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Economic and Environmental Impacts of Collecting Waste Cooking Oil for use as Biodiesel under a Localized Strategy

BY
CHRISTOPHER R. WOOD

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE MASTER OF SCIENCE DEGREE IN
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KATE GLEASON COLLEGE OF ENGINEERING OF
ROCHESTER INSTITUTE OF TECHNOLOGY

INDUSTRIAL AND SYSTEMS ENGINEERING DEPARTMENT
ROCHESTER INSTITUTE OF TECHNOLOGY
ROCHESTER, NEW YORK

OCTOBER 2007

COMMITTEE MEMBERS

DR. ANDRES CARRANO
ASSOCIATE PROFESSOR
INDUSTRIAL AND SYSTEMS ENGINEERING
ROCHESTER INSTITUTE OF TECHNOLOGY

DR. BRIAN THORN
ASSOCIATE PROFESSOR
INDUSTRIAL AND SYSTEMS ENGINEERING
ROCHESTER INSTITUTE OF TECHNOLOGY

KATE GLEASON COLLEGE OF ENGINEERING
ROCHESTER INSTITUTE OF TECHNOLOGY
ROCHESTER, NEW YORK

CERTIFICATE OF APPROVAL

MASTER OF SCIENCE DEGREE THESIS

The M.S. Degree Thesis of Christopher R. Wood
has been examined and approved by the thesis committee
as satisfactory for the thesis requirement for the
Master of Science degree

Dr. Andres Carrano, Ph.D. *Advisor*

Dr. Brian Thorn, Ph.D. *Advisor*

Abstract

Some of the vital aspects in the diffusion of renewable energies are the cost of producing the energy, as well as the environmental impacts associated with its lifecycle. As petroleum based energy becomes increasingly costly, alternatives will be relied upon to meet the ever increasing energy demand. Biofuels, and biodiesel in particular, could be a near term solution for providing a transitional fuel to meet the energy demand of the transportation sector. However, the costs of biodiesel, as well as perceptions of a negative energy balance are hindering its widespread adoption. Using waste cooking oil (WCO) can reduce the cost of raw materials necessary for producing biodiesel, when compared to traditional sources, and by collecting and using biodiesel locally, its cost can be further reduced. This research involves the design and development of a simulation model to analyze the costs and emissions associated with waste cooking oil collection for the local, or decentralized, production and use of biodiesel. A case study for the food and beverage industry is investigated. A series of simulation experiments was used to evaluate different scenarios for utilizing the unexploited capacity of a local food and beverage distribution network for the collection of waste cooking oils. The economic and environmental costs associated with collecting WCO were compared to the economic and environmental savings from using biodiesel, the impacts of such operation upon service level are also investigated. Based on the local food and beverage network used to construct the model parameters, biodiesel production from WCO on a localized scale has positive impacts to both cost and emissions without sacrificing customer service.

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1. Introduction

Sustainable development has been defined as development that meets the needs of the present without compromising the ability of future generation to meet their own needs (WCED, 1987.) It is common knowledge that our natural resources are decreasing while waste production is increasing. These trends have spurred regulations on emissions, waste, and energy. As more regulations are set in place, higher cost will be associated with compliance to the regulations unless strategies to mitigate the costs in a sustainable manner are developed.

Sustainable development and industrial ecology are key to complying with energy and environmental regulations in a cost effective manner. Industrial ecology is defined as the shifting of industrial process from open loop systems, in which resource and capital investments move through the system to become waste, to a closed loop system where wastes become inputs for new processes (Wikipedia, 2006). By closing these industrial loops, natural resource consumption will be reduced through the extraction of value from waste. In essence, waste from one industry will be the feedstock for another therein reducing the amount of raw material necessary to accomplish the same functionality.

Energy, material, waste, and emissions are the principle inputs and outputs from every process from manufacturing through the service industries. Energy is required to manipulate the system, while waste and emissions will be generated due to inefficiencies in that system. According to the Energy Information Agency (2005), world energy consumption has been increasing at a significant rate with 2003 world consumption amounting to 421 Quadrillion Btus. It is also predicted that global energy demand will double by 2050 (DOE, 2006). On the other hand, the Environmental Protection Agency

reports that the USA generated around 235.5 million tons of municipal solid waste in 2002 (EPA, 2003). Energy production and use and waste are also the largest producers of CO₂ and methane respectively in the USA (EPA, Global Warming, 2006.). These gases are both considered greenhouse gases.

Parallel to the trends in energy consumption and waste generation, the cost associated with them is increasing. Energy prices are rising and will continue to do so with reduced supplies of fossil fuels. The cost of waste disposal is also increasing as landfill space becomes limited and the logistics associated with its removal become more difficult.

1.1 Implications of Waste

Landfills are the largest producers of anthropogenic methane in the USA at 55.8 million metric tonnes of CO₂ equivalents in 1998. This represents 61% of all solid waste emissions (Waste, 2006.). Landfills also require vast land to accommodate such high volumes of waste and are known to leach harmful chemicals to ground water sources. These leached contaminants pose threats to soil and drinking water sources.

In addition to polluting the environment, landfilled waste contains inherent material and energy value that is lost. This waste material and energy could be utilized instead of harvesting new materials to provide the same function. By closing the material loop energy and resources can be conserved.

In order to reduce environmental impacts and resource use, waste materials that are typically land filled need to be analyzed to determine feasible reuse applications. The reuse strategy for waste could be as a material feedstock or an energy source depending on the characteristics of the substance.

1.2 Implications of Energy Use

Energy production has primarily been based upon the combustion of fossil fuels such as oil and coal. These resources are finite, and pose significant environmental impact from their combustion. While coal is predicted to be a viable energy resource for 90 - 200 years, it has been predicted that the world oil supply is reaching its peak (Energy Information Agency, 2005). Oil is the leading energy source for the transportation sector behind electricity production (Energy and Emissions -EPA). As oil is consumed it will gradually rise in price as supply drops, extraction becomes more difficult, and demand rises. With an increase in price and decrease of supply, consumers will look for more economical methods to provide energy for transportation.

The environmental impact associated with fossil fuel use is another issue concerning its longevity as a sustainable energy resource. The combustion of fossil fuels generates emissions harmful to human health and the environment. Greenhouse gases (GHG) are emitted more from the combustion of fossil fuels than from any other source. According to National Academy of Sciences (2006) anthropogenic GHG emissions are contributing to global warming and have aided in rising global temperature by 1.4 degrees Fahrenheit. Emissions associated with fossil fuel combustion include carbon monoxide, carbon dioxide, nitrogen oxides, sulfur dioxide, particulate matter, and volatile organic compounds. These pollutants cause a number of harmful impacts such as respiratory problems and the acidification of fresh water sources.

Within the energy sector, electricity production and transportation are the largest consumers of fossil fuels therefore the largest producers of emissions. The transportation industry is dominated by petroleum as an energy provider due to its transportability and

compatibility with current propulsion technology. According to the Energy Information Agency (2005) petroleum is approaching its peak production output. With dwindling supplies, petroleum will gradually lose the ability to fuel the transportation sector

Alternatives need to be evaluated to determine viable options for transitioning to a new transportation fuel base. This transition may not be provided by a single fuel source or be provided on a national scale as petroleum fuel is today. The transportation industry may need to be based on several fuel sources requiring different production, propulsion, and refueling technologies such as hydrogen, ethanol, and biodiesel.

For all the reasons stated above, the use of petroleum based fuels for transportation presents a challenge to sustaining mobility, the environment, and human health. Alternatives to oil need to be analyzed to determine a more sustainable solution. Alternatives have been developed such as hydrogen and biofuels, however their wide scale adoption has been hindered. One of the major setbacks to these alternatives is cost. For example, hydrogen and fuel cells for vehicles and the infrastructural requirement to supply it are too expensive with current technology, thus not commercially viable. Nevertheless, there are solutions that can compete with the traditional transportation energy and waste methods in terms of economics and also provide external benefits to the environment and human health.

There are transportation fuel alternatives that do not require new infrastructures. Biodiesel is a fuel that can be blended into regular diesel, or used on its own in order to reduce the rate at which petroleum based fuel is consumed. This reduction in the consumption rate can allow for more time to study alternative fuel sources and technology while reducing emissions associated with the transportation industry.

Biodiesel is a renewable, carbon neutral, fuel that can reduce the dependence of fossil fuels in the transportation sector especially from heavy duty vehicles. Carbon neutral refers to a system that neither produces nor eliminates carbon in the atmosphere, therefore not affecting global warming. However, widespread adoption of biodiesel is hindered by the cost and difficulty of raw material acquisition. Typically biodiesel is produced from virgin agricultural based oil such as soy or rapeseed oil, however many vegetable based oils will work. Virgin agricultural based oil costs roughly \$0.53/liter and the conversion to biodiesel another \$0.15/liter (Haas, 2005). These combined costs exceed the cost of petroleum derived diesel before profit mark-up or federal taxes are included. In order to make biodiesel viable, methods for cost reduction must be employed. A current method for reducing cost is through the use of waste cooking oil (WCO) as a cheap feedstock for production (Supple et al., 1999).

In 1998 the US Department of Energy National Renewable Energy Laboratory determined that each restaurant produces an average range of 6,268 - 9,453 lbs (3250 – 4875 liters) of WCO per year (Wiltsee,1998). Based on these numbers the national production of WCO with a population of 295 million is between 2.6 – 3.9 billion gallons a year. This is equivalent to 6.1 – 9.2% of the total US diesel use for the transportation sector in according to the Energy Information Agency (2005).

2. Problem Statement

With the current trend of increasing energy costs, businesses are experiencing higher operational costs. Companies with transportation fleets, such as distributors, have been impacted by the increase in fuel cost. As a result, these companies have to either absorb

these costs through profit reductions, or pass the cost on to their customers. The cost of energy will continue to rise with the increasing demand for petroleum fuels. Therefore, the cost of goods and services will continue to increase as well. In addition to increased costs, the use of petroleum fuels produce harmful emissions, such as CO₂ and particulate matter, and creates a reliance on foreign nations for energy.

Waste generation has also become an issue in terms of cost, land use, and soil and water contamination. Companies that produce waste material are required to dispose of these wastes in an appropriate manner. The disposal of waste costs money for pick-up, transport, and treatment method. These disposal costs can go straight to the bottom line increasing operations cost of restaurants. Once the waste has been disposed of, there is the possibility that it can contaminate local soil and water. Finally, the transportation associated with collecting the waste creates harmful emissions through the combustion of petroleum fuels.

In some cases waste is capable of providing energy through either direct use or conversion processes. In other words, the waste being generated from one system can be returned back into another system as fuel. For example, waste cooking oil can be converted to biodiesel for use in the transportation sector.

The major hurdle to overcome with waste oil based production of biodiesel is finding a reliable and economically feasible supply. This problem seems to be aggravated by the need for very large quantities of WCO required for operating national scale production facilities. To accommodate such high volumes, large cost would be incurred in the development of a collection infrastructure. Local and decentralized alternatives need to

be addressed to determine if there is a possibility for an industry to use its current distribution infrastructure and operations to recover and use the WCO.

The food and beverage (F&B) distribution industry has a unique possibility to recover WCO without having to develop a new infrastructure. In this case, the F&B distribution industry already have the infrastructure in place. The WCO that is produced by restaurants, the customers of the F&B distribution industry, can be collected and converted to biodiesel for use in the trucks that are delivering the food or beverages. This local and decentralized system may be more feasible than dedicating an entire vehicle fleet to recover WCO under a national centralized strategy. By collecting the WCO for use as biodiesel a material loop can be closed.

In the case of F&B distributors there is an opportunity to reduce emissions, the dependence on foreign oil, waste generation, and operations costs for themselves and their customers. This opportunity lies in 2 distinct areas. First, the F&B distribution industry can utilize a current waste stream, waste cooking oil, produced by restaurants as a fuel source, and secondly this can eliminate the need for a waste collection service to dedicate trucks for recovering the waste. There is an incentive for the restaurants to give the WCO to the distributor for free. Currently restaurants pay for the removal of their WCO, therefore they would likely appreciate a free removal service provided from one of their suppliers. This could also be a strategy to gain customers for a F&B distributor who wants to expand their share of the market.

The aim of this thesis will be to investigate a F&B distribution network that includes the recovery of WCO, the production of WCO to biodiesel, and the use of the biodiesel in the trucks that are making the deliveries. The analysis will address cost implications

associated with the added time and distance to pick-up the WCO and use biodiesel. Emissions changes through the use of biodiesel versus petroleum based diesel will also be determined. The ability to meet the core business demands with increased services will also be investigated.

