilized in the tool. The analysis and results section will detail how the outputs of the modelling tool were investigated. This section will give information on any trends in the data and summarize the findings holistically. Finally, the conclusion and recommendation section will dive into how the company, or other supply chain SaaS companies, can interpret the carbon footprint modelling tool's results and use them to give their customers and stakeholders sustainable strategic recommendations on inventory planning. The primary objective of this research is to provide a tool for companies, specifically the company partnered with, that can calculate carbon footprint around last mile transportation in supply chains. This information will provide an increase in visibility to stakeholders of the software company when this modelling tool is implemented, create a new service offering for said stakeholders, and reduce costs.

Chapter 2

Background

Climate Change Indicators

The hottest year on record is statistically tied between 2020 and 2016. There are natural processes that can play a role in affecting climate change such as variations in solar activity, changes in the Earth's rotations, volcanic eruptions, and even cow gas. Unfortunately, these natural processes cannot solely explain the warming observed over the past century (NASA, 2023). Climate change ramped up drastically at the start of the industrial revolution due to an increase in human activities linked to emitting heat-trapping greenhouse gases. In an environment of persistent climate change, it is important to understand how changes in the environment impact the planet directly as well as different metrics used to measure these impacts. Key climate change indicators include atmospheric greenhouse gas concentration, sea level rise, ocean heat and ocean acidification (World Meteorological Organization, 2022).

A greenhouse gas (GHG) is any gas that is capable of trapping heat in the atmosphere. The three most prevalent GHGs in the atmosphere include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). These GHGs can enter the atmosphere through the burning of fossil fuels like coal or oil, chemical reactions, agricultural practices, and industrial activities. In addition to the most prevalent GHGs, there are synthetic and more potent GHGs classified as fluorinated gases which include hydrofluorocarbons, perfluorocarbons, sulfur hexafluoride, and nitrogen trifluoride (Environmental Protection Agency, 2023). Atmospheric GHG concentration is the abundance of a particular gas in the air. There is a positive relationship between emissions and concentration leading to GHG's with large emissions to have higher concentrations. These concentrations are typically measured in parts per million (PPM) or parts per billion (PPB) and describe how levels of major GHGs in the atmosphere have changed over time. GHG concentration is measured through monitoring stations around the world and verified by satellite instruments that measure ozone density (Environmental protection Agency, 2022).

Another key indicator used to address climate change is sea level rise. As Earth's temperature rises, sea level follows. This is because water expands as it gets hotter as well as from the melting of glaciers and ice sheets increasing the volume of water. The change in sea level can negatively impact the lives of people living in coastal regions due to flooding, eroding, and damaging infrastructure. Scientists look at sea level rise in two parts. Relative sea level change is how the water level changes in relation to the land at a particular location. Absolute sea level change looks at water level of the ocean surface above the center of the Earth. This metric is important to be monitored because since 1993, average sea level rise has risen at a rate of 0.12 to 0.14 inches per year which is roughly twice as fast as the long-term trend of 0.06 inches. The sea level rise indicator is measured by satellites and through tide gauges located in coastal areas around the world (Environmental protection Agency, 2022).

More energy from the sun is being trapped in the atmosphere due to Earth's GHG concentration increasing over time. The ocean absorbs this energy and stores it as heat. The total amount of heat stored by the oceans is called "ocean heat content." The data collected for this indicator represents nearly half the ocean's total volume measuring the top 6,600 feet. Additionally, the top 2,300 feet are measured separately as this is where much of the observed heating takes place. The ocean heat indicator has a direct relationship with the sea level rise indicator due to water expanding as it gets warmer. This is one of the primary causes for sea level rise which makes this an important metric to monitor. The data collected for the ocean heat indicator comes from ships, airplanes, and underwater robots. Temperatures are taken at different depths and then indexed together to create a meaningful measure (Environmental protection Agency, 2022).

The final key climate change indicator investigated for this research is ocean acidity. The ocean is crucial for filtering carbon dioxide (CO2). Since atmospheric GHG concentration is increasing, the ocean must absorb more and more CO2. Over the past 250 years, the ocean absorbed twenty-eight percent of CO2 produced by human activity. When CO2 reacts with the sea water in the ocean it creates carbonic acid. This process is known as ocean acidification and can have a negative impact on the ocean's ecosystem. Ocean acidity is tracked through pH level and is based on a combination of observations, calculations, and modelling (Environmental Protection Agency, 2023).

All four climate change indicators mentioned above reached new record highs in 2021. According to the World Meteorological Organization (WMO) this should be another clear sign human activity is causing planetary scale changes across the Earth which will have harmful and long-lasting ramifications (World Meteorological Organization, 2022). It is important for businesses to act now on this. Governmental changes in policy take much longer to be approved and take effect than organizational shifts. Additionally, there is pressure from the public stressing the importance of climate change to organizations. These are two reasons explaining why climate change is becoming a main aspect of businesses' strategic goals.

Climate Change: The Role Business Plays

Since businesses can create the largest collective impact in minimizing climate change, it is important that organizations understand the role they play and the actions they should take to make a difference. The largest proponent of climate change for a business, making up ninety percent of the GHG emissions, is related to a company's supply chain (Environmental Protection Agency, 2023). This creates many opportunities for leaders to utilize different techniques to aid in accelerating towards net zero emissions. McKinsey Consulting has identified techniques used by companies for scaling their green businesses which include proactively create business ecosystems, lead on sustainable operations through ambitious targets, innovation, partnerships, and secure a cost advantage by identifying a scaling break point for new technology (Bland et al., 2022).

The first technique business leaders are looking into for reducing carbon footprint revolves around proactively creating business ecosystems. In many cases, it is possible to strategically align a company's business goals with a value-chain. In these cases, organizations can find ways to lower costs while also reducing their net carbon impact. One of the prime examples of how a company can align sustainability goals with its value chain is through the circular economy business model. This business model's goal is to reduce waste through designing products that are repairable and durable with materials that can be recycled at the end of the products' life cycle. This allows the product to be repurposed instead of ending up in a landfill at the end of its life, which is how a linear economy business model works. A circular economy model can create value for an organization while preserving natural resources, lowering waste, and advocating for environmental and social justice (Hayes, 2023). Figure 1 shows a visual representation regarding the flow of the circular economy model. It shows the regenerative nature from the start of the process of gathering raw materials all the way to proper collection and recycling to ensure a circular lifespan of the product.

Figure 1

(European Parliament, 2023).

Another strategy organizational leaders utilize to reduce carbon emissions is to lead sustainable operations through ambitious targets, innovation, and partnerships. Many global companies are announcing ambitious targets to aid in an organizational culture shift toward sustainable operations. An example of this is the Climate Pledge which is an initiative co-founded by Global Optimism and Amazon to encourage organizations to reach net-zero carbon emissions by 2040 which is ten years before the Paris Climate Agreement's goal. There are currently over 401 companies in thirty-six countries around the globe that have signed this pledge including Microsoft, IBM, Verizon, and hundreds more (Global Optimism, 2021).

Additionally, there are many organizations such as the Environmental Protection Agency that leaders can choose to strategically partner with to aid in driving sustainable operations. Through these partnerships businesses can achieve certifications and pool together sustainable knowledge from many different stakeholders. There are thousands of certifications for businesses to choose from, but some notable ones include Certified B Corp, LEED, SmartWay, and ISO 14000 Environmental Management (Library of Congress, 2021). This research was completed through a partnership with a SaaS company currently working with EPA SmartWay representatives to achieve certification.

The final technique identified that business leaders are utilizing to become more environmentally friendly is to secure a cost advantage by identifying a scaling break point for new technology. For a business to set these ambitious goals, form strategic partnerships, and report carbon footprint improvement they must first be able to measure their environmental impact. The primary technology around measuring a business's environmental impact is a carbon emissions calculator tool. It is beneficial for businesses to invest in this technology as it identifies areas of improvement within business operations and creates value for customers. Once the tool is created, businesses can track their emissions and determine the effect their sustainable actions have. Examples of technological advancements that have proven to have a sustainable impact include renewable energy, biodegradable plastic, eco-friendly packaging, electric vehicles, and energy efficient data centers (iED Team, 2022).

The standards around the creation of carbon calculator modelling tools come from the Greenhouse Gas Protocol. This protocol became standardized after the Paris Agreement out of the need to aid countries and companies in measuring, reporting, and mitigating GHG emissions. The primary GHG emissions looked at when measuring carbon footprint are Carbon Dioxide

(CO2), Hydrofluorocarbons (CH4), Nitrous Oxide (N20), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), Sulphur hexafluoride (SF6), and Nitrogen trifluoride (NF3). These GHG emissions are classified into Scopes 1, 2 and 3 based on how much control the organization has over the source (World Resources Institute, 2019). Additionally, a constant referred to as Global Warming Potential (GWP) is assigned to each GHG to explain the amount of impact it has on the environment with larger quantities referring to a greater impact. It measures how much energy one ton of GHG will absorb over a period in relation to one ton of carbon dioxide (Environmental Protection Agency, 2023). GWP allows multiple GHGs to be combined into one meaningful metric referred to as a carbon dioxide equivalent (C02e) that organizations can report and measure. Table 1 references the standard GWP constants that were utilized for this research. As an example, this table shows that one gram of methane has equivalent environmental impact twenty-five grams of carbon dioxide.

Table 1

Greenhouse Gas	Global Warming Potential (GWP)
1. Carbon Dioxide (CO2)	1
2. Methane (CH4)	25
3. Nitrous Oxide (N2O)	298
4. Hydrofluorocarbons (HFCs)	124 - 14,8000
5. Perfluorocarbons (PFCs)	7,390 – 12,200
6. Sulfur Hexafluoride (SF6)	22,800
7. Nitrogen Trifluoride (NF3)^3	17,200

Climate Change: The Impact of Last Mile Ecommerce

This research creates a carbon calculator modelling tool with data related to last mile e-commerce distribution. While ecommerce may have less of an impact on carbon footprint compared to traditional shopping, it still generated three percent of total global greenhouse gas emission in 2021. This percentage is expected to increase to seventeen percent by 2050 (Harbaugh, 2022). Additionally, last-mile parcel deliveries are estimated to increase by seventy-eight percent globally by 2030 which can lead to a thirty-two percent jump in GHG emissions from urban delivery traffic (FarEye, 2022). It is becoming increasingly important to have research that investigates the sustainability in this space. Some methods that ecommerce businesses use to increase supply chain efficiencies and decrease overall emissions are ideal inventory placement, distributed order management, and cartonization.

Ideal inventory placement is how an organization strategically manages the position of its inventory. Organization's base ideal inventory placement by looking into what stock-keeping units (SKUs) best fit within its supply chain network as well as geographically. The primary goal of ideal inventory placement is to place the correct amount and types of inventories in locations to match customer demand. This concept helps bring value to customer needs and improve economic efficiency while eliminating unnecessary miles travelled in the process (Jenkins, 2022). When a product is ordered but not within inventory nearby additional miles are incurred on the order, which in turn creates additional greenhouse gas emissions. Other reasons organizations investigate ideal inventory placement are to improve customer service, avoid stockouts, and prevent supply chain disruptions.