3. Literature Review

Biodiesel from different feedstocks has been researched thoroughly in terms of processes, costs, and emissions that arise throughout its production and use phases (Haas, 2005, Graboski, 1998). Models have been built to understand municipal solid wastes (MSW) logistical issues. Other research has been conducted to understand simultaneous pick –up and delivery logistics; and the quantities of WCO produced in the USA has been determined. However, no studies have brought these ideas together to examine the logistics of WCO as the raw material for biodiesel production and use under a decentralized scenario.

3.1 Waste Cooking Oil Resources in the USA

There have been a number of studies conducted to determine the quantity of WCO produced per year nationally or per restaurant. In 1998 the US Department of Energy's National Renewable Energy Laboratories (NREL) conducted a waste grease resource study of 30 metropolitan cities in the US. This study indicated little variability between the number of restaurants per 1000 people in urban areas with a range of 1 to 2 restaurants/1000 people and a weighted average of 1.41. The NREL study also concluded that each restaurant produces a weighted average range of 6,268 - 9,453 pounds (3250 – 4875 liters) of WCO per year (Wiltsee, 1998). Based on these numbers the national production of WCO with a population of 295 million is between 2.61 – 3.94 billion gallons a year. This is equivalent to 6.1 – 9.2% of the total US diesel use for the transportation sector in 2004 (Energy Information Agency, 2005)

The Minnesota Department of Agriculture also conducted a study to determine the quantity of WCO produced per year in the USA. This study concluded that between the years of 1995 and 2001 the average production of WCO was 2.63 billion gallons (Groschen, 2002). All of the studies reported the possible quantities of WCO that could be recovered, but none looked into the feasibility of physically collecting it.

3.2 Biodiesel production

Currently the two most common processes to produce biodiesel are by way of an alkali-catalyst system or an acid-catalyst system. Both systems are known as transesterification processes. These two methods have different strengths and weaknesses based upon the oil feedstock used to produce the biodiesel. The alkali-catalyst method is better suited for virgin oils, due to its inability to break down the high content of free fatty acids in waste oils, and has a faster processing time. These characteristics have made it the most predominantly used in biodiesel production processes. The acid-catalyst method is better suited for producing biodiesel from WCO, but requires longer processing times. When using WCO in the alkali process, a pretreatment step is required to remove the high content of free fatty acids from the waste oil. This added equipment increases the cost of the setup and increases the processing time. It has also been reported that 70-95% of biodiesel production cost arise from the raw material cost (Krawczyk, 1996; Connemann and Fischer, 1998), therefore causing virgin oil based biodiesel production costs to be much higher than waste oil based biodiesel. This figure highlights a need to use waste oils in the production of biodiesel based on the impacts to cost.

The alkali-catalyst process has been studied in laboratories to determine optimum process parameters (Freedman et al., 1984; Nouredini and Zhu, 1997; Darnoko and Cheryan,

2000). Industrial scale production alkali-catalyst processing was demonstrated in 1984 by Kreutzer and has been studied further since then (Krawczyk, 1996; Connemann and Fischer, 1998). It was also determined that the alkali-catalyst system could only work with oils with low fatty acid content, hindering its ability to produce biodiesel from waste WCO with out a pretreatment step (Freedman et al., 1984; Jeromin et al., 1987). The pretreatment step, esterification, was identified and introduced by Lepper and Fienhagen (1986).

The acid catalyst process has only been demonstrated at the bench scale, even though it is robust to different feedstock oils in terms of their free fatty acid content. Acid-catalyst transesterification was explored by Freedman et al. (1984) to determine operating parameters. Canakci and Gerpen (2001) investigated the acid-catalyst process to understand the effects of different operating parameters on the conversion percentages from oil to biodiesel. The parameters were examined independently so no optimal solutions were recommended. WCO was converted to biodiesel using the acid-catalyst process in a laboratory by Ripmeester (1998) and McBride (1999). It has been shown that the acid-catalyst process is advantageous when creating biodiesel from WCO, because there is no pretreatment step required (Zyang et al., 2003).

The economics of biodiesel production using both the alkali and acid catalyst methods were compared to determine the pros and cons of each using different feedstock oils in terms of their process technology (Zhang, Et al. 2003). Each process was compared using both virgin oils and waste oils. It was determined that the alkali-catalyst process using virgin oil had the lowest fixed capital cost, but the acid-catalyst process using WCO was the most economically feasible. The acid-catalyst process had the lower total

manufacturing cost, a greater after tax rate of return, and a lower biodiesel break even price. Zyang et al. (2003) showed that biodiesel production from WCO using the acid-catalyst process is a potentially competitive alternative to the commonly used alkali-catalyst process using virgin oils.

These findings show that the use of waste oils can have a beneficial impact on the cost of biodiesel production. The findings also highlight a waste product that can be diverted from the waste stream and cascaded into another use. These reports do not however state an economically feasible way of collecting the waste material for use in the production of biodiesel.

3.3 Waste Management

Waste management has been researched with respect to its supply chain using various techniques under a vast array of scenarios. The economic and environmental performance have been taken in to account, however the methods have not provided a technique for modeling decentralized collection of waste for use as fuel in the distribution industry. The major research in waste management has been focused on understanding and optimizing centralized or large scale waste issues. In order to understand waste management, the rate at which waste is generated was determined (Hockett et al., 1995; Chen and Chang, 2000). Once the generation levels were understood optimum treatment locations were established (Huang et al., 1995; Chang and Wang, 1996; Fredriksson, 2000) to manage the wastes using different treatment methods such as landfilling, recycling, and incineration (Huhtala, 1997; Dalemo et al., 1998; Highfill and McAsey, 2001).

Other research looked into the environmental and social impacts associated with waste management systems (Nixon et al., 1997; Slater and Frederiksson, 2001; Powell, 1996).

Life cycle inventories have been built around the different waste management treatment scenarios mostly based on the work done by White et al. (1999). Some models also included a life cycle analysis to determine the impacts associated with the system (Munda and Romo, 2001). The economics of municipal solid waste systems has also been considered when making decisions on which treatment method and/or collection scenario should be chosen (Morris and Holthausen, 1994; Jenkins et al., 2000; Palmer et al., 1997; Fullerton and Wu, 1998; Hong, 1999).

These studies analyzed centralized, regional scale collection and treatment scenarios for municipal solid waste (MSW) without looking into the holistic approach of utilizing specific waste streams directly as feedstocks for other systems. These methods also neglect the local decentralized approach to waste management such as collecting waste for local reuse.

4. Scope and Methodology

The objective of this study is to analyze the parameters that affect the collection of WCO for use as biodiesel, on a decentralized scale, in terms of economics and the environment. In order to analyze the key factors, a simulation model was built to represent two scenarios under which this system can take place. This model was flexed under different experimental conditions to understand the systems dynamics.

4.1 Overview of Model

The simulation model represents a single truck within an F&B distribution system that has a variable number of customers and distances between those customers. The customers will produce different quantities of WCO, and will be supplied different amounts of products freeing up space in the truck for the WCO to be collected. Once the truck has visited all the required stops, it will return to the warehouse where the WCO and any remaining product will be offloaded. The WCO will then be traded to a local biodiesel producer for biodiesel at a reduced price. Once the first batch of WCO has been traded the truck will be filled with a mix of biodiesel and petroleum based diesel. The costs of collecting the WCO will be calculated dynamically, while the saving from the use of biodiesel will also be tracked. During the simulation, emissions savings from the biodiesel use will be updated for each route.

Two scenarios will be explored, the first model scenario will represent a current state F&B distribution system that only recovers WCO from restaurants who are already being supplied. This system will be referred to as the full piggy backed system (See Figure 1). This model was run with out picking up WCO in order to set a baseline for comparison.

The second scenario, to be referred to as the hybrid piggy back system was constructed similar to the first scenario, except WCO could also be recovered from restaurants that are not currently customers of the distribution company (See Figure 2). In the hybrid piggy back model the extra distance traveled will result in added emissions and costs, therefore those emissions and cost will be estimated to determine if the added distance traveled was worth while in terms of its environmental and economic impact.

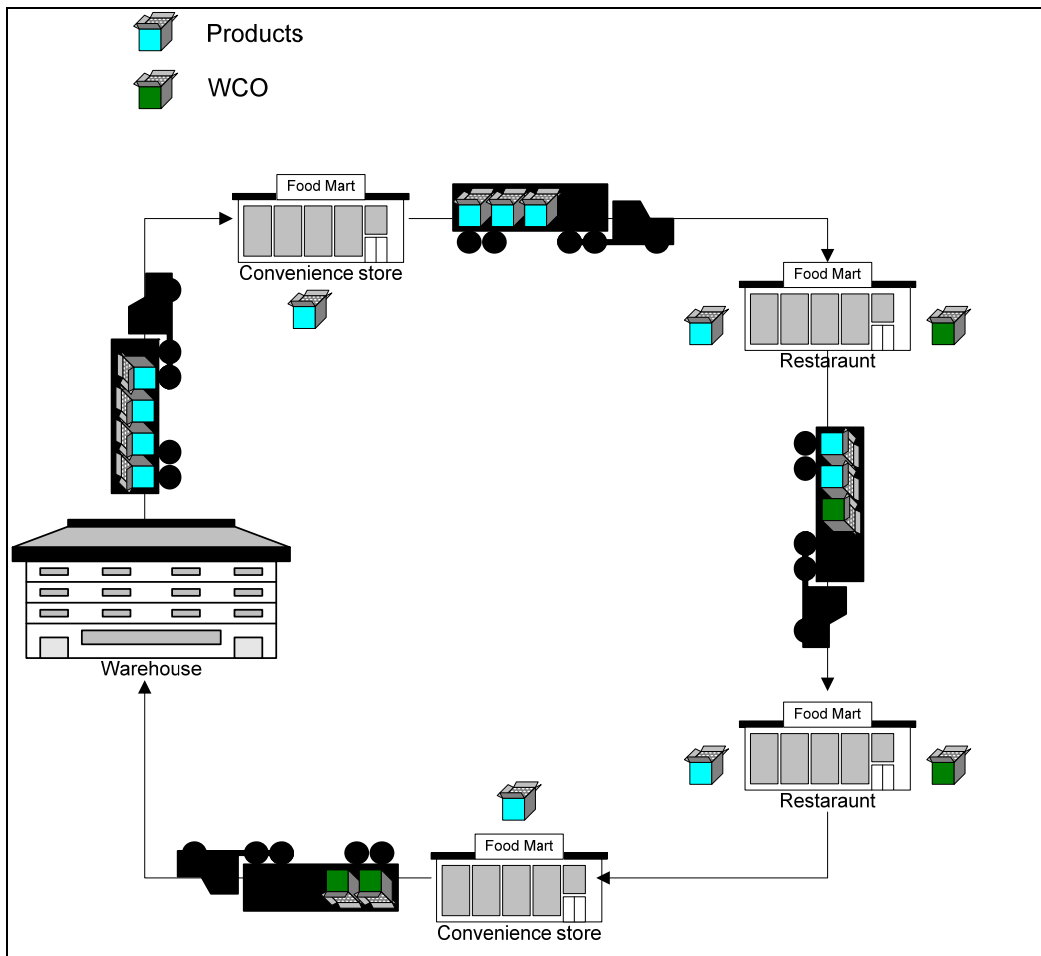


Figure 1. Full Piggy Back System

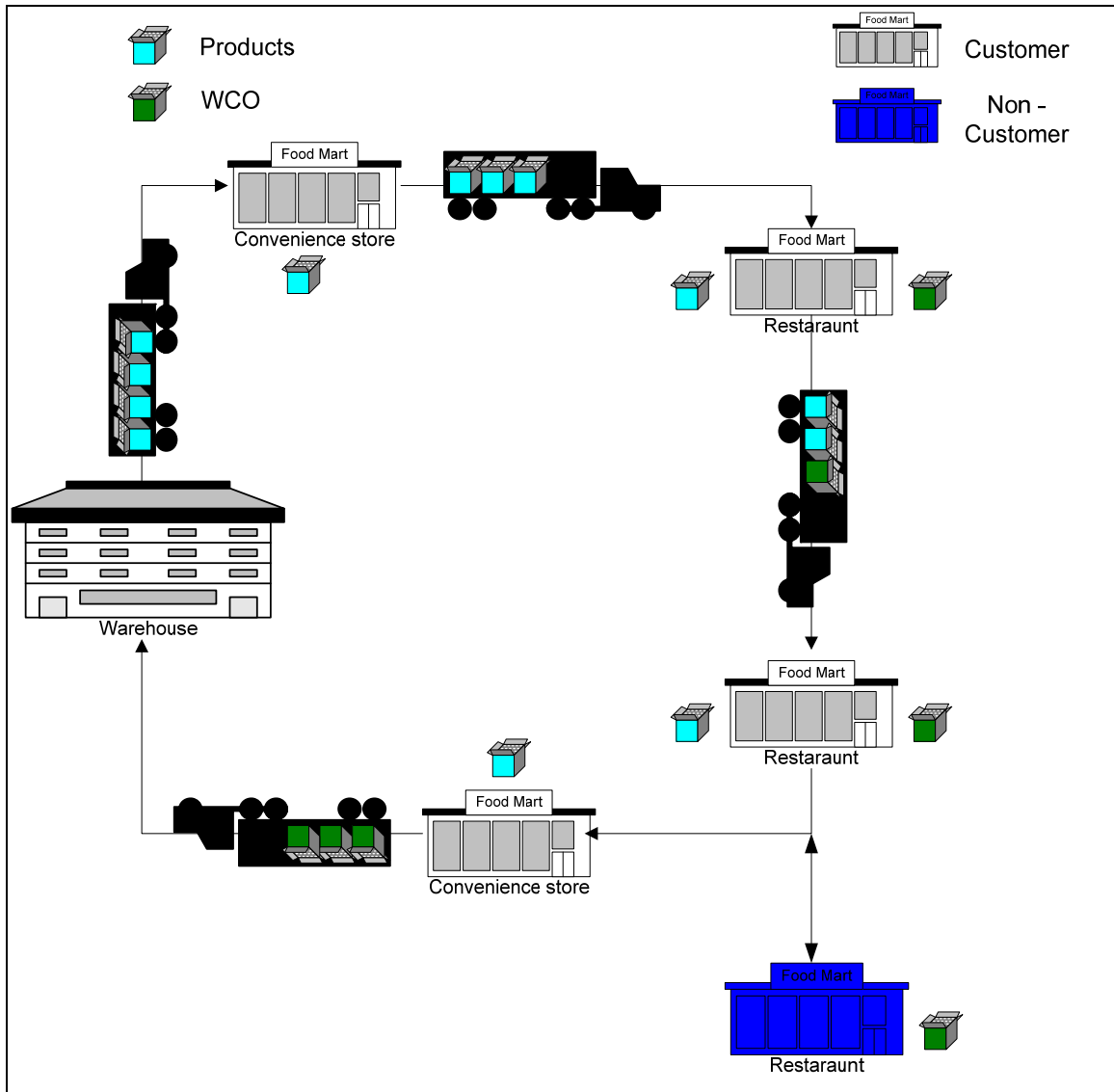


Figure 2. Hybrid Piggy Back System

Both models will be addressing the operations costs and emissions associated with the collection and use of WCO derived biodiesel under certain assumptions. In the hybrid piggy-back model the added distance and time traveled to non-customers will be factored into the cost and emissions in order to determine if this scenario, under different parameters, is economically feasible and environmental beneficial.

In order to model the full and hybrid piggy back scenarios, data from a local F&B distributor was collected. The distributor used was solely a distributor of beverages such

as beer, energy drinks, and soda. The data collected from the local distributor was used to build the model to closely represent how the system actually works. Data on WCO production at restaurants was obtained from literature (Wiltsee, 1998).

Routing sheets containing information on distance, time, number of stops, average loads were obtained from the local distributor. The routing sheets were the basis for the assumptions built into the model and are as follows:

- Fuel consumption and emissions will not change based upon the load of the truck
- Every stop is visited one time per week
- Every route has 15 stops
- The cost of labor (Truck Driver) is \$25 per hour
- All WCO collected will be converted to biodiesel at a 90% conversion factor
- All produced biodiesel will be used in the distribution fleet or traded for equal value
- All WCO collected will come in 5 gallon drums (partially full is allowed)
- The average speed of the truck is 35 MPH
- The cargo capacity of the truck is 567000 in³
- The truck has a 277 HP diesel motor
- The average fuel economy of the truck is 6 MPG
- The fuel capacity of the truck is 100 gallons

4.2 Simulation Model

The model was built using the Arena 7.01 software package. Other tools such as linear programming were considered and evaluated, however Arena was chosen based on the ability to accommodate for the high levels of variability within the system. Arena also allows for quick manipulation of the parameters in the model to aid in the experimentation process. Finally, the problem being investigated could be looked at for many different locations in the future, so the ability to quickly change parameters through a graphical user interface makes Arena a good long term tool to build upon for future research purposes. The ability to easily change the variability within the system is useful when modeling the recovery of WCO for use as biodiesel due to the fact that the distances traveled, packing percent of the vehicle at route start, the amounts of WCO at each stop, and the volume of products dropped at each stop are variables that could be different for each system. The model can be customized to represent an exact scenario, or it can be run under different parameters to create a heuristic for the best cases in which F&B distributors should collect WCO for use as biodiesel. This approach and the idea of further studies of distribution systems is made easy with a package such as Arena.

A graphical user interface (GUI) was constructed to allow the modeler to set the parameters for different runs of the model (See Figure 3). The parameters that can be manipulated by the modeler from the GUI include the number of routes to be made per replication, the number of customers who have WCO, the number of customer who do not have WCO, the additional distance traveled to go to non-customers, the number of non customers that will be visited, the hybrid (1) or full piggy back(0) scenario, the cost

of diesel, the cost of biodiesel, the percentage of biodiesel to be mixed with the regular diesel, and the time the truck is delayed at each stop during the pick-up process. Once the parameters have been entered by the modeler the run button is clicked to begin the simulation.

The screenshot shows a GUI with a light beige background. It is divided into three main sections for inputting parameters:

- General Information:** Located on the left, it contains seven input fields:
 - Number of Routes per replication (with the value '1' entered)
 - Scenario 0 or 1
 - Allowable Route Time
 - Diesel Cost per Gallon
 - Biodiesel Process Cost per Gallon
 - Biodiesel Mix Percentage
 - Truck Delay Time
- Scenario 0 and 1 Information:** Located in the top right, it contains two input fields:
 - Number of Customer Stops with WCO
 - Number of Customer Stops without WCO
- Scenario 1 Information Only:** Located in the bottom right, it contains two input fields:
 - Number of Non-Customer Stops
 - Add Max Distance For Non-Customers

At the bottom center of the GUI is a button labeled "Run".

Figure 3. GUI at model start

The simulation model can be broken into five functional sections, truck and route creation, dispatching, stops, warehouse, and reporting. These functional sections can be further reduced to more detailed stations. The truck and route creation section can be divided into model start, route set-up, and refueling and cost calculation. The dispatching section has no further breakdown. The stops section can be broken into three different stop types, customer delivery and WCO pick up (Stop type 1), customer delivery only (Stop type 2), and non-customer WCO pick-up only (Stop type 3). The warehouse section can be divided into biodiesel production and emissions calculations. The reporting section is stand alone like the dispatching section.

In the truck and route creation section, the first station, model start, includes the creation of the truck, truck and model variable assignment, and an entity separation module. The

entity separation module duplicates the truck entity, allowing for two sets of logic to be completed simultaneously. The duplicated entity is sent to keep track of cost and fuel while the original entity is used to complete the routes (See figure 4).

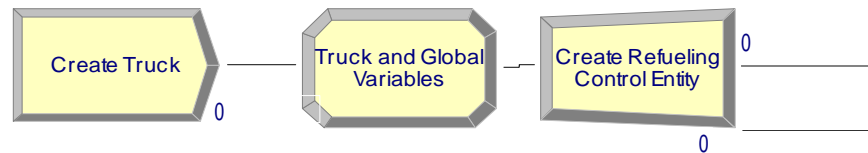


Figure 4. Model Start

In the first module of model start, one entity is created using the create module to represent the truck. The truck entity then moves to an assign module where the truck specifications of cargo capacity, fuel capacity, fuel economy, and horsepower, are assigned to that truck as seen in Table 1. Also within the assign module, model variables are declared for keeping track of the dynamic parameters and informing the model whether the full or hybrid piggy back method is being used. The attributes that are initialized in this module are the cost of diesel, the cost of biodiesel, the maximum time allowed to be in route, the time at each stop, and the percentage of biodiesel that will be mixed with regular diesel for use in the trucks. These variables are initialized to the values entered by the user in the GUI. This module also determines the max distance a truck can go on a tank of fuel which is based on fuel capacity and fuel economy. The response variables that will keep track of total cost, total biodiesel, and total additional cost for the hybrid piggy back scenario are also declared in this module. The truck entity then moves to a separate module where a duplicate entity is created. The duplicated entity goes to the refueling and cost calculation section, where it waits to be signaled to begin the refueling process. The original entity then moves to the route set- up station.

Table 1. Truck Specifications

Specification	Assigned Value
Cargo Capacity	567,000 in ³
Fuel Capacity	100 Gallons
Fuel Economy	6 MPG
Horsepower	277 HP

The route set-up station initializes the route and emissions variables and attributes, as well as creates the route to be followed by the truck.

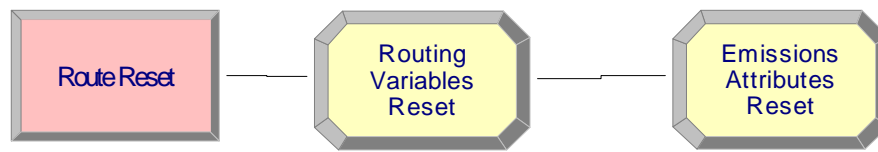


Figure 5. Route and Emissions Variable and Attribute Initialization Modules

The first module in this station is the route reset station module. This module allows for the truck to be sent back to this section when all the subsequent processes have taken place. In the routing variables reset module, the remaining values entered by the user in the GUI are initialized to the number of pick-up and delivery stops, the number of delivery only stops, the number of pick up only stops, and the additional distance traveled under the hybrid piggy back scenario. The total route distance and packing percentage of the truck at route start are set to default distributions of $22 + 275 * \text{BETA}(0.896, 2.77)$ and $\text{TRIA}(0.3, 0.951, 1)$ respectively. The beta and triangular distributions are used based on the data collected from a local F&B distribution company. This data was inputted to Arena 7.01s input analyzer to determine the best fit distribution. Scotts rule was applied

to determine the number of levels within the histograms used to fit the data. This module also reinitializes the remaining cargo capacity, biodiesel produced, the amount of WCO collected, time in route, the number of stops made, the number of stops for each type as they are created for building the route, previous stop location, and the number of late stops to zero. These variables are set to zero in order to clear the values from the previous route so that the new route parameters can be tracked. For example, the amount of WCO collected from the previous route may have been 100 gallons; therefore this value needs to be reset to zero. When a WCO pick-up occurs for the new route that variable is updated to reflect the pick-up.

The emissions attribute reset module sets all the emissions values to zero in order to calculate the emissions for the following route. The emissions that are tracked are carbon dioxide, carbon monoxide, total hydrocarbons, and nitrogen oxides.

From the emissions attributes reset module the truck entity moves to the route creation part of this station (See Figure 6). The first module in this station determines whether there are any customer stops with both pick-ups and deliveries. If there are, the next module is the assign block. This assign block creates a two dimensional array that is filled with the new stop location and type. The stop location is determined by sampling a uniform distribution with a range from zero to the total route distance. The uniform distribution was used based on the data from the F&B distribution company data that showed no correlation between distance traveled and number of stops made, therefore giving equal likelihood that a stop location could be anywhere along the route. This position is then placed in the array along with a stop type of one. Stop type one is defined as a stop with both pickups and deliveries (Example in Table 2). Then, if there is only

one type one stop, the entity flows to the type two stop creation code. If there are more than one type one stops, the entity is looped back to the assign module to create another position along the route for another stop type one, this is repeated until all the type one stops are placed on the route. When all the stop type ones are placed along the route, the stop type twos are created using the same logic (See Figure 6). The only difference in logic is the stop type is changed from one to two. Upon completing the generation of all stop type ones and twos, the model checks for the method being used, the full piggy back or hybrid piggy back method. If the model has been set to the hybrid piggy back method, then non-customer stops or stop type threes are created using the same logic as stop types one and two, except the stop type is set to three (See Figure 7).

Figure 6. Stop Type 1 and Stop Type 2 Creation

If the full piggy back system is being used the truck bypasses the stop type three creation process and is sent to the dispatching section through the final module in this station the route truck module.