A distributed order management (DOM) system unifies online retailer's business channels through blending multiple platforms. This gives the business additional visibility to their inventory across their complete supply chain network. Many customer-centric businesses have adopted an omni-channel approach for distribution by selling products through multiple ecommerce platforms in addition to physical locations. A DOM system focuses on the tradeoff of meeting customer expectations while minimizing price. It works to automate key functions such as synchronizing order routing and inventory data, processing orders from multiple sales channels, shipping, and inventory management. As retail businesses increase the number of warehouses, it becomes increasingly difficult to keep track of inventory without a system for consolidating this data from multiple streams (Muppirala, 2022). Companies such as SAP, IBM, Manhattan Associates, Adobe, and many more have invested in creating DOM software due to its high demand. These systems can increase the efficiency of an organization's supply chains and in turn decrease emissions.

Finally, cartonization is the process of determining the best packaging configurations for an order shipment based on a variety of parameters. These parameters can include optimal carton size based on dimensions, weight, order quantity, and product type. Cartonization fixes the challenges in packing and shipping created by ecommerce parcels being different in shapes and sizes. Cartonization can create immense cost savings for business with Ikea saving 1.4 million dollars just by optimizing packaging for one sofa (Hopstack, 2022). Cartonization can also have a positive impact on the environment. Through optimizing package configuration, less vehicles will be required to ship the same number of products creating fewer emissions.

Chapter 3

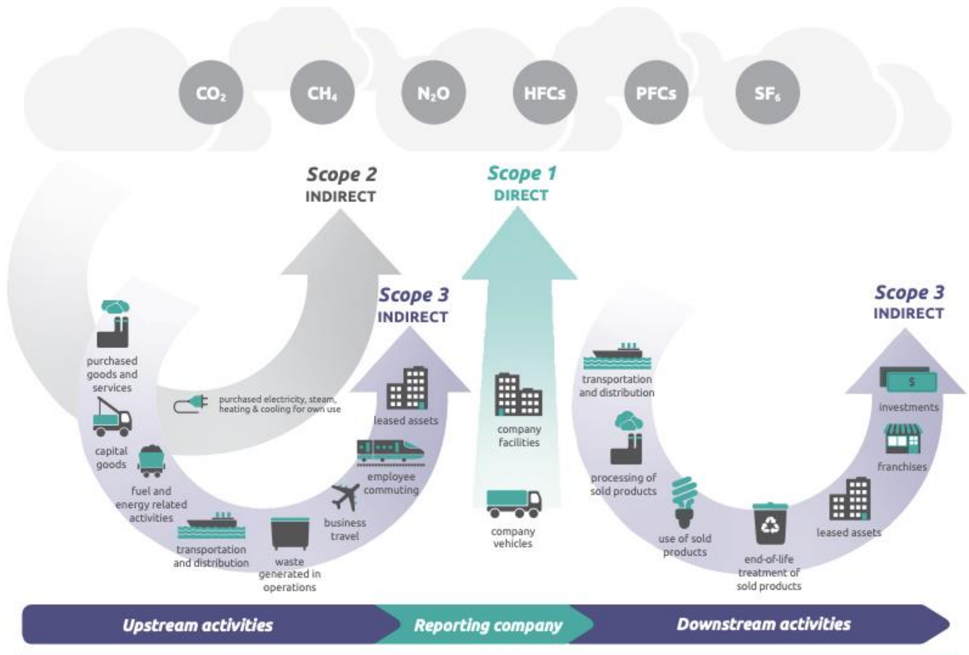
Methodology

Scope and Identification of Emissions

When businesses or organizations evaluate GHG emissions, three silos are categorized to effectively evaluate the carbon footprint: Scope 1, Scope 2, and Scope 3 emissions. This emission scoping was developed and standardized by the Greenhouse Gas Protocol to help measure progress in reducing CO2e and limit global temperature rise. Scope 1 emissions can also be referred to as “direct emission.” These direct emissions are produced through operating machinery and equipment owned by the company or organization, such as vehicles. Scope 2 emissions look at “indirect emissions” related to energy produced through commerce. An example of Scope 2 emissions would be the GHG emissions from generating electricity used in an office. Finally, Scope 3 emissions investigate “indirect emissions” created by consumers of the company’s product or created by suppliers making product for the company. These emissions tend to be the most difficult to influence because they are in the control of customers and supplier (World Economic Forum, 2022). Figure 2 demonstrates some of the upstream to downstream activities that are relevant when considering the scope of emissions.

The data being looked at for this research is from a customer of the Software-as-a-Service company it partnered with. It will be investigating Scope 1 emissions of ecommerce last mile delivery vehicles serviced by the company. Delivery method of the company’s product is controlled and owned by the organization which qualifies it as “direct emissions.” The miles driven will have a correlation to the amount of GHG emissions produced which will be evaluated through the carbon footprint modelling tool.

Figure 2



(World Resources Institute, n.d.)

There are six primary greenhouse gases identified by the GHG protocol that have negative impacts on the environment. These GHG's have had accounting and reporting standards created around them that will be utilized for this research (World Resources Institute, 2019). In calculations for GHG emissions, each GHG is evaluated separately based on emissions factors. These emissions factors are either self-reported or standardized bin numbers. The specific emissions factors for this research come from the EPA SmartWay program and are expressed in Table 2. The SmartWay Program tracks emission factors for the GHG's of CO2 and N2O as well as Particulate Matter 2.5 and 10. This research only investigates the calculation around the GHGs and avoided PM. After the different GHG emissions are calculated, they will be converted into a carbon dioxide equivalent (CO2e). This will be done using Global Warming Potential (GWP) factors to normalize the numbers with carbon dioxide or CO_2 as the base. The GWP factors were previously mentioned and are expressed in Table 1. Finally, the total grams of CO_2e calculated will be converted into tons of CO_2e (tCO_2e) to allow for simplified evaluation.

Table 2

Category (LTL)	*CO2 (grams / mile)*	*N2O (grams / mile)*
Bin	1,720	5.15
DHL Solutions	1,350	6.75
FedEx	1,450	2.55
United Parcel Service	1,650	3.25
XPO Logistics	1,450	1.85
US Post Office	1,950	5.65

Corporation Background

Due to confidentiality and legal reasons, the Software-as-a-Service company, and their customer whose data was analyzed request to remain anonymous. The company develops software that utilizes the supply chain efficiencies of ideal inventory placement, distributed order management, and cartonization to determine whether a last-mile ecommerce order met the criteria of an ideal order. The customer data comes from a small to mid-cap company with a consumer-facing product selling direct across multiple websites, marketplaces, and first party digital sales channels. They generate over 370 million dollars in revenue and have four distribution centers nationwide to provide two-day shipping to the lower forty-eight states.

Project Scope

This research will focus on a specific customer of the SaaS company and utilize the information generated from their omnichannel ecommerce sales. The objective of this research is to develop a standardized method for the SaaS company to provide visibility on an environmental impact metric, such as tCO2e, to their customers. This metric will help drive value to the SaaS company's customers by providing a new variable to consider besides fuel cost and customer service when determining inventory placement. It was determined the best way to achieve this goal is to take a subset of data from a high-volume customer and develop a carbon footprint calculator around it.

The SaaS company identified creating a sustainability metric for their customers as a key area of focus since customer demand favors a green business model. Giving customers visibility on a sustainability metric enables them to leverage environmental benefits in addition to financial impact created from extra miles incurred. Once the carbon footprint is calculated, customers will be able to make more informed decisions around their inventory placement and fulfillment operations by being able to evaluate multiple factors influencing decision making. The SaaS company provided ecommerce order fulfillment data on 16,377 orders for a four-month period in 2023 from one of their largest customers. The data was anonymized by removing visibility into private information to protect confidentiality in relation to the customer. The fulfillment data provided is Less-than-Truckload (LTL) shipments due to the nature of the ecommerce direct to consumer business model the SaaS company specializes in, but the modelling tool can add parameters for other modes of transportation such as air freight, truckload, and barge utilizing SmartWay emission factors shown in Table 3. The data on which shipping carrier was used has been included in the dataset which allows for a more exact calculation by leveraging the many partnerships carriers have with the SmartWay program.

Table 3

Emissions Factor Category	*CO2 (grams/mile)*	*N20 (grams/mile)*
Truck-load Dry Van	1,850	4.70
Short-haul Air	100,000	900
Long-haul Air	50,000	650
Barge	23,295	672

Data Preparation

This tool was developed with the data structure and interests of the software company in mind. A generic carbon footprint tool could have been used; however, it would not have been able to utilize all the data the company provided in a logical and efficient manner. The raw data export was received after multiple brainstorming sessions with the primary stakeholders of the software company and a general methodology was developed. The structure of the raw data was provided in an excel file format. Figures 3 and 4 identify the different column headings that were provided through the raw data export including: sales order date, sales channel code, fulfillment channel code, shipping carrier, shipping service level, fulfillment location name, shipping mileage, ideal fulfillment location name, ideal mileage, profit loss, ideal profit loss, shipping weight, shipping paid, estimated shipping cost, actual shipping costs, and delta of shipping cost.

Figure 3

	A	B	C	D	E	F	G
1	SalesOrderDate	SalesChannelCode	FulfillmentChannelCode	ShippingCarrier	ShippingServiceLevel	FulfillmentLocationName	ShippingMileage

Figure 4

	H	I	J	K	L	M	N	O	P
1	IdealFulfillmentLocationName	IdealMileage	ProfitLoss	IdealProfitLoss	ShippingWeight	ShippingPaid	EstimatedShippingCost	ActualShippingCost	DeltaShippingCost

Upon receiving the raw data export, the first step was to evaluate each column and determine its usefulness for creating a carbon footprint modelling tool. The primary characteristics looked for included distance travelled metrics and the shipping carriers. Distance would enable the utilization of emissions factors provided by SmartWay. The shipping carrier enables an additional parameter of specificity for the software company allowing for a more precise calculation. After evaluating all the raw data provided it was determined that six columns should be segmented from the export to further evaluate as shown in Figure 5. These columns include sales order date, shipping carrier, shipping mileage, ideal mileage, profit loss, and ideal profit loss.

Figure 5

	A	B	C	D	E	F
1	SalesOrderDate	ShippingCarrier	ShippingMileage	IdealMileage	ProfitLoss	IdealProfitLoss

Many deductions can be drawn from the data prior to the calculation or analysis of carbon footprint. The sales order date gives the information that approximates four months' worth of data from April 26th, 2023, to August 29th, 2023, were provided. Shipping carrier provides visibility to the five specific carriers responsible for all deliveries. The carriers used to ship goods for this customer of the software company include FedEx, United Parcel Service (UPS), US Post Office, XPO Logistics, or an unknown carrier as shown in Figure 6. The unknown carrier metric was created for simplicity. Data that was either unknown, “blank”, or a simple space were all converted to the same unknown carrier metric. Each of the specific carriers has a reciprocal emissions factor provided by their SmartWay partnership that allows for a more precise calculation based on the mix of distribution options a company uses as shown in Table 4. The unknown carrier categories use a bin value determined by SmartWay when a carrier is not partnered and is calculated through an index of averages.