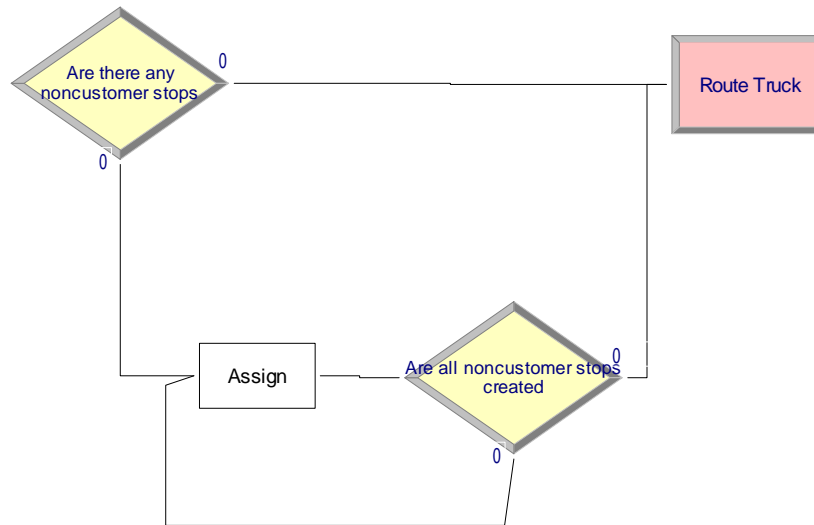


Figure 7. Stop Type 3 Creation and Route to Dispatch Station

Table 2. Sample Stop Location and Stop Type Array

Stop Location	Stop Type
72 mi	2
37 mi	1
134 mi	1
16 mi	3
80 mi	2

The next functional section is the dispatching section (Figure 8). The dispatch section scans through the array created in the previous section to determine which stop is first. It then sends the truck to that type of stop in order to make its deliveries or pickups depending on the stop type. After each stop the entity returns back to the dispatching section to be routed to the next stop or back to the warehouse after all stops have been

made. The dispatching process happens in zero time and incurs no distance, therefore not affecting the routes' physical properties.

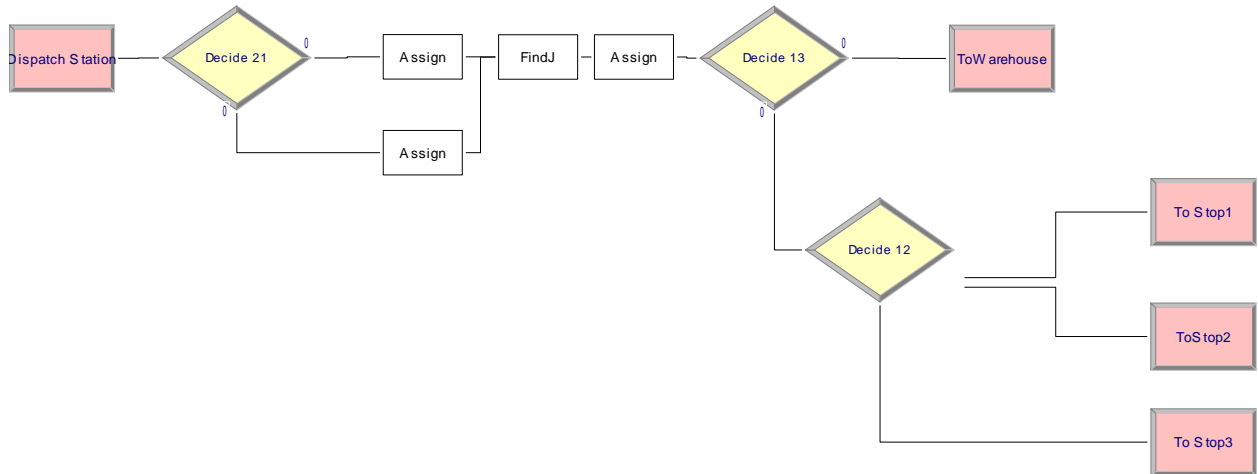


Figure 8. Dispatch Section

The dispatch section first determines whether or not the subsequent stop is the first stop in this route. If it is the first stop then the variable, number of stops made, is incremented by one in the following assign block. If it is not the first stop, then the number of stops made variable is incremented and the last stop location is reinitialized to a number outside of the feasible stop location distribution. This process insures that no stop is visited twice. Once the stop has been cataloged and the previous location reinitialized if necessary, the next step is to search through the array that was created in the route set up section for the stop with the smallest location value or the first stop along the route. This is accomplished using the Find J block. With the location found, the next stop location can be set to the stop location variable and the corresponding stop type can be assigned. For example, suppose it is the second stop of the route and the first stop location and type were 16 mi and 3 using the data from Table 2. With the truck entity back at the dispatch

section after visiting a stop type 3, it checks and determines that it was not the first stop, so the assign module increments the number of stops made to two and sets the previous location (16 mi) to a number outside of the feasible range of locations (~10000). Now the logic can find the next the next stop location and type, 37 mi and stop type one respectively. A decide module then determines whether all stops have been made. If all stops have been made, then the truck is routed back to the warehouse. However, if all stops have not been made it sends the truck to another decide module that determines which stop type is next and routes it accordingly.

Depending on the stop type, dispatch will send the truck to either a stop that has both a product delivery and WCO pickup process (Stop type 1), a product delivery only process (Stop type 2), or a WCO pickup only process (Stop type 3). The stops that contain both delivery and pickup processes (See Figure 9.) require time be spent at the stop to perform these actions. During this time products are delivered in the amount specified by sampling from the distribution $\text{TRIA}(1.26\text{e}+4, 1.8\text{e}+4, 8.93\text{e}+4)$. This distribution was created using the data from the local F&B distributor's data and using Arena 7.01s input analyzer similar to the previous distributions. The products that are delivered free up space within the truck equal to the volume of the products that were delivered. This freed capacity is tracked using the remaining capacity attribute. The time spent at the stop is also tracked to determine how long the truck has been in route. After the delivery has taken place the overall route time is checked to establish if the delivery was made within the specified length of time allowed for the route. If the delivery was not made on time a counter increments by one to record the late delivery. If the delivery was with in the time constraint or after the counter has incremented, then the pickup of WCO occurs. The

amount of WCO collected is determined by sampling from a uniform distribution between 16 and 23 gallons. This distribution is created from using data published by Wiltsee, (1998) on the range of WCO produced by each restaurant per year. This data range was then scaled back to determine how much would be produced per week per restaurant. It is assumed within the model that each customer is visited on a once a week schedule. This assumption was verified by the local F&B distributor to be valid. The truck will pick up the amount of WCO at the stop or as much as will fit on the truck based on the remaining cargo capacity. The WCO is assumed to be collected in five gallon containers, so if there are 17 gallons of WCO then four containers would be collected. The capacity in the truck would also need to accommodate the volume of 4 containers. The total amount of WCO is tracked along the route to determine the total collection amount at the end of the route. The time associated with pick up at each stop was set at five minutes and is incremented into the total route time. Five minutes was chosen for the pick up time during a stop type one, because the time associated with delivery will have already accounted for the time to park and get into the building. The only process that is necessary for pick up is carrying the WCO to the truck. It was assumed that this process would take an average of 5 minutes. The remaining capacity is again updated to represent the now collected WCO. After both the delivery and pickup processes have taken place the truck entity is sent back to the dispatch section to determine which stop type is next.

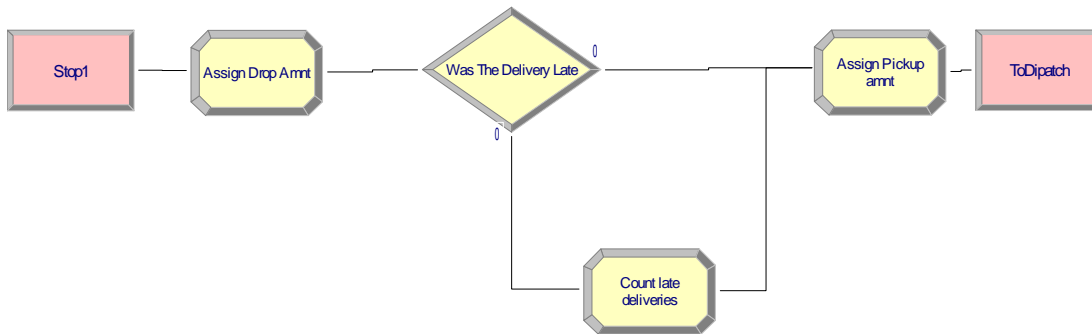


Figure 9. Delivery and Pickup Stop (Stop Type 1)

The dispatch logic may determine that another delivery and pick up stop is next, which will repeat the previous stop logic. The dispatch may however determine that a delivery only stop is next on the route (See Figure 10). In the case of a delivery only stop, the same delivery logic that was used in the delivery and pick up stop is applied. Again time is checked to see if the delivery was on-time. After the delivery process takes place, the truck entity is again routed back to the dispatch section to determine the next stop. If the full piggy back scenario is chosen then this logic will repeat until all type 1 and 2 stops are completed.

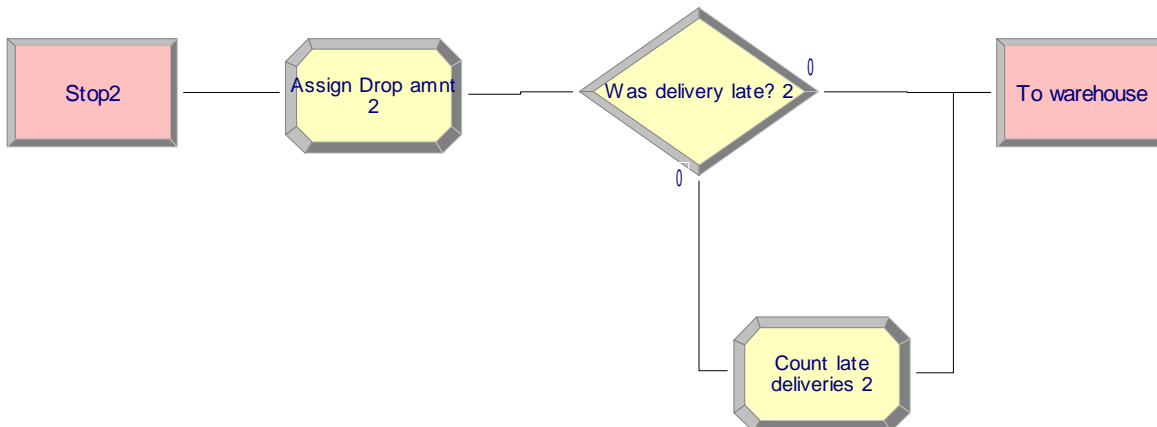


Figure 10. Delivery only Stop (Stop Type 2)

If the hybrid piggy back scenario has been selected then the third stop type, pick up only, could be selected by the dispatch as the next stop along the route (See figure 11). The pick up only stop uses the same logic as the pick up process from the delivery and pick up process stop except that the pickup time is initialized to the value set by the user in the GUI for delivery times. This time is changed because the time it takes to solely pickup WCO is assumed to take longer than picking up WCO at a location where you are already dropping products off. This extra time is attributed to parking, walking to the building, and speaking with the restaurant employees. This would have already been done in the delivery process for a stop type one. The truck is then sent back to the dispatch section to determine if all stops have been made.

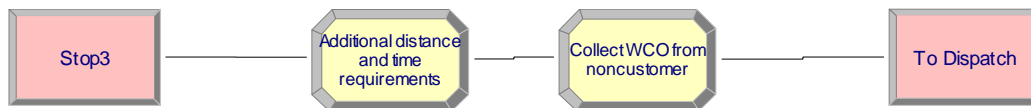


Figure 11. Pickup Only Stop (Stop Type 3)

After all stops have been visited, the truck is routed to the warehouse where the WCO is dropped off. The WCO is unloaded at the warehouse to be traded for biodiesel at a reduced cost. The biodiesel conversion process is ~90% efficient so only 90% of the WCO is turned into biodiesel, reducing the amount of biodiesel received by 10% compared to the WCO collected. After the WCO has been traded, the truck is sent to be refueled with the biodiesel and regular diesel mix. This happens in the biodiesel processing station (See figure 12.).

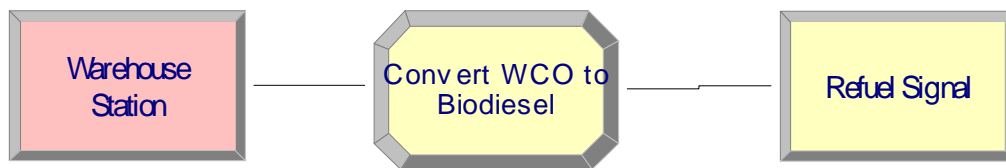


Figure 12. Warehouse Station

The first module in the biodiesel production process station sums all the route distances and route times for use in the refueling and cost calculation station. Also within this module WCO is reduced by 10% to determine the quantity of biodiesel that can be produced from that route. This biodiesel is added to the total biodiesel variable that keeps track of the total amount of biodiesel that has been produced. The cumulative route time is also incremented at this point in order to keep track of the total time required to complete all the routes. Following this module is the refuel signal module. This module signals the refueling and cost calculation station to activate.

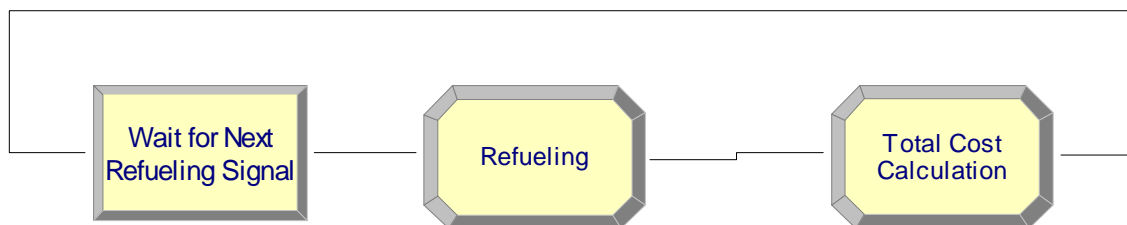


Figure 13. Refueling and Cost Calculation Station

When the refueling signal is sent to the hold module, the truck entity that was created in the model start station is released to be sent to the refueling module. The refueling module calculates the amount of diesel and biodiesel necessary to refill the truck's fuel

tank. This is determined by the distance traveled by the route and the inputted percent mix of biodiesel and diesel, this amount is also constrained by the amount of biodiesel that has been produced from the WCO. If there has not been enough biodiesel produced from the WCO, then the amount available is used in the refueling process. The refueling module also updates the total quantities of biodiesel and diesel that are used. The cost of refueling with the respective fuels is recorded for use in the total cost calculation module. The potential biodiesel saving is also calculated to determine how much savings would be incurred if all the biodiesel that was created was used by other trucks in the fleet. The next module is the total cost calculation module. In this module, total cost is determined by summing the cost of the driver's time and the fuel cost. The additional cost for collecting WCO is also calculated in this module for use in the reporting section. The total system cost is calculated by the normal operation cost of the route, plus the additional operations cost of the new system, minus the savings generated by using the biodiesel produced from the WCO. The normal operations cost is based on the cost of labor plus the cost of fuel. The operations cost associated with the new system include the addition labor cost plus the addition fuel for the hybrid piggy back system (See Equation Set 1.)

Equation Set 1. Cost Calculations

Cost of labor (L) = Time (T)*Wage (W)

Cost of Diesel Fuel (C_D) = $((0.8 * \text{Distance (D)}) / \text{Fuel Economy (E)}) * \text{Price of Diesel (F}_D)$

Cost of Additional Labor (L_A) = Additional Time (T_A) * Wage (W)

Cost of Additional Diesel (C_{DA}) = $((0.8 * \text{Additional Distance (D}_A)) / \text{Fuel Economy (E)}) * \text{Price of Diesel (F}_D)$

Total Cost of Route (CT) = $L + L_A + C_D + C_{DA} + C_B + C_{BA}$

Cost Savings from Trading all WCO for Biodiesel (S) = $((\text{Total WCO collected (G)} * .9) * \text{Price of Diesel (F}_D)) - ((\text{Total WCO collected (G)} * .9) * \text{Price of Biodiesel (F}_B))$

Total Cost of System after Savings (C_S) = $(L + L_A + ((D/E) * F_D) + ((D_A/E) * F_D)) - S$

The cost of the system after savings shows how much the cost of the route would be if all the WCO was traded for biodiesel at a reduced cost. This can be compared to the original cost of the route to see how much can be saved for each route, or for a number of routes. Once the duplicate entity leaves this module it loops back around to the wait for refueling signal module where it waits for another route to be complete and the refueling signal to be triggered so the actions can repeat for the new route parameters (Refer to Figure 13.).

After calculating the cost associated with the route, the emissions that are released are calculated to determine the reduction caused by using biodiesel. The emissions are calculated based upon the percent of biodiesel in the fuel mix from 10% to 40% in increments of 10%, the distance traveled divided by the speed, and the horsepower of the truck, these emissions calculations are based on information published by (Manicom, 1993). The emissions produced using the specified biodiesel blend are then compared to

the emissions if the truck had not used any biodiesel to determine the savings from the biodiesel use (See Figure 14.).

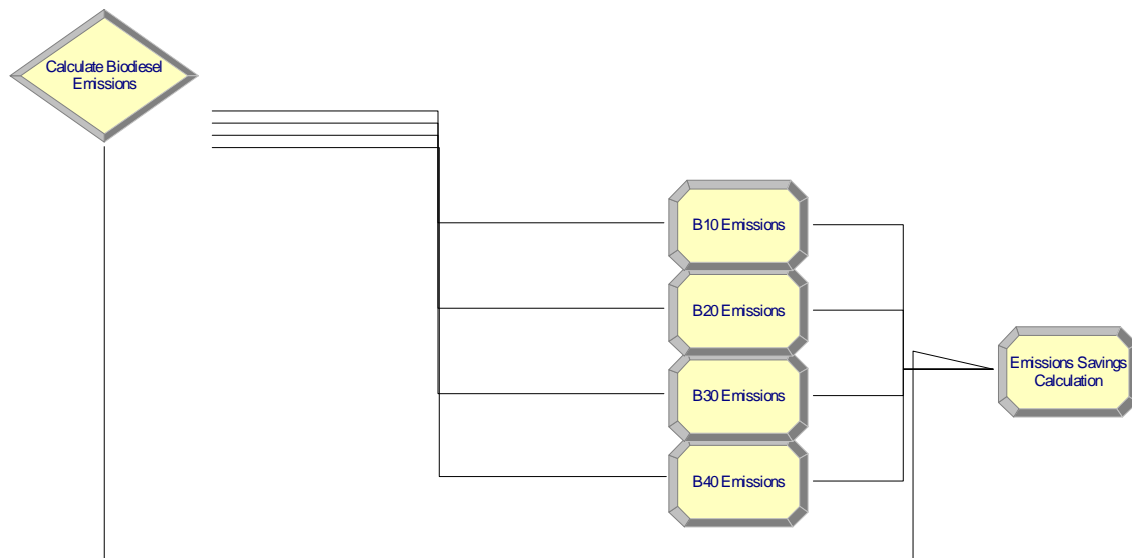


Figure 14. Emissions Calculations

In the emissions calculation station, the first module determines what percent biodiesel is used in the fuel mixture 10, 20, 30, or 40 percent. The corresponding biodiesel mix emissions are then calculated for that route and recorded as the route CO₂, CO, NO_x, and THC emissions. The emissions that would have resulted if no biodiesel had been used are calculated and recorded. The route emissions using biodiesel are then subtracted from the route emissions without using biodiesel to determine the change in emissions from using biodiesel, these changes are recorded as CO₂, CO, THC, and NO_x Emissions Savings. B20 was used in this study based on Manicom's findings, suggesting that 20% is the optimal mixing percent for cost and emissions reductions. It was assumed that all the biodiesel will be used, therefore 20 percent mix allows for the biodiesel to be used in any truck without conversions. Based upon Manicom's findings and the ease of use of B20 it was chosen as the blend ratio. The emissions savings equations associated with the use of B20 are:

Equation Set 2. Emissions Calculations

$$CO_2 \text{ Savings} = \left(WCO \text{ Collected} \times \frac{MPG}{Avg \text{ Speed}} \times Truck \text{ HP} \times B20 \text{ Emissions Coefficient}_{CO_2} \right) - \left(\frac{Distance \text{ Traveled}}{Avg \text{ Speed}} \times Truck \text{ HP} \times Diesel \text{ Emissions Coefficient}_{CO_2} \right)$$

$$CO \text{ Savings} = \left(WCO \text{ Collected} \times \frac{MPG}{Avg \text{ Speed}} \times Truck \text{ HP} \times B20 \text{ Emissions Coefficient}_{CO} \right) - \left(\frac{Distance \text{ Traveled}}{Avg \text{ Speed}} \times Truck \text{ HP} \times Diesel \text{ Emissions Coefficient}_{CO} \right)$$

$$THC \text{ Savings} = \left(WCO \text{ Collected} \times \frac{MPG}{Avg \text{ Speed}} \times Truck \text{ HP} \times B20 \text{ Emissions Coefficient}_{THC} \right) - \left(\frac{Distance \text{ Traveled}}{Avg \text{ Speed}} \times Truck \text{ HP} \times Diesel \text{ Emissions Coefficient}_{THC} \right)$$

$$NO_x \text{ Savings} = \left(WCO \text{ Collected} \times \frac{MPG}{Avg \text{ Speed}} \times Truck \text{ HP} \times B20 \text{ Emissions Coefficient}_{NO_x} \right) - \left(\frac{Distance \text{ Traveled}}{Avg \text{ Speed}} \times Truck \text{ HP} \times Diesel \text{ Emissions Coefficient}_{NO_x} \right)$$

With the route complete and cost and emissions savings calculated, the reporting section provides a way to easily view the outputs of the model. The outputs that are reported are, total cost, biodiesel cost savings, total cost after biodiesel savings, quantity of WCO collected, CO₂, CO, NO_x, and THC Savings, the number of trucks that could be fueled at the specified percentage using the biodiesel from this trucks routes, the amount of biodiesel produced, and the cost of collecting WCO and producing biodiesel (See Figure 15.). Once all these outputs are reported, the truck waits for the next morning when it can be routed to the routes setup station. This repeats until the number of specified routes have all been made.

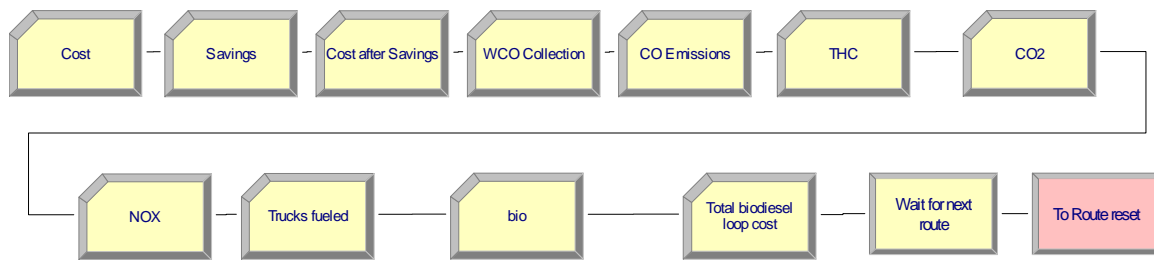


Figure 15. Reporting Section

4.3 Verification and Validation

The model was constructed based on information from a real system. The model was also evaluated by other programmers who were familiar with the system and the Arena 7.01 software to verify that the model was constructed in a logical manner. The model was also run under different inputs to determine proper output control. For example, the density of stop types was checked to make sure that the inputted number of each stop was occurring in the model. The cost of fuel parameters were changed to see if the total cost was affected accordingly. Also the times associated with stopping were manipulated to see how the route times and cost changed. The outcomes of these tests show that the model was created to respond similarly to the real system.

The model was built to accommodate real values to be entered from companies. By allowing for real data to be inputted, the model can provide the information needed by the company to make decisions regarding this system. This insures that the results are aligned with the system being modeled.

4.4 Experimental Design

A series of experiments were conducted to analyze the trends in cost and CO₂ savings, under different parameters for both the full and hybrid piggy back scenarios. The experimentation takes place over 20 days of routes for all analysis cases. CO₂ was chosen as the indicator for emissions reductions due to the interest in reducing GHG emissions. Also, the responses in total hydrocarbon and carbon monoxide emissions will follow the same patterns as CO₂. On the other hand, NO_x emissions will increase from biodiesel use. The cause of the opposite trend for NO_x can be attributed to the increase of NO_x emissions for biodiesel compared to regular diesel. All the other emissions are reduced when using biodiesel.

The model will be used to answer the following questions:

1. Is the operation of recovering and trading WCO for biodiesel economically feasible under the full piggy back decentralized scenario? Why or why not?
 - a) What are the savings that can be achieved?
2. Is the operation of recovering and trading WCO for biodiesel economically feasible under the hybrid piggy back decentralized scenario? Why or why not?
 - a) What are the savings that can be achieved?
3. Is the environmental impact of recovering and trading WCO for biodiesel reduced under the full piggy back decentralized scenario, compared to the current system? Why or Why not?
 - a) What are the emissions reductions that can be achieved?