Figure 6

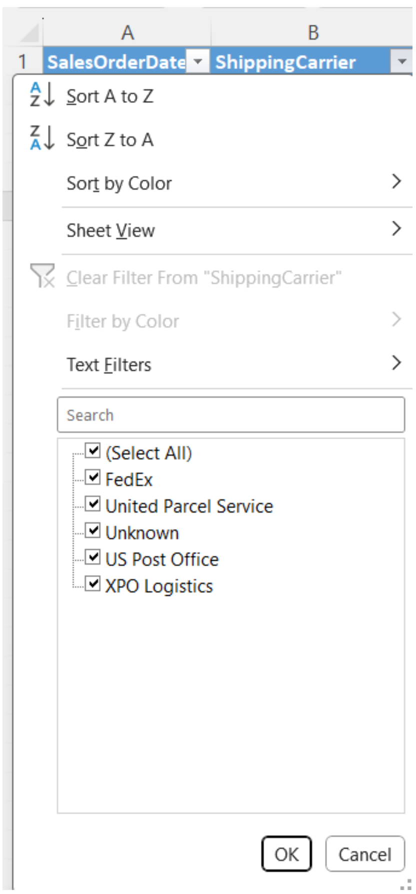


Table 4

Emissions Factor Category	*CO2*	*N2O*
Bin	1,730	5.15
DHL Solutions	1,350	6.75
FedEx	1,450	2.55
United Parcel Service	1,650	3.25
XPO Logistics	1,450	1.85
U.S. Post Office	1,950	5.65

The shipping mileage column allows for the deduction of total milage by the company. This column can be totaled to view the entire distance travelled for all packages over the approximate four-month span of data given. Ideal milage allows the deduction of whether a specific order was ideal or not. If the order was not ideal this column will provide data on the distance that should have been travelled. This mileage information will have a direct correlation to the amount of GHG emissions produced. The two final columns segmented for further inspection were profit loss and ideal profit loss. This information allows for the deduction of the monetary impact related to this distribution. These final two columns were not utilized in the methodology calculation but were necessary for reference when speaking with stakeholders. The creation of the formula to calculate carbon footprint, or tCO2e, was ready to be developed once the dates were in chronological order, shipping carrier outliers were converted to the unknown category, and deductions for each column's significance were made.

Methodology

The project resulted in the development of a model the estimates carbon footprint based on two specific inputs the software company tracks from its customers: shipping mileage and shipping carrier. The additional inputs required to create a logical GHG emissions calculation include global warming potential (GWP) factors referenced in Table 1 and SmartWay emissions factors for specified less-than-truckload carriers referenced in Table 4. The formula created through excel can take the shipping mileage and carrier, convert it into carbon dioxide (CO2) and nitrous oxide (N2O) emissions, and finally convert N2O emissions into a carbon dioxide equivalent (CO2e) metric allowing for the different greenhouse gases to be synthesized together. This formula can best be explained through breaking it down into four primary components as shown in Figure 7.

Figure 7

```
=(IF(CompanyData[@ShippingCarrier]="Unknown",1,CompanyData[@ShippingMileage])*IFERROR(VLOOKUP(CompanyData[@ShippingCarrier],Emission_Table,2,FALSE),CompanyData[@ShippingMileage]*CO2_Bin))+(
N2O_GWPFactor*IF(CompanyData[@ShippingCarrier]="Unknown",1,CompanyData[@ShippingMileage])*IFERROR(VLOOKUP(CompanyData[@ShippingCarrier],Emission_Table,3,FALSE),CompanyData[@ShippingMileage]*
N20_Bin))
```

Component 1:

```
=(IF(CompanyData[@ShippingCarrier]="Unknown",1,CompanyData[@ShippingMileage])*
```

Component 2:

```
IFERROR(VLOOKUP(CompanyData[@ShippingCarrier],Emission_Table,2,FALSE),CompanyData[@ShippingMileage]*CO2_Bin))+
```

Component 3:

```
(N2O_GWPFactor*IF(CompanyData[@ShippingCarrier]="Unknown",1,CompanyData[@ShippingMileage])*
```

Component 4:

```
IFERROR(VLOOKUP(CompanyData[@ShippingCarrier],Emission_Table,3,FALSE),CompanyData[@ShippingMileage]*N20_Bin))
```

The first component, as seen in Figure 7, of the carbon footprint calculation formula looks at the shipping carrier metric using a conditional IF statement to determine whether the carrier is FedEx, United Parcel Service (UPS), US Post Office (USPS), XPO logistics, or Unknown. It bases the decision on whether the shipping carrier is unknown or any other carrier. If the carrier is unknown, then shipping mileage will not be multiplied into the second component of the formula. However, if the shipping carrier is anyone besides unknown then the shipping mileage will be multiplied into the second component.

The second component, as seen in Figure 7, of the carbon footprint calculation formula uses both an IFERROR and VLOOKUP statement in excel to determine which EPA SmartWay CO2 emissions factor to multiply with shipping mileage. To evaluate this portion of the formula, first look at the VLOOKUP section. This VLOOKUP statement determines which shipping carrier is responsible for the transportation of each load. If the shipping carrier is FedEx, UPS, USPS, or XPO logistics it will pull the respective CO2 emission factor as shown in Table 4. This CO2 emissions factor will then be multiplied with the shipping milage number that is produced from component one. The IFERROR portion of the formula comes into play when the shipping carrier is not one of the primary specified carriers for the study, otherwise known as the unknown carrier. When the carrier is unknown, the IFERROR statement multiplies the shipping milage by the CO2 bin value provided in Table 4. When this is the case, component one is reverted to one allowing for a true calculation. When component one and component two are combined through multiplication the result is the estimated carbon dioxide emissions related to the specific delivery based on shipping mileage and carrier.

The third component, as seen in Figure 7, of the carbon footprint calculation formula operates very similarly to the first component, but with an additional step. Component three looks at the shipping carrier metric using a conditional IF statement to determine whether the carrier is FedEx, UPS, USPS, XPO logistics, or Unknown and multiplies in the nitrous oxide global warming potential (GWP) factor as shown in Table 1. When the carrier is unknown, shipping mileage will not be multiplied into the second component of the formula. However, if the shipping carrier is anyone besides unknown then the shipping mileage will be multiplied into the second component. Also, the N2O GWP factor allows for the standardization of a nitrous oxide emissions calculation into a base of carbon. This enables the evaluation of carbon dioxide equivalent or CO2e rather than having two separate metrics to evaluate: one for carbon dioxide and one for nitrous oxide.

The fourth and final component, shown in Figure 7, of the carbon footprint calculation formula works similarly to the second component, but utilizes N2O rather than CO2 emission factors. This component uses both an IFERROR and VLOOKUP statement in excel to determine which EPA SmartWay N2O emissions factor to multiply with shipping milage. The VLOOKUP statement determines which shipping carrier is responsible for the transportation of each load. If the shipping carrier is FedEx, UPS, USPS, or XPO logistics it will pull the respective N2O emission factor as shown in Table 4. This N2O emissions factor will then be multiplied with the shipping mileage number that is produced from component three. However, when the carrier is unknown, the IFERROR statement multiplies the shipping mileage by the N2O bin value provided in Table 4. When this is the case, component three is reverted to one allowing for a true calculation. When component three and component four are combined through multiplication, the result is the estimated CO2e emissions converted from N2O emissions in relation to shipping mileage and carrier.

Finally, when components one and two are combined to form CO2 emissions and components three and four are combined to form CO2e emission from N2O, it is time to add them together to create a meaningful metric: grams of carbon dioxide equivalent (gCO2e). The emission factors provided by SmartWay are in terms of grams, however, due to the large scale of emissions it was decided there may be value in converting grams to tons for portions of evaluation. The conversion is 907,185 grams is equivalent to one ton. This final step provides the company with tons of carbon dioxide equivalent (tCO2e) which can be evaluated further and provided to customers for visibility on their emissions impact.

Chapter 4

Analysis and Results

Assumptions

There are several reasons for tracking and documenting the assumptions made throughout this research. One reason is to ensure the sustainability and future use of the model is intact. Another reason is to ensure transparency is provided for the method used to develop the calculation. This research provides a methodology any person or company can use to track GHG emissions for LTL last-mile deliveries. The assumptions provide the foundation of what was believed to develop the model, which is crucial to understand if alterations are to be made later. Finally, there are extensive guidelines when it comes to reporting of GHG emissions. To show this, this research follows these guidelines and assumptions made during the creation of the original tool and the analysis must be documented.

While building the model, the first key assumption was determining which government body to obtain the correct standardized global warming potential (GWP) factor from. The GWP metrics used for this research were obtained through the Intergovernmental Panel on Climate Change (IPCC). The most recent version of the GWP factors was used. These numbers were originally established during the Kyoto protocol in 1997.

The second key assumption was deciding which government body to obtain trustworthy emissions factor data from. Many organizations such as the Environmental Defense Fund (EDF) and the Environmental Protection Agency (EPA) provide emission factor metrics. The emission factors used for this research come from the EPA SmartWay program. It was determined these were the best emission factors to use due to the large number of companies that are SmartWay participants and because the Software company strives for the goal of satisfying customers under this scope.

Another key assumption made around the model is the possibility of incomplete data being provided. Considering this data was provided entirely and directly from the Software company partnered with for this research, the odds of missing or incomplete data are very low. The data provided was narrowed down to approximately a four-month span and is from their highest volume customer. Upon careful review, there were no order loads that had fields incomplete other than some with the shipping carrier metric needing to be referred to as unknown. It is possible entire shipments were left out or other data discrepancies prior to retrieval occurred.

Multiple important assumptions were made to provide the analysis for the second research question: “How can these emissions savings be portrayed to give greater understanding to the public?” One assumption is that the average work commute is twenty-three miles in distance (GoodBye Car Service, 2023). Another assumption made was that the round-trip flight distance travelled from SFO International Airport and JFK International Airport is 5,166 miles (Flight Free USA, n.d.). The final assumption made for this research question was that the average passenger vehicle is twenty-two miles per gallon and drives 11,500 miles per year (Environmental Protection Agency, 2023).

Finally, multiple assumptions were made around the third and final analysis question: “What are the financial savings related to transportation costs with perfect inventory placement?” One assumption made is that the average tractor trailer’s fuel consumption is seven and a half miles per gallon (Rowe, 2019). Another assumption made was that the average last-mile delivery van’s fuel consumption is six and a half miles per gallon (Kukolj, 2022). The third assumption made for this research question is that the miles driven between tractor trailer and last-mile delivery van is a seventy to thirty percent split respectively. Another assumption is that labor cost is equal to fifty cents per loaded mile (Henry, 2020). The final assumption for this analysis question and research is that the average diesel price in 2023 is equal to $4.48 per gallon (Energy Analytics Institute, 2022).

Question 1: What are the emission savings with perfect inventory placement?

The first analysis question that is relevant to this research and the software company partnered with revolves around the most ideal situation. This analysis will investigate the amount of GHG emissions that can be saved through perfect inventory placement adhering to the standards of ideal inventory placement, cartonization, and distributed order management. To determine an answer to this question, the carbon footprint for total shipping mileage, ideal shipping mileage, and extra shipping mileage must be calculated through the methodology explained in chapter 3. Total shipping mileage is the actual total distance travelled for the shipment. Ideal shipping mileage is the optimal distance that could have been travelled if inventory was placed in the nearest distribution center. Extra shipping mileage is the additional mileage incurred and can be calculated by subtracting total shipping mileage and ideal shipping mileage.

After calculating the carbon footprint or tCO_2e for total shipping mileage, ideal shipping mileage, and extra mileage summary statistics and visualizations can be analyzed. It was determined, over this four-month period, if all extra mileage was eliminated, meaning all orders were from ideal locations, then a 35.5 percent decrease in overall carbon emissions is possible.