4. Is the environmental impact of recovering and trading WCO for biodiesel reduced under the hybrid piggy back decentralized scenario, compared to the current system?

Why or Why not?

a) What are the emissions reductions that can be achieved?

5. Is the full or hybrid piggy back scenario more beneficial in terms of economics and the environment? Under what conditions?

a) What are the differences?

b) What factors have the biggest influence on the outcome of the model?

c) What are the effects to service level caused by the extra time and distance associated with the collection of WCO?

With these questions answered it will be possible for the F&B industry to determine which companies have the right fit to utilize the WCO from their customers or for each distributor to analyze its own situation. This study will also provide insight into areas for improvement, as well as provide other distribution sectors the understanding of the potential for closing material loops as it may pertain to their industry.

The factors that were manipulated in the experiment for the full piggy system were the cost of diesel, cost of biodiesel, time at each stop, number of stops with WCO compared to the number without WCO (stop type density), total distance traveled, the percentage of the truck that is filled with products at route start (packing percent), the amount of WCO picked up at each WCO producing stop (WCO collected), and the volume of products delivered at each customer stop (See Table 3). These factors values were all changed by 25% in both the positive and negative directions from baseline to be used in the fractional factorial design. The eight factors were used to build a 2^{8-3} fractional factorial design to

test which factors have a significant impact on the systems cost and CO₂ emissions. This same strategy was applied to the hybrid piggy back system, however the hybrid method included 2 more factors, additional non-customer stops and the maximum addition distance traveled for each additional non-customer stop (See Table 3). The experimental design used to analyze this system was a 2^{10-5} . Both experiments had 32 treatment combinations. The full system was a 1/8 fraction of the full factorial design while the hybrid system was a 1/32 fraction of the full factorial design. Because the experiments were not full factorials, some effects were aliased. This experiment is a screening iteration to condense the experiment further in order to provide less aliased results in the subsequent experiments. The second iteration of experiments for the full piggy back system will be a 2^{6-1} fractional factorial, see table 9, and the hybrid piggy back system will be a 2^{8-3} fractional factorial. A full factorial experiment was not conducted based on time constraints. The full and hybrid experimental designs are shown in tables 5 and 6 respectively.

Table 3. Factors and Their Corresponding Baseline Values for the Full and Hybrid Piggy Back Scenarios

Factors	Full System Baseline Values	Hybrid System Baseline Values
Diesel Cost	\$3.00	\$3.00
Biodiesel Cost	\$1.00	\$1.00
Stop Time	10 mins	10 mins
Stop Density	10 Without WCO, 5 With	10 Without WCO, 5 With
Total Distance	$22 + 275 * \text{BETA}(0.896, 2.77)$	$22 + 275 * \text{BETA}(0.896, 2.77)$
Packing %	$\text{TRIA}(0.3, 0.951, 1)$	$\text{TRIA}(0.3, 0.951, 1)$
WCO Collected	$\text{UNIF}(16,23)$	$\text{UNIF}(16,23)$
Product Volume	$\text{TRIA}(1.26\text{e}+4, 1.8\text{e}+4, 8.93\text{e}+4)$	$\text{TRIA}(1.26\text{e}+4, 1.8\text{e}+4, 8.93\text{e}+4)$
Non-customers	N/A	4 Additional Stops
Add Distance	N/A	10 mi

Table 4. Experimental Design Factors

A = Diesel Cost
B = Biodiesel Cost
C = Delay time
D = Stop Density
E = Distance
F = Packing percent
G = WCO
H = Product volume
I = Non customer
J = Additional Distance

Table 5. Aliasing Structure for 2^{8-3} Fractional Factorial Design

<u>Design Generators</u>		
F = ABC G = ABD H = BCDE		
Defining Relationship: I = ABCF = ABDG = CDFG = BCDEH = ADEFH = ACEGH = BEFGH		
<u>Aliases</u>		
A = BCF = BDG	AE = DFH = CGH	DE = BCH = AFH
B = ACF = ADG	AF = BC = DEH	DH = BCE = AEF
C = ABF = DFG	AG = BD = CEH	EF = ADH = BGH
D = ABG = CFG	AH = DEF = CEG	EG = ACH = BFH
E =	BE = CDH = FGH	EH = BCD = ADF = ACG = BFG
F = ABC = CDG	BH = CDE = EFG	FH = ADE = BEG
G = ABD = CDF	CD = FG = BEH	GH = ACE = BEF
H =	CE = BDH = AGH	ABE = CEF = DEG
AB = CF = DG	CG = DF = AEH	ABH = CFH = DGH
AC = BF = EGH	CH = BDE = AEG	ACD = BDF = BCG = AFG
AD = BG = EFH		

Table 6. Aliasing Structure for 2^{10-5} Fractional Factorial Design

<u>Design Generators</u>	
F = ABCD G = ABCE H = ABDE J = ACDE K = BCDE	
Defining Relationship: I = ABCDF = ABCEG = DEFG = ABDEH = CEFH = CDGH = ABFGH = ACDEJ = BEFJ = BDGJ = ACFGJ = BCHJ = ADFHJ = AEGHJ = BCDEFGHJ = BCDEK = AEFK = ADGK = BCFGK = ACHK = BDFHK = BEGHK = ACDEFGHK = ABJK = CDFJK = CEGJK = ABDEFGJK = DEHJK = ABCEFHJK = ABCDGHJK = FGHJK	
<u>Aliases</u>	
A = EFK = DGK = CHK = BJK	AH = BDE = BFG = DFJ = EGJ = CK
B = EFJ = DGJ = CHJ = AJK	AJ = CDE = CFG = DFH = EGH = BK
C = EFH = DGH = BHJ = AHK	AK = EF = DG = CH = BJ
D = EFG = CGH = BGJ = AGK	BC = ADF = AEG = HJ = DEK = FGK
E = DFG = CFH = BFJ = AFK	BD = ACF = AEH = GJ = CEK = FHK
F = DEG = CEH = BEJ = AEK	BE = ACG = ADH = FJ = CDK = GHK
G = DEF = CDH = BDJ = ADK	BF = ACD = AGH = EJ = CGK = DHK
H = CEF = CDG = BCJ = ACK	BG = ACE = AFH = DJ = CFK = EHK
J = BEF = BDG = BCH = ABK	BH = ADE = AFG = CJ = DFK = EGK
K = AEF = ADG = ACH = ABJ	CD = ABF = GH = AEJ = BEK = FJK
AB = CDF = CEG = DEH = FGH = JK	CE = ABG = FH = ADJ = BDK = GJK
AC = BDF = BEG = DEJ = FGJ = HK	CF = ABE = EH = AGJ = BGK = DJK
AD = BCF = BEH = CEJ = FHJ = GK	CG = ABE = DH = AFJ = BFK = EJK
AE = BCG = BDH = CDJ = GHJ = FK	DE = FG = ABH = ACJ = BCK = HJK
AF = BCD = BGH = CGJ = DHJ = EK	DF = ABC = EG = AHJ = BHK = CJK
AG = BCE = BFH = CFJ = EHJ = DK	

The number of replications for each treatment combination was chosen to be 10,000. This number was chosen because of the relatively fast run time of the model and its good estimation of the confidence interval. This large number of replications also provides for an accurate analysis of the system.

5. Full Piggy Back System Results

When analyzing the results from the full piggy back system under the resolution IV 2^{8-3} design, it can be seen by the ANOVA tables in Tables 7 and 8, that the main effects are driving cost and CO₂ savings under these conditions. While the F statistics for 2-way interactions for both cost and CO₂ are significant, they do not seem practically relevant in comparison to the main effects when comparing the magnitudes of their F statistics in tables 7 and 8. The F statistics for the main effects in both responses are at least an order of magnitude greater than that of the 2-way interactions. The fact that the 2-way interactions are considered statistically relevant is most likely due to the large number of replications and that the fractional factorial design is aliasing interactions together. When looking at the factors and interactions alone, it can further be seen that the main effects are really driving the cost and CO₂ savings in the system under these conditions and assumptions.

Because the P-values in the estimated effects and coefficients tables for both cost and CO₂ savings show significance for factors that do not seem practically relevant (for example refer to table 10), the sums of squares (effects) and the response plots are used to determine how strong the factor or interaction effect is on the given response in the following results sections.

Table 7. Full Piggy Back System ANOVA for CO₂ Saving (2⁸⁻³)

Source	DF	Seq SS	Adj SS	Adj MS	F
Main Effects	8	1.37464E+20	1.37464E+20	1.71830E+19	73573470.32
2-Way Interactions	20	5.49826E+18	5.49826E+18	2.74913E+17	1177113.33
Residual Error	319971	7.47288E+16	7.47288E+16	2.33549E+11	
Lack of Fit	3	460461712	460461712	153487237	0.00
Pure Error	319968	7.47288E+16	7.47288E+16	2.33551E+11	
Total	319999	1.43037E+20			

Table 8. Full Piggy Back System ANOVA for Cost (2⁸⁻³)

Source	DF	Seq SS	Adj SS	Adj MS	F
Main Effects	8	1.64427E+12	1.64427E+12	2.05534E+11	2189648.64
2-Way Interactions	20	1.05726E+11	1.05726E+11	5286277223	56317.17
Residual Error	319971	30034451983	30034451983	93866	
Lack of Fit	3	0	0	0	0.00
Pure Error	319968	30034451983	30034451983	93867	
Total	319999	1.78003E+12			

5.1 Full Piggy Back System Results for Emissions Savings

CO₂ savings under the full piggy back system is primarily driven by the stop density, and the amount of WCO that is collected per stop as seen in table 10. The main effects plots for stop density and WCO collected also depict the steepest slopes in figure 16, meaning that the change in these factors creates the largest change in CO₂ savings, under these assumptions. The degree of change can also be noted by the effect associated with stop density and WCO in figure 17 compared to the effect associated with the other factors in figure 17. A 25% change in stop density represents a 33% change in CO₂ savings as compared to baseline. Whereas a 25% change in WCO represents a 25% change in CO₂ savings. The remaining factors contribute to less than one percent of the response change for CO₂ savings under these assumptions. The interaction effect that also shows to be highly significant is diesel cost*biodiesel cost as depicted in the interaction effects plots

in Figure 18. The interaction between diesel cost and biodiesel cost should not logically effect the CO₂ emissions in anyway. CO₂ savings as dictated by its equation is based upon, the distances traveled, speed, the horse power of the truck, and the amount of WCO collected.

CO₂ Savings Equation:

$$CO_2 \text{ Savings} = \left(WCO \text{ Collected} \times \frac{MPG}{Avg \text{ Speed}} \times Truck \text{ HP} \times B20 \text{ Emissions Coefficient}_{CO_2} \right) - \left(\frac{Distance \text{ Traveled}}{Avg \text{ Speed}} \times Truck \text{ HP} \times Diesel \text{ Emissions Coefficient}_{CO_2} \right)$$

The calculation of CO₂ is not effected by the cost of diesel or biodiesel in any way. The significance of the interaction between diesel cost and biodiesel cost could be explained using the aliasing structure. With the 2⁸⁻³ design, diesel cost*biodiesel cost are aliased with the two most significant factors interaction, WCO collected*stop density plus it is also aliased with delay time*packing percent as seen in table 5 (AB = CD = FG). The aliasing structure also confounds the significance of WCO collected*stop density therefore its significance or relative importance cannot be determined directly. However, seeing that the effects value for diesel cost*biodiesel cost is so large in table 10, and the fact that it should have no logical effects on CO₂, as noted earlier, suggest that the interaction of WCO collected and stop density are significant and showing through in the response plots for diesel cost*biodiesel cost in figure 18. These two interactions are also aliased with delay time*packing percent which also should have no effect on CO₂ savings either, as noticed by the equation for calculating CO₂ savings. Looking at the interaction effects plot for diesel cost*biodiesel cost and delay time*packing percent in figure 18 aids in validating the theory that the interaction between WCO and stops

density is showing through in both the interactions of diesel cost*biodiesel cost and delay time*packing percent. The two interaction effects are identical yet neither should have any effect on the CO₂ savings, and they are both aliased with WCO*Stop density as depicted in the interaction effects plots in figure 18. To further understand this interaction, the design was reduced from a 2⁸⁻³ to a 2⁶⁻¹ 1/2 fraction factorial.

Table 9. Aliasing Structure for 2⁶⁻¹ Fractional Factorial Design

Design Generators	
I = ACDF	
<u>Aliases</u>	
A = CDF	AE = CDEF
B = ABCDF	AF = CD
C = ADF	BC = ABCF
D = ACF	BD = ABCF
E = ACDEF	BE = ABDEF
F = ACD	BF = ABCD
AB = CDF	CE = ADEF
AC = DF	DE = ACEF
AD = CF	EF = ACDE

This was done by eliminating the two factors that seem to have minimal effect, or a flat response line, on CO₂ savings. The factors showing the no effect on CO₂ savings were packing percent and product volume (See Figure 16). With these factors removed, the interaction diesel cost*biodiesel cost is only aliased with WCO collected*stop density. With the 2⁶⁻¹ design the interaction between diesel cost*biodiesel cost was significant but not practically relevant, this further supports the fact that WCO collected*stop density is the interaction that is showing through to be significant. The pareto chart in seen in Figure 18 shows the impacts to the responses by the individual factor and the interaction. The pareto chart shows no practical relevance for the interaction between diesel cost and biodiesel cost. No other interaction effects seem to have any practical relevance to the

CO₂ savings response as shown in the pareto chart and interaction plots for CO₂ savings under the full piggy back system in figures 17 and 18 respectively.

Table 10. Estimates Effects and Coefficients for CO₂ Savings (2⁸⁻³)

Estimated Effects and Coefficients for CO ₂ Savings (coded units)					
Term	Effect	Coef	SE Coef	T	P
Constant		49745169	854.3	58228.72	0.000
diesel cost	-0	-0	854.3	-0.00	1.000
biodiesel cost	0	0	854.3	0.00	1.000
Delay time	-0	-0	854.3	-0.00	1.000
Stop Density	33161013	16580506	854.3	19408.15	0.000
Distance	910	455	854.3	0.53	0.595
Packing percent	0	0	854.3	0.00	1.000
WCO	24872584	12436292	854.3	14557.18	0.000
Product volume	0	0	854.3	0.00	1.000
diesel cost*biodiesel cost	8290253	4145127	854.3	4852.04	0.000
diesel cost*Delay time	0	0	854.3	0.00	1.000
diesel cost*Stop Density	0	0	854.3	0.00	1.000
diesel cost*Distance	0	0	854.3	0.00	1.000
diesel cost*Packing percent	0	0	854.3	0.00	1.000
diesel cost*WCO	-0	-0	854.3	-0.00	1.000
diesel cost*Product volume	-0	-0	854.3	-0.00	1.000
biodiesel cost*Distance	0	0	854.3	0.00	1.000
biodiesel cost*Product volume	0	0	854.3	0.00	1.000
Delay time*Stop Density	-0	-0	854.3	-0.00	1.000
Delay time*Distance	-0	-0	854.3	-0.00	1.000
Delay time*WCO	-0	-0	854.3	-0.00	1.000
Delay time*Product volume	0	0	854.3	0.00	1.000
Stop Density*Distance	303	152	854.3	0.18	0.859
Stop Density*Product volume	-0	-0	854.3	-0.00	1.000
Distance*Packing percent	0	0	854.3	0.00	1.000
Distance*WCO	227	114	854.3	0.13	0.894
Distance*Product volume	0	0	854.3	0.00	1.000
Packing percent*Product volume	0	0	854.3	0.00	1.000
WCO*Product volume	-0	-0	854.3	-0.00	1.000
S = 483269 R-Sq = 99.95% R-Sq(adj) = 99.95%					

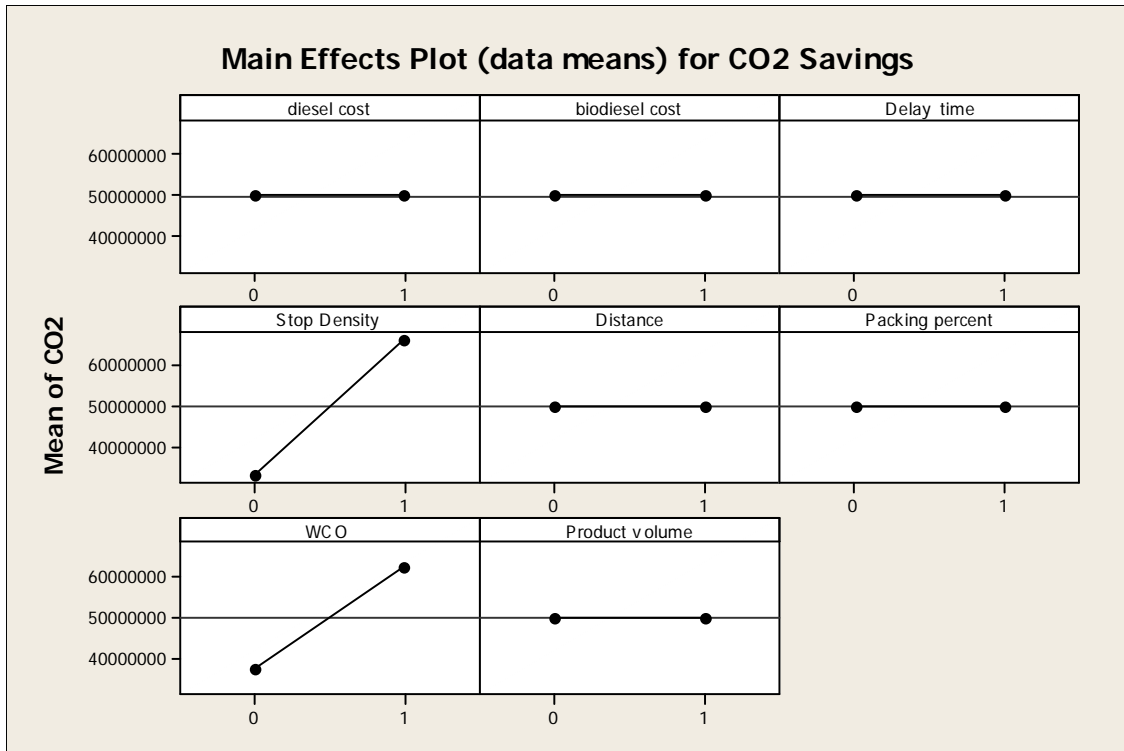


Figure 16. Main effects plot for CO₂ Savings (2⁸⁻³)

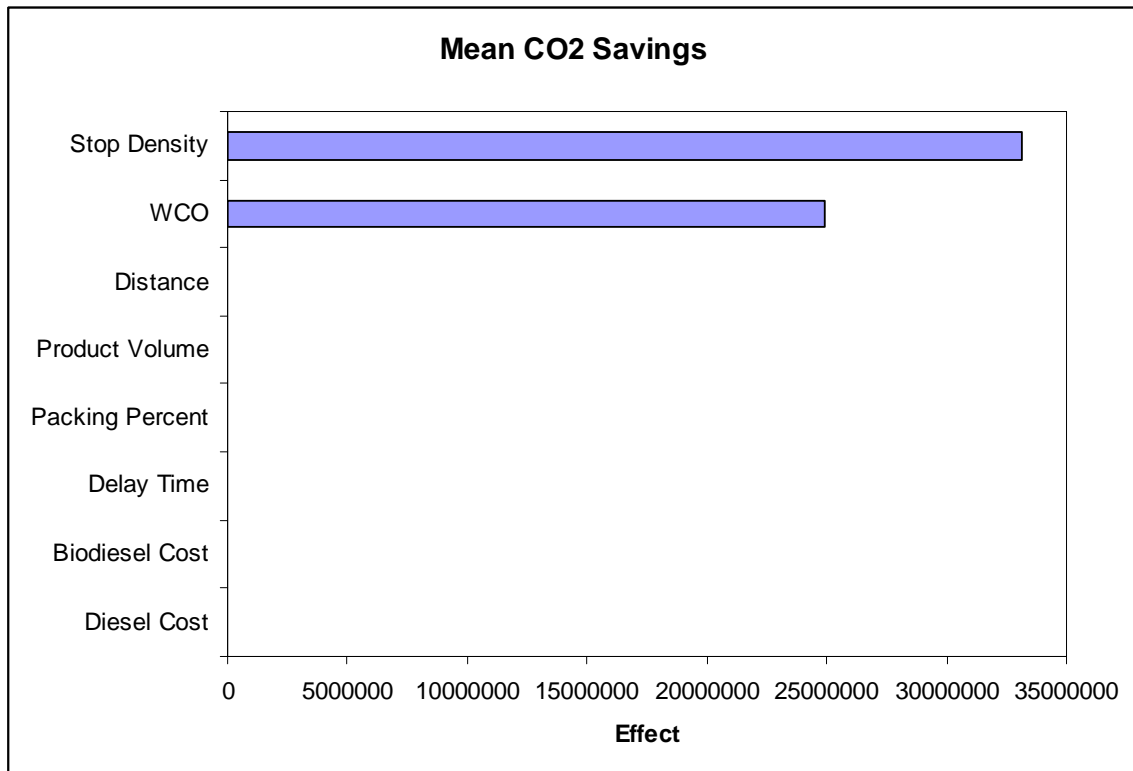


Figure 17. Pareto of Main Effects Response Values for CO₂ Savings

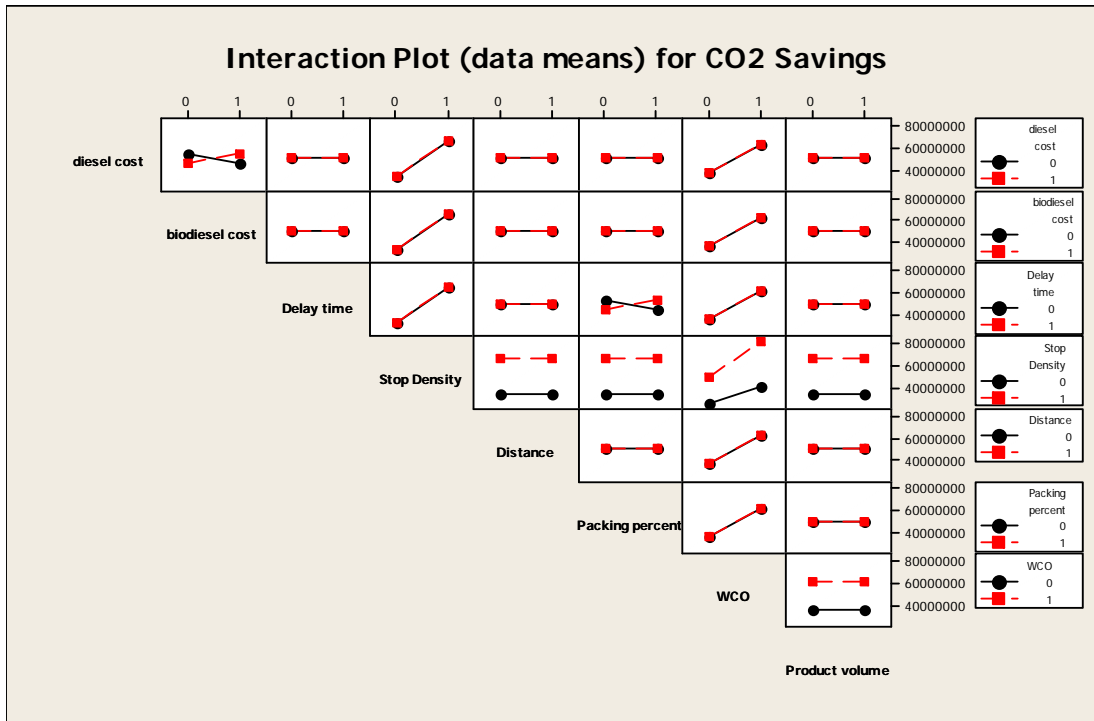


Figure 18. Interaction effects plot for CO₂ Savings (28-3)

Table 11. Estimates Effects and Coefficients for CO₂ Savings (2⁶⁻¹)

Estimated Effects and Coefficients for CO ₂ Savings (coded units)						
Term	Effect	Coef	SE Coef	T	P	
Constant	49745169	854.3	58229.63	0.000		
diesel cost	-0	-0	854.3	-0.00	1.000	
WCO	24872584	12436292	854.3	14557.41	0.000	
biodiesel cost	0	0	854.3	0.00	1.000	
Distance	910	455	854.3	0.53	0.595	
Delay time	-0	-0	854.3	-0.00	1.000	
Stop Density	33161013	16580506	854.3	19408.45	0.000	
diesel cost*WCO	0	0	854.3	0.00	1.000	
diesel cost*biodiesel cost	8290253	4145127	854.3	4852.11	0.000	
diesel cost*Distance	-0	-0	854.3	-0.00	1.000	
diesel cost*Delay time	0	0	854.3	0.00	1.000	
diesel cost*Stop Density	-0	-0	854.3	-0.00	1.000	
WCO*Distance	227	114	854.3	0.13	0.894	
WCO*Delay time	0	0	854.3	0.00	1.000	
biodiesel cost*Distance	-0	-0	854.3	-0.00	1.000	
biodiesel cost*Delay time	-0	-0	854.3	-0.00	1.000	
Distance*Delay time	0	0	854.3	0.00	1.000	
Distance*Stop Density	303	152	854.3	0.18	0.859	
Delay time*Stop Density	0	0	854.3	0.00	1.000	
S = 483261 R-Sq = 99.95% R-Sq(adj) = 99.95%						