Figure 8 visualizes the difference in carbon footprint for total shipping mileage compared to ideal shipping mileage through trend lines over the given four-month period for the study. The 35.5 percent decrease can be seen through the space between the total shipping mileage tCO2e and ideal shipping mileage tCO2e trend lines. The carbon footprint can be analyzed further through monthly time increments as shown in Figure 9. This additional analysis allows the reader to determine the tCO2e produced in each month of the study for extra shipping mileage, ideal shipping mileage, and total shipping mileage in case of seasonality concern, curiosity on monthly performance, or other business needs.

Figure 8

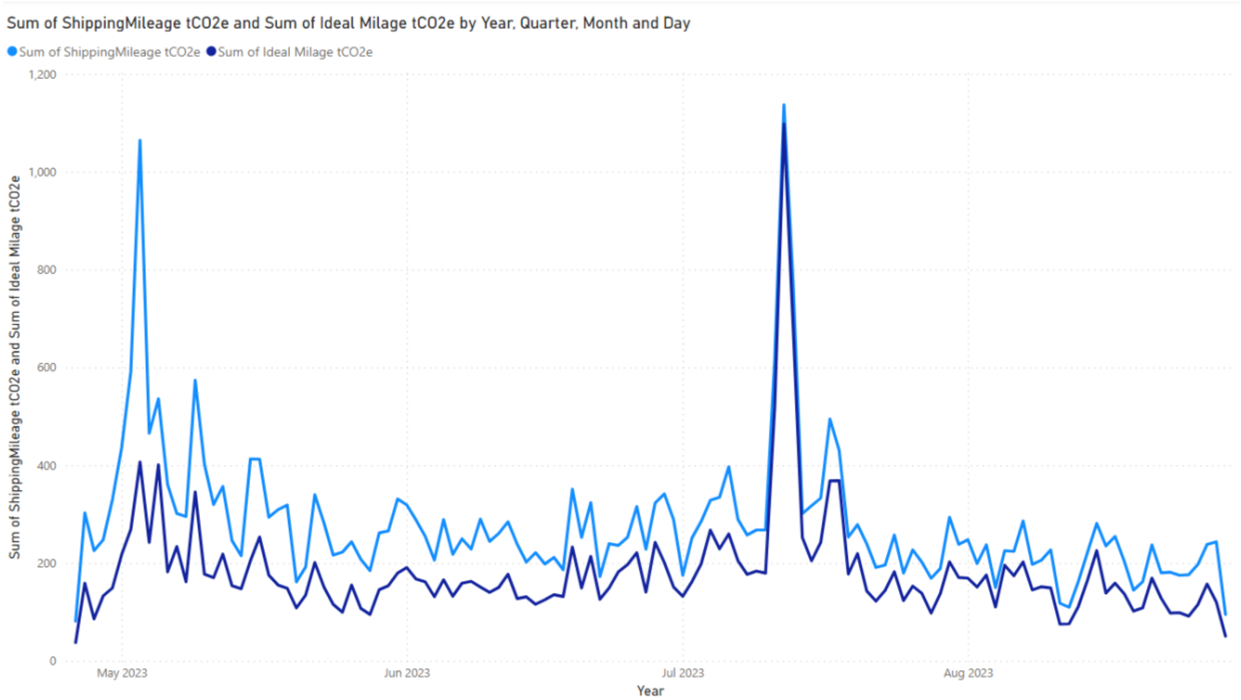
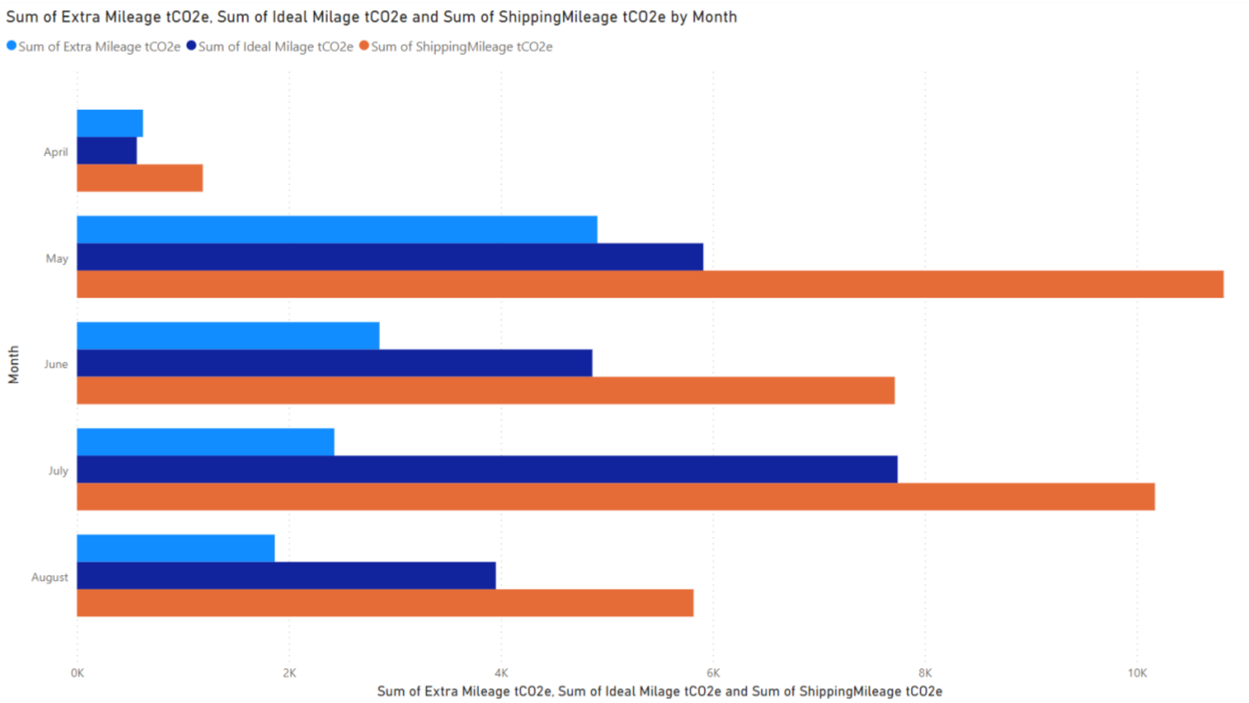


Figure 9



Question 2: How can these emission savings be portrayed to give greater understanding to the public?

Another analysis question that is relevant to this research involves portraying tCO2e emissions in a meaningful way that allows many people to understand. This analysis investigates the 121-day period May 1st to August 29th, 2023, and projects out yearly emissions impact in tCO2e by multiplying these emissions by a factor of three for the company being studied. The projected yearly emissions impact and the actual emissions impact from the period in the study can be seen in Figure 10 for total shipping mileage, ideal shipping mileage, and extra shipping mileage respectively. This yearly projection has limitations due to demand uncertainty and seasonality affecting the number of shipments that occur each month but can provide an estimate of what yearly tCO2e will look like.

Figure 10

123		Total shipping mileage tCO2e	Ideal shipping mileage tCO2e	Extra shipping mileage tCO2e
124	May - Aug tCO2e	34,524.83	22,467.41	12,057.42
125	Projected Yearly tCO2e	103,574.48	67,402.22	36,172.26

After the yearly carbon footprint for total shipping mileage, ideal shipping mileage, and extra shipping mileage is determined, it is time to portray this number in understandable metrics. For the largest number of people possible to understand the metrics shown in Figure 10, data was gathered from multiple sources to provide carbon emission or tCO2e impact on commonly understood activities. This data was aggregated, converted into the correct metric (tCO2e) being studied, and displayed in Table 5. Listed below are some examples of how the total shipping mileage number of 103,574.48 tCO2e can be represented using Table 5.

- Yearly emissions impact from the total shipping mileage in the study is equivalent to 62,772 people flying round trip from San Francisco International Airport to John F Kennedy International Airport (5,166 miles).
- Yearly emissions impact from the total shipping mileage in the study is equivalent to 139,966 people commuting to work by train, 111,371 people commuting to work by bus, or 49,087 people commuting to work by car assuming the average work commute is 23 miles.
- Yearly emissions impact from the total shipping mileage in the study is equivalent to 6,951 people living in the United States for a year.

Table 5 can be used to aid in comprehending any emissions impact given in carbon dioxide equivalent. For example, if the company wished to better understand their impact of emission savings for having ideal inventory placement, they could evaluate the 36,172.26 tCO2e created from extra shipping mileage. Finally, Table 5 can be used to put other company's emissions impact into perspective. For example, the Scope 1 emissions in 2021 for FedEx were equivalent to 18,364,331 tCO2e (FedEx ESG Team, 2022). Listed below are examples of statements that can be drawn by using Table 5 to evaluate the carbon footprint of extra mileage and FedEx.

- Saved yearly emissions impact from removing extra miles shipped in the study is equivalent to 17,143 people commuting to work by car.
- Yearly scope 1 direct emissions from FedEx in 2021 is equivalent to the yearly carbon footprint of 347,086 typical United States households.

Table 5

Activity	*Emissions Impact (tCO2e)*
1. Yearly carbon footprint from thirty minutes of scrolling on Instagram a day.	**0.04**
2. Yearly carbon footprint from using a computer eight hours a day.	**0.28**
3. Yearly carbon footprint from one hour of virtual meetings a day.	**0.40**

4. Carbon footprint from the average work commute by train (23 miles).	**0.74**
5. Carbon footprint from the average work commute by bus (23 miles).	**0.93**
6. Carbon footprint from a passenger flying round trip from San Francisco International Airport to John F Kennedy International Airport (5,166 miles round trip).	**1.65**
7. Carbon footprint from the average work commute by car (23 miles).	**2.11**
8. Yearly carbon footprint from cooking an English breakfast daily.	**2.31**
9. Yearly carbon footprint from an average passenger vehicle (22-miles per gallon at 11,500 miles per year).	**5.07**
10. Carbon footprint from manufacturing an electric vehicle excluding the battery.	**6**
11. Yearly carbon footprint from cooking a roast dinner daily.	**11.27**
12. Yearly carbon footprint per person in Canada.	**14.30**
13. Yearly carbon footprint per person in the United States.	**14.90**
14. Yearly carbon footprint per person in Australia.	**15.10**

15. Yearly carbon footprint from one NFT transaction a day.	**19.31**
16. Yearly carbon footprint per person in Qatar.	**35.6**
17. Yearly carbon footprint for the typical United States household.	**52.91**

(University of Michigan, 2022; GoodBye Car Service, 2023; Flight Free USA, n.d.; Environmental Protection Agency, 2023; Mathieu, 2021; Ritchie, 2020)

Question 3: What are the financial savings related to transportation costs with perfect inventory placement?

The final analysis question that is relevant to this research investigates the transportation costs that can be saved in addition to the reduction in GHG emissions through ideal inventory placement. Over the four-month span of time in study from April 26th, 2023, to August 29th, 2023, approximately $5,763,963.53 in total transportation costs could have been avoided through ideal inventory placement. To determine the total transportation costs savings multiple inputs must be calculated or assumed and then formulated together. An input that must be calculated is the extra mileage. Extra mileage is determined through subtracting the total shipping mileage with the ideal shipping mileage. This extra mileage was evaluated with previously mentioned assumed inputs that can be seen in Table 6. The methodology used to calculate the transportation cost for tractor trailer and last-mile delivery van can be seen in Figure 11.

Table 6

Additional Transportation Cost Category	*Additional Transportation Cost Metrics*
Tractor Trailer MPG	7.5
Last-Mile Delivery Van MPG	6.5
Percent of Deliveries Tractor Trailer	70%
Percent of Deliveries Last-Mile Delivery Van	30%
Labor Cost per Loaded Mile	$0.50
Average Price of Diesel per gallon in 2023	$4.48

(Energy Analytics Institute, 2022; Henry, 2020; Kukolj, 2022; Rowe, 2019)

Figure 11

Tractor Trailer Transportation Cost

Component 1

=(((SUM(Table4[SumofExtraMileage])*Tractor_Trailer)/Tractor_Trailer_MPG)*_2023_Average_Price_of_Diesel)+

Component 2

(SUM(Table4[SumofExtraMileage]) * Labor_cost*Tractor_Trailer)

Last-Mile Delivery Van Transportation Cost

Component 3

=(((SUM(Table4[SumofExtraMileage])*Last_Mile_Van)/Last_Mile_Van_MPG)*_2023_Average_Price_of_Diesel)+

Component 4

(SUM(Table4[SumofExtraMileage]) * Labor_cost*Last_Mile_Van)

The first component, as seen in Figure 11, of the formula divides the extra shipping mileage for tractor trailer by the average miles per gallon of a tractor trailer mentioned in Table 6. This results in the total gallons of diesel fuel consumed by tractor trailer for extra shipping mileage over the four-month period in the study. This extra fuel consumption in gallons is then multiplied by the average cost per gallon of diesel fuel in 2023 shown in Table 6. The result of component one gives the total transportation costs related to fuel for tractor trailers. This same methodology was extrapolated and used for last-mile delivery vans seen in component three of the formula. Component three takes the total extra shipping mileage for last-mile delivery vans and divides it by the average miles per gallon, mentioned in Table 6, resulting in gallons of diesel fuel consumed for last-mile delivery vans. The total gallons of diesel fuel consumed by last-mile delivery vans is then multiplied by the average cost of diesel fuel in 2023 to get the total transportation cost related to fuel for last-mile delivery vans. The fuel cost is one of two major considerations when looking at transportation costs.

The second major consideration when evaluating transportation costs is labor cost. Components two and four, as shown in Figure 11, are used to evaluate labor costs for tractor trailer and last-mile delivery van respectively. Component two multiplies the extra shipping mileage for tractor trailers with the labor cost per loaded mile shown in Table 6. This results in the total labor costs for miles driven by tractor trailer. Component four multiplies the extra shipping mileage for last-mile delivery vans with the labor cost per loaded mile shown in Table 6. This results in the total labor costs for miles driven by last-mile delivery van.

To determine total transportation costs that could have been avoided with ideal inventory placement over the period in study, the tractor trailer and last-mile delivery van transportation costs via fuel cost and labor costs are added together. The total transportation costs that could have been avoided through ideal inventory placement are $5,763,963.53. Out of this total possible transportation cost savings, the amount of savings from tractor trailer related costs are

$3,935,889.79 while the savings from last-mile delivery van transportation costs are $1,828,073.74.

The total transportation costs can be broken down further through monthly increments and looked at via last-mile delivery van transportation costs, tractor trailer transportation costs, and total additional transportation costs. Figure 12 uses a stacked area line chart to visualize these three different transportation costs over the four-month period. The month of May had the largest transportation costs and the difference between last-mile delivery van and tractor trailer can be seen between the dark and light blue colored areas.

Figure 12

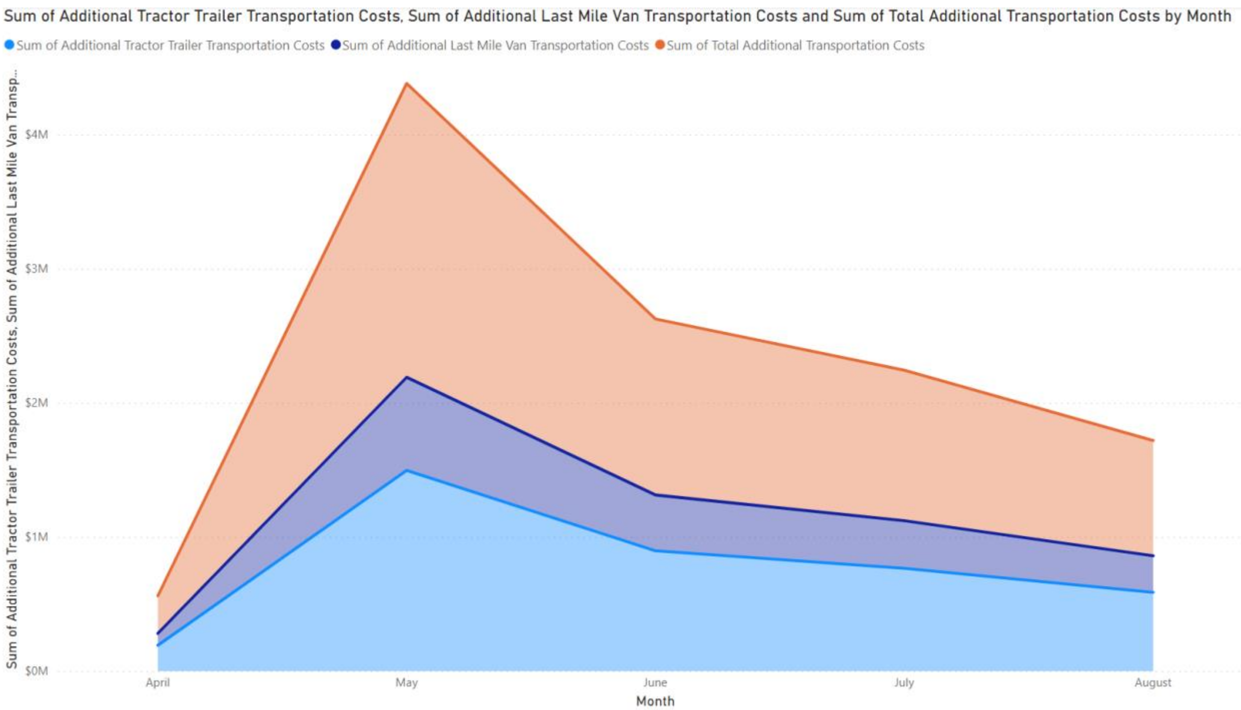
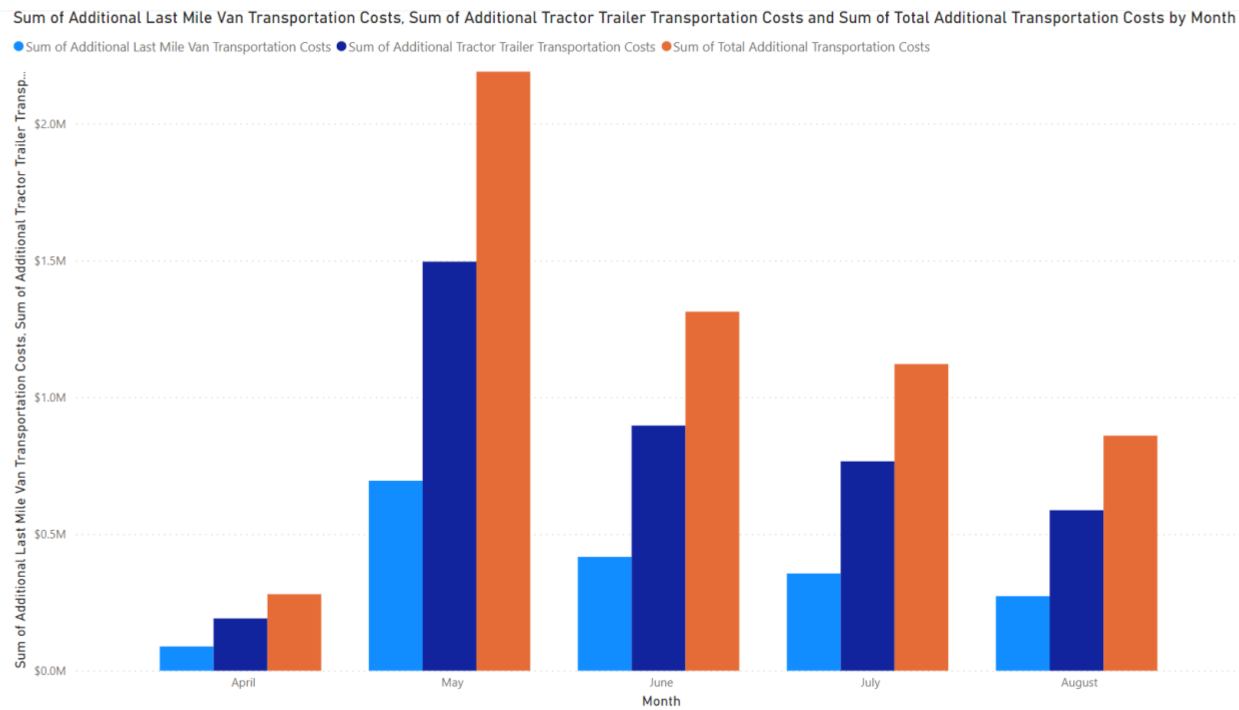


Figure 13 uses a clustered bar chart to show the difference in monthly total transportation costs for last-mile delivery van, tractor trailer, and their total. An interesting finding is that while the assumed split was thirty percent last-mile delivery van and seventy percent tractor trailer, the percent difference in total transportation costs for last-mile delivery van was 31.72 percent while tractor trailer was 68.28 percent. This shows that transportation costs for last-mile delivery van are slightly more expensive than tractor trailer.

Figure 13



In conclusion, total transportation cost savings are a monetary benefit to consider while looking into ideal inventory placement. An additional benefit is the reduction of carbon emissions which this research primarily studies. The combination of large monetary savings in transportation costs and a decrease in overall climate emissions are two strong reasons to consider ideal inventory placement when designing a network.

Chapter 5

Conclusions and Recommendations

Conclusions

A summary of the deductions made throughout this research will be addressed to conclude this thesis. This research provided a reproducible methodology for any party of interest to calculate the carbon emissions of distribution shipments if certain data points such as shipping mileage and mode of transportation are tracked by a business management system. This research investigated non-optimal, last mile, ecommerce shipments through the data of a customer of the Software-as-a-Service supply chain company partnered with.

It was found that non-optimal shipments will cause a direct increase in overall transportation costs through analyzing the data provided. In addition to the extra transportation costs, these non-optimal shipments also create a worse overall experience for the customer. This decrease in customer service comes from an increase in transportation costs which are inevitably passed onto the customer and the possibility of extended lead times from the increase in last mile mileage the parcel travels. The final factor to consider when looking at non-optimal shipments is the impact on the environment the additional mileage causes through the calculation of GHG emissions metric. If a shipment is non-optimal, the total shipping mileage will increase which will lead to an increase in greenhouse gas emissions. The transportation cost, customer experience, and GHG emissions are three strong considerations that favor the investment of additional inventory being stored in high-volume distribution centers to minimize the amount of non-optimal shipment miles travelled.

Limitations

The operations and data infrastructure of a start-up Software-as-a-Service (SaaS) company are quite complex. In addition, the procedure and methodology for calculating the carbon footprint around shipping mileage has its own complexities. Considering the large number of complexities involved in this research, limitations arise and must be documented.

The first limitation comes from the uncertainty of the data provided by the SaaS company partnered with. This data was provided as an excel file that was pulled from a database management system. Information such as vehicle engine types or fuel types are not specifically provided which leads to generalizing. The output of the model calculates the carbon footprint of each order based on the shipping mileage and carrier. If the shipping mileage or carrier data is off, then the output of the model will be off to the same degree. With real-world data entry there is the possibility of these data points being off which will cause inconsistency in the model.

Another limitation arises from uncertainties around characteristics of the Environmental Protection Agency's (EPA) SmartWay program. The emission factors for the EPA SmartWay program, which this research is based on, are self-reported numbers (Scott et al., 2023). Like safety metrics, the self-reporting of sustainability metrics can lead to skewed results due to the possibility of conflicting interests. Due to this, the reliability of the emission factors should be brought into question. In addition, there are approximately 4,000 partners in the EPA SmartWay program, but hundreds of thousands of carriers on the road. For companies to become certified by the EPA SmartWay program, they must use carriers under SmartWay certification. However, many potential clean carriers may be missed by companies due to the barriers of entry to the SmartWay program with this system.

The final limitation of this research involves the number of outputs calculated for the carbon footprint calculator. This research utilizes carbon dioxide and nitrous oxide emission factors to calculate the total carbon footprint from ecommerce last mile distribution. However, there are additional harmful emissions from vehicles this calculator fails to capture. A greenhouse gas this research does not include in its scope is methane. While methane is produced through vehicle emissions, there were not recent enough emissions factors for this GHG to be considered reliable. In addition, the EPA SmartWay program provides emission factors for particulate matter (PM) 2.5 and PM 10. However, these are not direct emissions covered under the IPCC's GWP which would mean they must be reported separately. Since particulate matter could not have been combined into a carbon dioxide equivalent using GWP factors, it was deemed out of scope. Due to methane, PM 2.5, and PM 10 not being calculated in the carbon footprint, there is potential in the underestimation of overall GHG emissions.

Future Research

The scope of the project was to provide a carbon footprint calculation methodology to the supply chain Software-as-a-Service company partnered with. This is so they could provide the additional visibility on GHG emissions to their customers. This information will be useful a consideration in addition to extra mileage transportation costs when looking at non-optimal shipments for customers. It is important to note that there are areas in which future research in this topic could be of use.

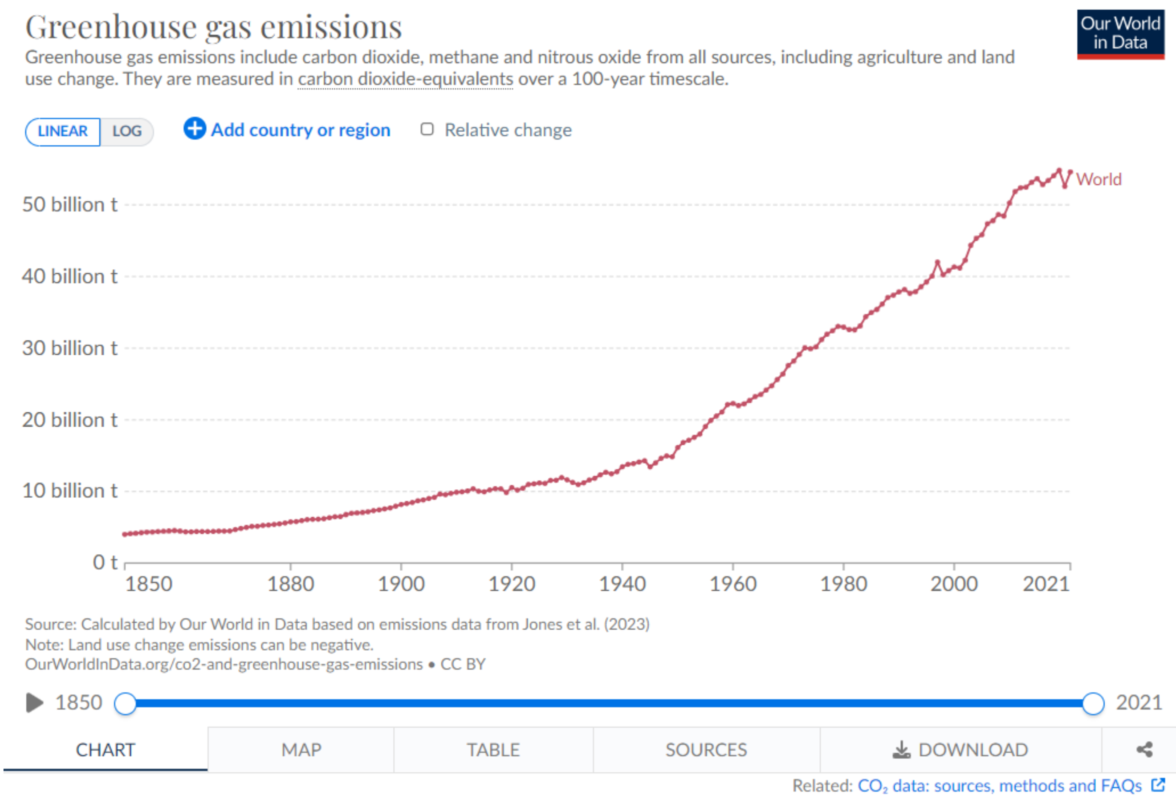
One area in which future research would prove useful is investigating the inclusion of a larger breadth of harmful emissions. Currently, this research evaluates the total carbon footprint, in tCO2e, by calculating carbon dioxide and nitrous oxide emissions separately and then combining them through GWP constants. However, if the emissions of methane, PM 2.5, or PM 10 could be added to the calculation without infringing on the integrity of the model, this would add to its useability and function. This is an area in which future research could be investigated if the SaaS company partnered with wants to give a more refined calculation on total emissions.

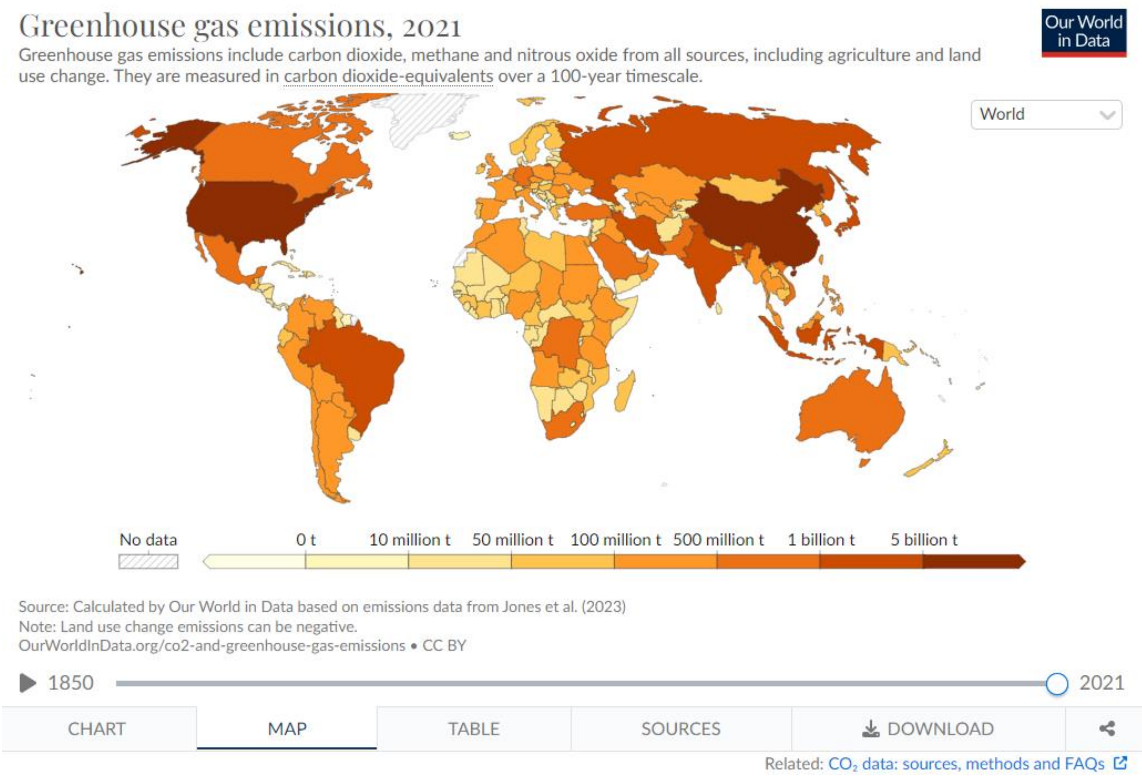
The final area future research would be useful in is investigating additional tradeoffs for network optimization. For example, the tradeoff between extra transportation costs versus additional inventory holding costs from storing inventory in optimal locations. Currently, this research investigates the additional transportation costs and emissions incurred from the extra miles because of non-optimal shipments. However, future research should consider these factors and perform a tradeoff analysis to other relevant factors in network optimization. This comprehensive tradeoff analysis will help prove if it is finically feasible to always store inventory in the correct location. The current analysis investigates transportation costs and GHG emissions but does not consider all other factors involved in the complexity of network optimization. If additional financial tradeoffs, such as inventory holding costs, are considered, then a more comprehensive analysis and argument in favor or against storing inventory in optimal locations can be formed.

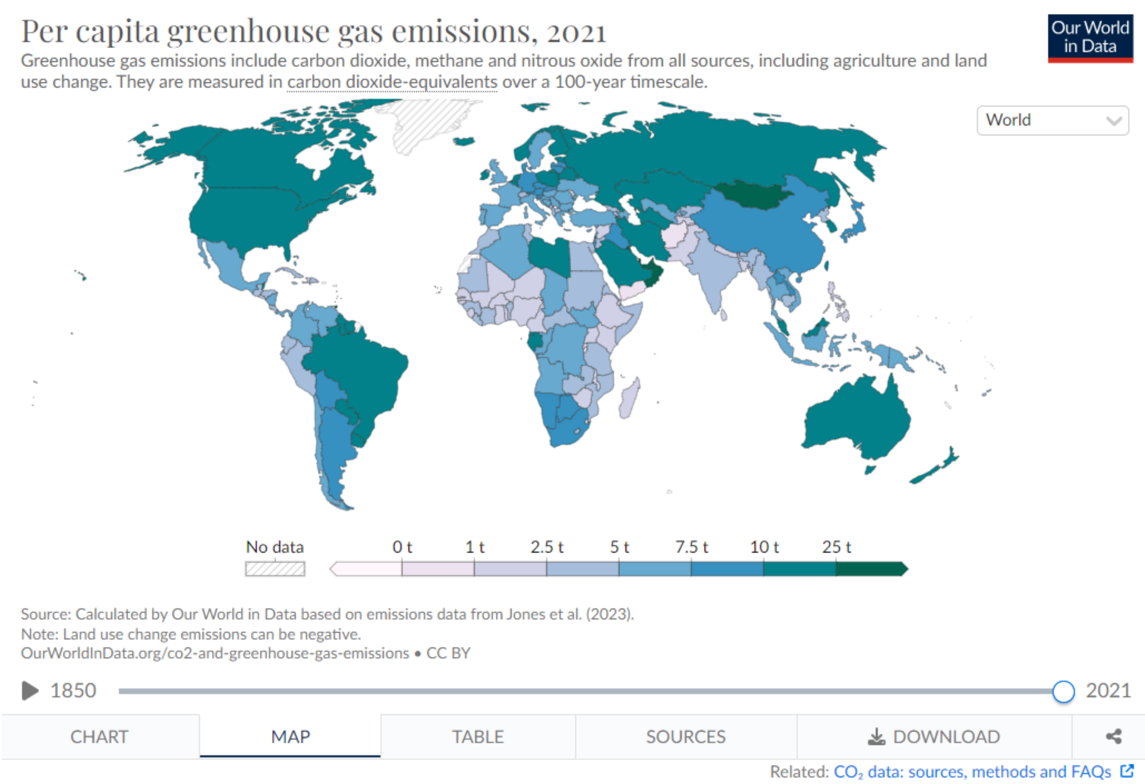
Appendix A

Emission Calculation Tables and Research Graphics

https://ourworldindata.org/greenhouse-gas-emissions







https://storage.googleapis.com/scsc/Green%20Freight/EDF-Green-Freight-Handbook.pdf

NORTH AMERICAN FREIGHT EMISSIONS FACTORS

Mode	Category	Functional Unit		Emission Factor	Greenhouse Gases Included	Source
Air	Longer flights (>3,700 km/ 2,300 miles)	grams per short ton-mile	Weight	868.3	CO2	A
	Shorter flights (<3,700 km/ 2,300 miles)	grams per short ton-mile	Weight	2,050.0	CO2	A
Barge	All	grams per short ton-mile	Weight	17.5	CO2	A
Ocean-Dry Goods	Asia to North America (east coast)	grams per TEU kilometer	Volume	68.1	CO2	B
	Asia to North America (west coast)	grams per TEU kilometer	Volume	59.1	CO2	B
	Mediterranean to North America (east coast)	grams per TEU kilometer	Volume	79.6	CO2	B
	Mediterranean to North America (west coast)	grams per TEU kilometer	Volume	76.8	CO2	B
	North America to Africa	grams per TEU kilometer	Volume	89.5	CO2	B
	North America to Oceania	grams per TEU kilometer	Volume	81.3	CO2	B
	North America to South America	grams per TEU kilometer	Volume	68.6	CO2	B
	North American (east coast) to Middle East and India	grams per TEU kilometer	Volume	77	CO2	B
	North Europe to North America (east and gulf)	grams per TEU kilometer	Volume	78.2	CO2	B
	North Europe to North America (west coast)	grams per TEU kilometer	Volume	69.6	CO2	B
Ocean-Refrigerated Goods	Asia to North America (east coast)	grams per TEU kilometer	Volume	95.3	CO2	B
	Asia to North America (west coast)	grams per TEU kilometer	Volume	87.9	CO2	B
	Mediterranean to North America (east coast)	grams per TEU kilometer	Volume	113.9	CO2	B
	Mediterranean to North America (west coast)	grams per TEU kilometer	Volume	112.4	CO2	B
	North America to Africa	grams per TEU kilometer	Volume	127.1	CO2	B
	North America to Oceania	grams per TEU kilometer	Volume	109.2	CO2	B
Mode	Category	Functional Unit		Emission Factor	Greenhouse Gases Included	Source
Ocean-Refrigerated Goods (*Continued*)	North America to South America	grams per TEU kilometer	Volume	102.1	CO2	B
	North American (east coast) to Middle East and India	grams per TEU kilometer	Volume	101	CO2	B
	North Europe to North America (east and gulf)	grams per TEU kilometer	Volume	107.6	CO2	B
	North Europe to North America (west coast)	grams per TEU kilometer	Volume	98.2	CO2	B
Rail	All	grams per rail-car mile	Distance	1,072.0	CO2	A
	All	grams per TEU-mile	Volume	292.8	CO2	A
	All	grams per short ton-mile	Weight	22.9	CO2	A
Truck	All	grams per mile	Distance	1,700.0	CO2	C
	Dray	grams per mile	Distance	1,750.0	CO2	C
	Expedited	grams per mile	Distance	1,200.0	CO2	C
	Flatbed	grams per mile	Distance	1,800.0	CO2	C
	Heavy Bulk	grams per mile	Distance	2,000.0	CO2	C
	LTL Dry Vans	grams per mile	Distance	1,625.0	CO2	C
	Mixed	grams per mile	Distance	1,700.0	CO2	C
	Refrigerated	grams per mile	Distance	1,750.0	CO2	C
	Tanker	grams per mile	Distance	1,750.0	CO2	C
	Truck-load Dry Vans	grams per mile	Distance	1,700.0	CO2	C
	All	grams per TEU-mile	Volume	597.4	CO2	A
	All	grams per short ton-mile	Weight	161.8	CO2	A

Distance	Weight	Total Ton-Miles	Emissions Factor	Total Emissions	Total Emissions (Metric Tons)
1,000 miles	20 short tons	1,000 x 20 = 20,000	161.8 grams of CO2/ton-mile	3,236,000 grams CO2	3.24 metric tons CO2
750 miles	13 short tons	750 x 13 = 9,750	161.8 grams of CO2/ton-mile	1,577,550 grams CO2	1.58 metric tons CO2

Distance	Weight	Total Ton-Miles	Emissions Factor	Total Emissions	Total Emissions (Metric Tons)
1,000 miles	N/A	N/A	1,700 grams of CO2/ mile	1,700,000 grams CO2	1.7 metric tons CO2
750 miles	N/A	N/A	1,700 grams of CO2/mile	1,275,000 grams CO2	1.3 metric tons CO2

Example	Move	Mode	Trips	Distance	Weight	Volume	Total Ton-or TEU-Miles	Emissions Factor	Total Emissions	Total Emissions (Metric Tons)
1	Shanghai to Port of LA	Ocean (dry container)	1	5,699 miles/ 9,172 kilometers	N/A	1 TEU	5,899 TEU miles/ 9,172 TEU km	59.1 kg/ TEU-km	542,065 grams CO2	0.54 metric tons CO2
	Port of LA to Company DC	Truck (dray)	1	75 miles	16 short tons	N/A	1,200 ton-miles	161.8 grams CO2/ton-mile	194,160 grams CO2	0.19 metric tons CO2
2	Manufacturing Facility to Rail Yard	Truck (dray)	2	35 miles	18.5 short tons	N/A	1,295 ton-miles	161.8 grams CO2/ton-mile	209,531 grams CO2	0.21 metric tons CO2
	Long-haul rail trip	Rail	1	800 miles	37 short tons	N/A	29,600 ton-miles	22.9 grams CO2/ton-mile	677,840 grams CO2	0.68 metric tons CO2
	Destination Rail Yard to Distribution Center	Truck (dray)	2	45 miles	18.5 short tons	N/A	1,665 ton-miles	161.8 grams CO2/ton-mile	269,397 grams CO2	0.27 metric tons CO2

https://nepis.epa.gov/Exe/ZyNET.exe/P1015QB2.TXT?ZyActionD=ZyDocument&Client=EPA&Index=2016+Thru+2020&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C16thru20%5CTxt%5C00000031%5CP1015QB2.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL

Table 3. Non-SmartWay Truck Carrier Performance Metrics (Data Year 2022)

Category	CO_2 g/tmi	CO_2 g/mi	NO_x g/tmi	NO_x g/mi	PM2.5 g/tmi	PM2.5 g/mi
Auto Carrier	129	2,300	0.32	7.00	0.001	0.009
Dray	112	2,000	0.65	12.50	0.005	0.096
Expedited	980	1,825	0.63	4.80	0.008	0.017
Flatbed	99	2,060	0.235	6.50	0.002	0.013
General	100	2,015	0.29	5.60	0.002	0.028
Heavy/Bulk	83	2,540	0.185	6.50	0.001	0.010
LTL/Dry Van	192	1,730	0.425	5.15	0.003	0.013
Mixed	100	2,015	0.29	5.60	0.002	0.028
Moving	475	1,865	0.565	11.00	0.015	0.588
Package	890	1,090	1.04	2.75	0.012	0.007
Refrigerated	112	2,075	0.265	5.20	0.002	0.031
Specialized	113	2,310	0.325	7.10	0.002	0.031
TL/Dry Van	103	1,850	0.29	4.70	0.001	0.010
Tanker	80	1,950	0.215	4.90	0.002	0.012

Table 4. Non-SmartWay Logistics Carrier Performance Metrics (Data Year 2022)

Category	CO_2 g/tmi	CO_2 g/mi	NO_x g/tmi	NO_x g/mi	PM2.5 g/tmi	PM2.5 g/mi
Logistics	139	2,550	0.395	7.85	0.005	0.395

Table 5. Performance Metrics for Non-SmartWay Air and Barge Carriers

	CO_2/tmi	CO_2/mi	NO_x/tmi	NO_x/mi	PM/tmi	PM/mi
Short-haul Air	4,300	100,000	40	900	2	35
Long-haul Air	1,500	50,000	20	650	1	25
Barge	18.58	23,295	0.64	672	0.02	22.24

Table 6. Rail Carrier Performance Metric Calculation Inputs & Results (2017 R-1 Data)

Rail Company	Gal/Yr ('000) Sch. 750 Line 4	Freight Ton Mi/Yr ('000) Sch. 755 line 110	Railcar Mi/Yr ('000) Sch. 755 sum of lines 30, 46, 64 & 82	g CO_2/railcar mile	g CO_2/short ton mile
BNSF Railway	1,353,897	665,948,516	11,606,520	1,187	20.70
CSX Transportation	426,721	208,127,221	4,713,411	922	20.87
Grand Trunk	116,986	62,708,628	1,486,205	801	18.99
Kansas City Southern	68,873	34,582,626	724,012	968	20.27
Norfolk Southern*	458,179	201,451,969	4,383,081	1,064	23.15
Soo Line	65,299	35,244,079	745,550	892	18.86
Union Pacific	1,016,161	466,721,215	10,090,926	1,025	22.16
Total/Industry Average	3,506,116	1,674,784,254	33,749,705	980	20.72

* and combined subsidiaries

Table 11. U.S. Freight Truck Industry Average Factors Used in Modal Shift

Units	CO_2	NO_x	$PM_{2.5}$
gram/short ton-mile	210	0.744	0.027
gram/mile	1,578	5.586	0.199

Table 12. Underlying Data for Freight Truck Industry Average Factors (2019)

CO_2 (grams)	436,853,902,968,783
NO_x (grams)	1,547,043,757,414
$PM_{2.5}$ (grams)	55,183,809,776
Miles	276,927,898,414
short ton-miles	2,078,299,600,000

Table 13. Modal Average Barge Emission Factors

	CO_2	NO_x	$PM_{2.5}$
gram/short ton-mile	17.48	0.4691	0.0111

Table 14. Modal Average Performance Metric Estimates for Air Carriers

Mode	g/mi			g/ton mi		
	CO_2	NO_x	PM	CO_2	NO_x	PM
Short Haul Air	96,998	878.37	5.743	4,236	38.134	0.251
Long Haul Air	33,448	301.13	1.98	1,461	13.15	0.086

Table 15. BSR Marine Emission Factors (g CO_2/short ton-mile)

Ship_general	International	13.0678
Ship_Barge	International	29.1937
Ship_Feeder	International	29.1937
Ship_inland_Germany	Germany	41.5280
Ship_inland_China	China	35.0578
Ship_Asia-Africa	Asia--Africa	11.9227
Ship_Asia-South America (EC/WC)	Asia--South America (EC/WC)	13.1897
Ship_Asia-Oceania	Asia--Oceania	13.4028
Ship_Asia-North Europe	Asia--North Europe	10.8586
Ship_Asia-Mediterranean	Asia--Mediterranean	12.1358
Ship_Asia-North America EC	Asia--North America EC	12.9854
Ship_Asia-North America WC	Asia--North America WC	12.0818
Ship_Asia-Middle East/India	Asia--Middle East/India	13.5459
Ship_North Europe-North America EC	North Europe--North America EC (incl. Gulf)	14.1823
Ship_North Europe-North America WC	North Europe--North America WC	13.0642
Ship_Mediterranean-North America EC	Mediterranean--North America EC (incl. Gulf)	12.6788
Ship_Mediterranean-North America WC	Mediterranean--North America WC	10.1433
Ship_Europe (North & Med)-Middle East/India	Europe (North & Med)--Middle East/India	13.4276
Ship_Europe (North & Med)-Africa	Europe (North & Med)--Africa	15.8361
Ship_Europe (North & Med)-Oceania (via Suez / via Panama)	Europe (North & Med)--Oceania (via Suez / via Panama)	14.4056
Ship_Europe (North & Med)-Latin America/South America	Europe (North & Med)--Latin America/South America	12.6146
Ship_North America-Africa	North America--Africa	17.4549
Ship_North America EC-Middle East/India	North America EC--Middle East/India	12.8788
Ship_North America-South America (EC/WC)	North America--South America (EC/WC)	13.4379
Ship_North America-Oceania	North America--Oceania	15.0552
Ship_South America (EC/WC)-Africa	South America (EC/WC)--Africa	11.7432
Ship_Intra-Americas (Caribbean)	Intra-Americas (Caribbean)	15.9222
Ship_Intra-Asia	Intra-Asia	15.2012
Ship_Intra-Europe	Intra-Europe	17.1790

Table 16. IMO Marine Emission Factors

TYPE	SIZE	AVERAGE CARGO CAPACITY (metric tonne)	Average yearly capacity utilization	Average service speed (knots)	Transport work per ship (tonne NM)	Loaded efficiency (g of CO_2/ ton mile)	Total efficiency (g of CO_2/ton mile)
Crude oil tanker	2000,000+dwt	295,237	48%	15.4	14,197,046,742	2.34	4.23
Crude oil tanker	120,000-199,99 dwt	151,734	48%	15	7,024,437,504	3.21	6.42
Crude oil tanker	80,000-119,999 dwt	103,403	48%	14.7	4,417,734,613	4.38	8.61
Crude oil tanker	60,000-79,999 dwt	66,261	48%	14.6	2,629,911,081	6.28	10.95
Crude oil tanker	10,000-59,999 dwt	38,631	48%	14.5	1,519,025,926	7.59	13.28
Crude oil tanker	0-9,999 dwt	3668	48%	12.1	91,086,398	30.22	48.61
Products tanker	60,000+ dwt	101,000	55%	15.3	3,491,449,962	4.82	8.32
Products tanker	20,000-59,999 dwt	40,000	55%	14.8	1,333,683,350	10.51	15.03
Products tanker	10,000-19,999 dwt	15,000	50%	14.1	464,013,471	16.49	27.30
Products tanker	5,000-9,999 dwt	7,000	45%	12.8	170,712,388	21.60	42.62
Products tanker	0-49,999 dwt	1,800	45%	11	37,598,072	38.68	65.69
Chemical tanker	20,000 + dwt	32,200	64%	14.7	1,831,868,715	8.32	12.26
Chemical tanker	10,000-19,999 dwt	15,000	64%	14.5	820,375,271	10.66	15.76
Chemical tanker	5,000-9,999 dwt	7,000	64%	14.5	382,700,554	15.62	22.04
Chemical tanker	0-4,999 dwt	1,800	64%	14.5	72,147,958	27.15	32.41
LPG tanker	50,000 + m^3	46,656	48%	16.6	2,411,297,106	7.59	13.14
LPG tanker	0-49,999 m^3	3,120	48%	14	89,631,360	39.41	63.50
LNG tanker	200,00 + m^3	97,520	48%	19.6	5,672,338,333	7.88	13.58
LNG tanker	0-199,999 m^3	62,100	48%	19.6	3,797,321,655	12.26	21.17
Bulk carrier	200,000 +dwt	227,000	50%	14.4	10,901,043,017	2.19	3.65
Bulk carrier	100,000-199,999 dwt	163,000	50%	14.4	7,763,260,284	2.63	4.38
Bulk carrier	60,000-99,999 dwt	74,000	55%	14.4	3,821,361,703	3.94	5.98
Bulk carrier	35,000-59,999 dwt	45,000	55%	14.4	2,243,075,236	5.55	8.32
Bulk carrier	10,000-34,999 dwt	26,000	55%	14.3	1,268,561,872	7.74	11.53
Bulk carrier	0-9,999 dwt	2,400	60%	11	68,226,787	33.43	42.62
General cargo	10,000 + dwt	15,000	60%	15.4	866,510,887	11.09	17.37
General cargo	5,000-9,999 dwt	6,957	60%	13.4	365,344,150	14.74	23.06
General cargo	0-4,999 dwt	2,545	60%	11.7	76,645,792	15.91	20.29
General cargo	10,000+ dwt, 100+ TEU	18,000	60%	15.4	961,054,062	12.55	16.06
General cargo	5,000-9,999 dwt, 100+TEU	7,000	60%	13.4	243,599,799	20.14	25.54

Table 16. IMO Marine Emission Factors

TYPE	SIZE	AVERAGE CARGO CAPACITY (metric tonne)	Average yearly capacity utilization	Average service speed (knots)	Transport work per ship (tonne NM)	Loaded efficiency (g of CO_2/ ton mile)	Total efficiency (g of CO_2/ton mile)
General cargo	0-4.999 dwt. dwt+TEU	4,000	60%	11.7	120.938.043	22.63	28.90
Refrigerated cargo	All	6,400	50%	20	392.981,809	18.83	18.83
Container	8000+TEU	68,600	70%	25.1	6,968,284,047	16.20	18.25
Container	5,000-7,999 TEU	40.355	70%	25.3	4,233,489,679	22.19	24.23
Container	3,000-4,999 TEU	28,784	70%	23.3	2,280,323,533	22.19	24.23
Container	2,000-2,999 TEU	16,800	70%	20.9	1,480,205,694	26.71	29.19
Container	1,000-1,999 TEU	7,000	70%	19	578,339,367	42.91	46.86
Container	0-999 TEU	3,500	70%	17	179,809,363	48.61	52.99
Vehicle	4000 +ceu	7,908	70%	19.4	732,581,677	36.78	46.71
Vehicle	0-3999 ceu	2,808	70%	17.7	226,545,399	68.90	84.08
Ro-Ro	2,000 + lm	5,154	70%	19.4	368,202,021	66.12	72.25
Ro-Ro	0-1,999 lm	1432	70%	13.2	57,201,146	80.57	88.02

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ACADEMIC VITA

Reilly McCarthy

EDUCATION

The Pennsylvania State University | Schreyer Honors College Class of Dec 2023
Smeal College of Business | B.S. Supply Chain and Information Systems Dean's List 7/7
College of Information Sciences Technology | Information Science Technology Minor

Thesis: Modelling the Carbon Footprint of Non-Optimal Ecommerce Last Mile Distribution
Technological Skills: Proficient in SQL, Tableau, RStudio (ggplot2), SAP, Python, Microsoft Excel, and PowerBI.

RELEVANT WORK EXPERIENCE

Lenovo – Global Supply Chain Intern – Research Triangle Park, NC Summer 2023
- Effectively communicated with 13 upstream data experts to locate, analyze, & query SQL server database tables.
- Developed a PowerBI dashboard connected to 4 tables with 12,000,000 rows to provide insights to Product team.
- Collaborated across 5 functional teams to provide data visibility reducing cycle time by greater than 70%.

Ernst & Young (EY) – Nittany Lion National Bank Consultant Project – State College, PA Spring 2023
- Led weekly Scrum meetings for a 5-person team utilizing Agile methodology to develop a risk assessment tool.
- Delivered a high-level overview to the banking client on best practices to alleviate the primary 3 risks identified.

Corning Inc. – Inventory Lead Time Optimization Project – State College, PA Fall 2023
- Aggregated, analyzed, and validated lead time data for Corning's 4500+ product portfolio to evaluate variance.
- Delivered a high-level presentation of analysis to 8 Corning seniors and data team to ensure sustainability.

Amazon Operations – Robotics Site Area Manager Intern – Denver, CO Summer 2022
- Achieved a cost avoidance greater than $40,000 annually through reducing cycle times for scanners by 48%.
- Remodeled the layout of outbound problem solve to create less waste by implementing 5S Lean principles.
- Utilized Amazon leadership principles to effectively lead and coach a team of 25 to 50 Amazon Associates.

Odyssey Logistics – Routed Carrier Acceptance and Cost / Pound Project – State College, PA Spring 2022
- Led a brainstorm with 5 SMEs to identify factors influencing carrier acceptance and cost per pound figures.
- Developed a clean, working dataset from raw data to construct a linear regression analysis using probit model.

Unilever – Ben & Jerry's Domestic vs. International Sourcing Project – State College, PA Fall 2021
- Identified a potential problem in the current nodes being used to source product sold throughout U.S. network.
- Created a solution by designing a cost analysis for a new manufacturing plant to alleviate identified problem.

LEADERSHIP EXPERIENCE

Sigma Chi Mu Tau Honors Society – Research Project Mentor – State College, PA Fall 2023
- Mentored a group of 3 students to successfully complete a research project provided by a PSU corporate sponsor.
- Led weekly standups to answer common research questions and provide guidance on next steps in the project.

Penn State University – Teaching Assistant SCM 404 & SCM 405 – State College, PA Fall 2022 – Spring 2022
- Aided professor in all teaching duties such as mentoring through office hours, lecturing, researching, and grading.
- Assisted students in navigating the course, assignments, discussion, and other key areas to ensure their success.

Sigma Phi Epsilon Fraternity, Penn Eta Chapter – State College, PA Spring 2020 - Present
Brother Mentor Coordinator
- Chosen to lead mentors of Penn Eta's 100+ brother chapter based on prior executive and academic achievements.

THON Family Relations, Chairman & Elected Dancer for 2023
- Spearheaded fundraising efforts alongside board resulting in $202,000 raised for childhood cancer support.
- Cultivated a supportive and inclusive environment for our chapter to spend time with THON families.

Supply Chain Management Association (Formerly CSCMP) – State College, PA Fall 2020 - Present
- Foster academic and professional advancement through conversations with peers and supply chain professionals.
- Selected to tour and learn from industry leaders at the Walmart and REI distribution centers in Bedford, PA.

CERTIFICATIONS, HONORS, & INTERESTS

Certified in Data Analytics through program developed by Google and Coursera. Summer 2022

HONORS: Beta Gamma Sigma International Honors Society, Schreyer Honors College Academic Excellence Scholarship, The Traffic Club of Pittsburgh Scholarship, Ivan A. Olson Scholarship, Francis and Catherine Zernhelt Endowed Scholarship in Business, Marjorie Roberts Memorial Scholarship, and Dean's List all semesters.

INTERESTS: Poker, Hiking, Mental Health, Coaching, Cooking, Water Polo, Lifting, YouTube, and Video Games.