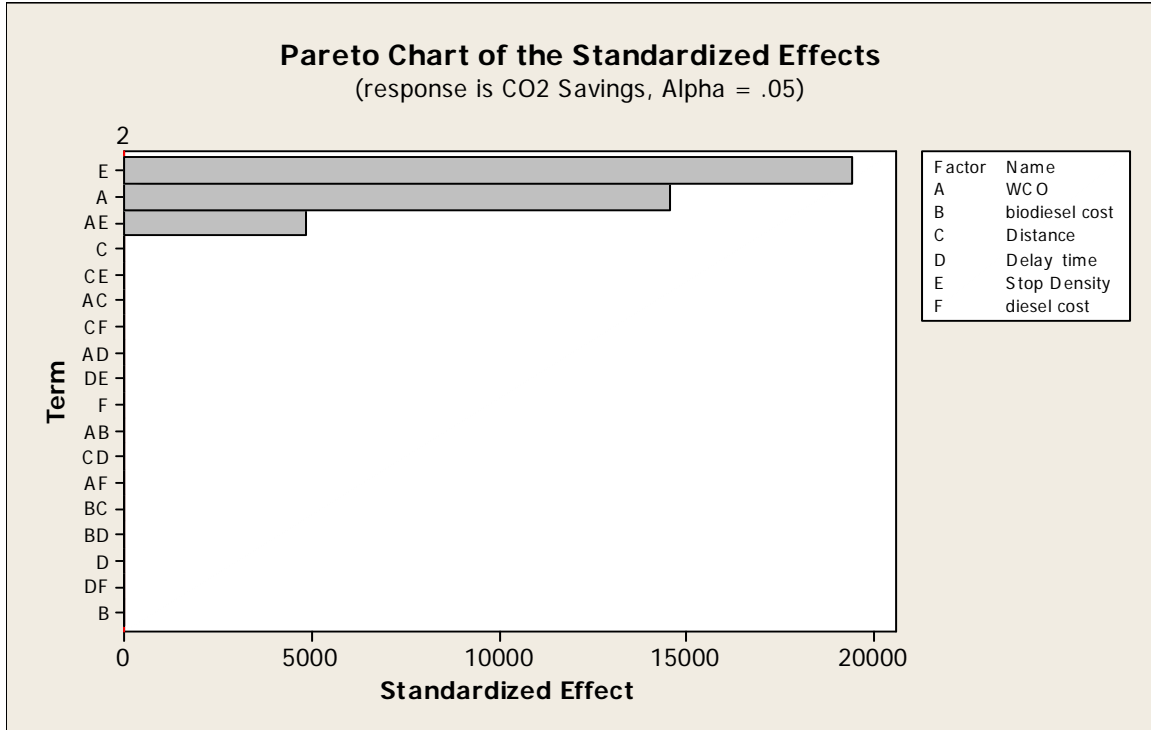


Figure 19. Pareto Chart of the Standardized effects for CO2 savings

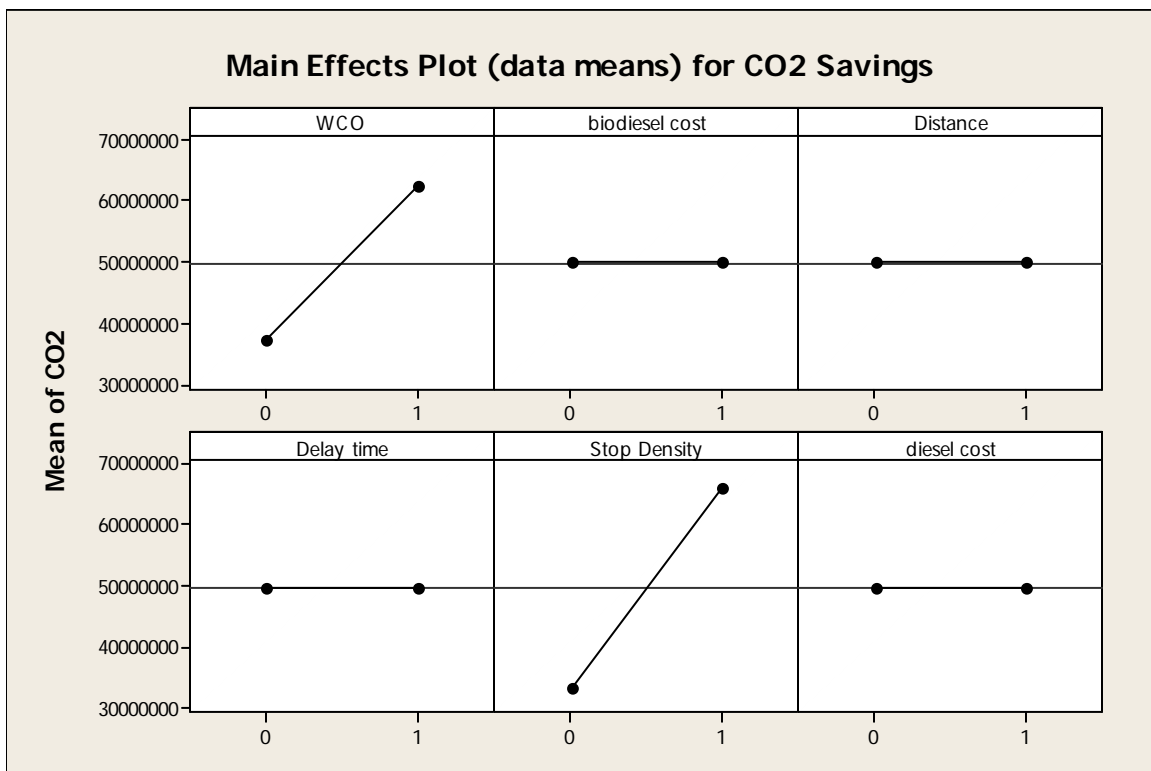


Figure 20. Main effects plot for CO2 Savings (26-1)

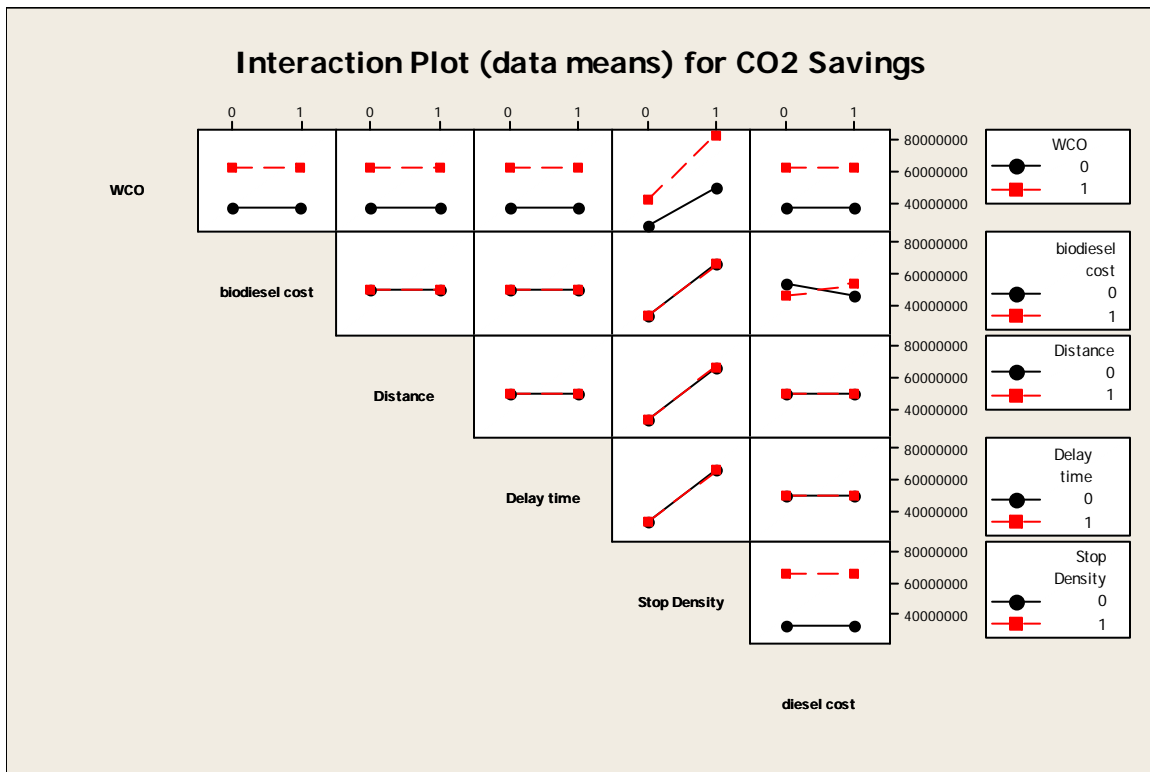


Figure 21. Interaction effects plot for CO₂ Savings (2⁶⁻¹)

Stop density was investigated more thoroughly because this factor had the larger effect on CO₂ savings under these assumptions. All possible stop densities up to 15 stops, under the baseline values as reported in Table 3, were examined to understand what degree of CO₂, CO, THC, and NO_x emissions savings could be achieved under the full piggy back system with this configuration figures 22 - 24.

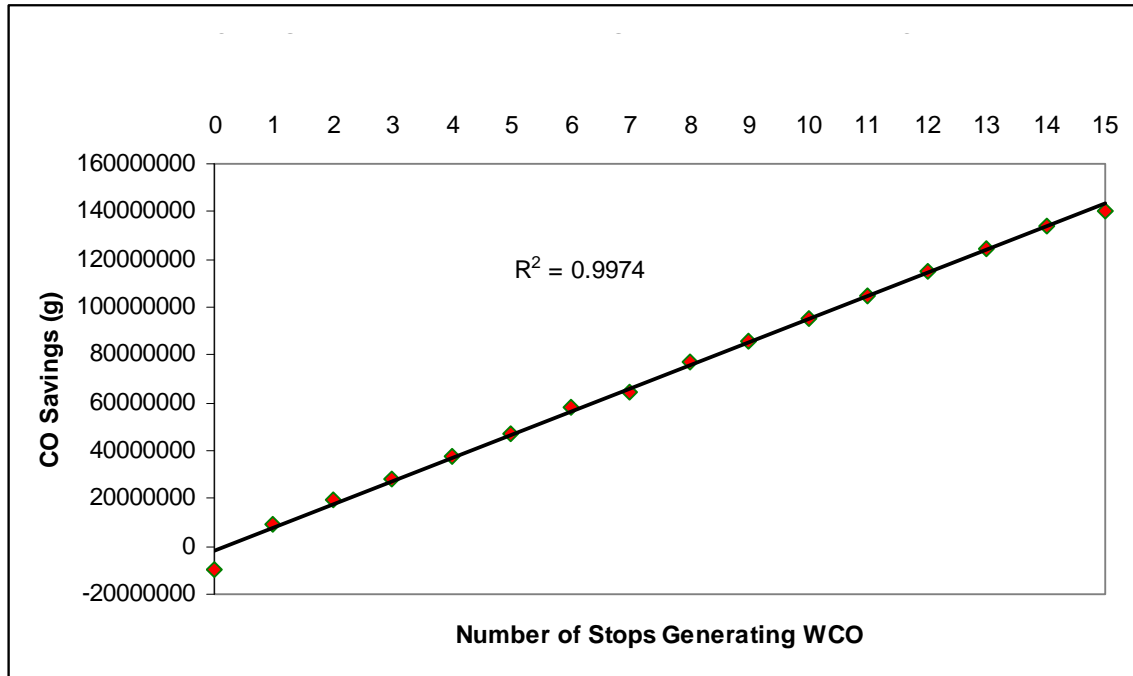


Figure 22. CO₂ Savings Vs Number of Stops Generating WCO out of 15 Total Stops

$$CO_2 \text{ Savings} = \left(WCO \text{ Collected} \times \frac{MPG}{Avg \text{ Speed}} \times Truck \text{ HP} \times B20 \text{ Emissions Coefficient}_{CO_2} \right) - \left(\frac{Distance \text{ Traveled}}{Avg \text{ Speed}} \times Truck \text{ HP} \times Diesel \text{ Emissions Coefficient}_{CO_2} \right)$$

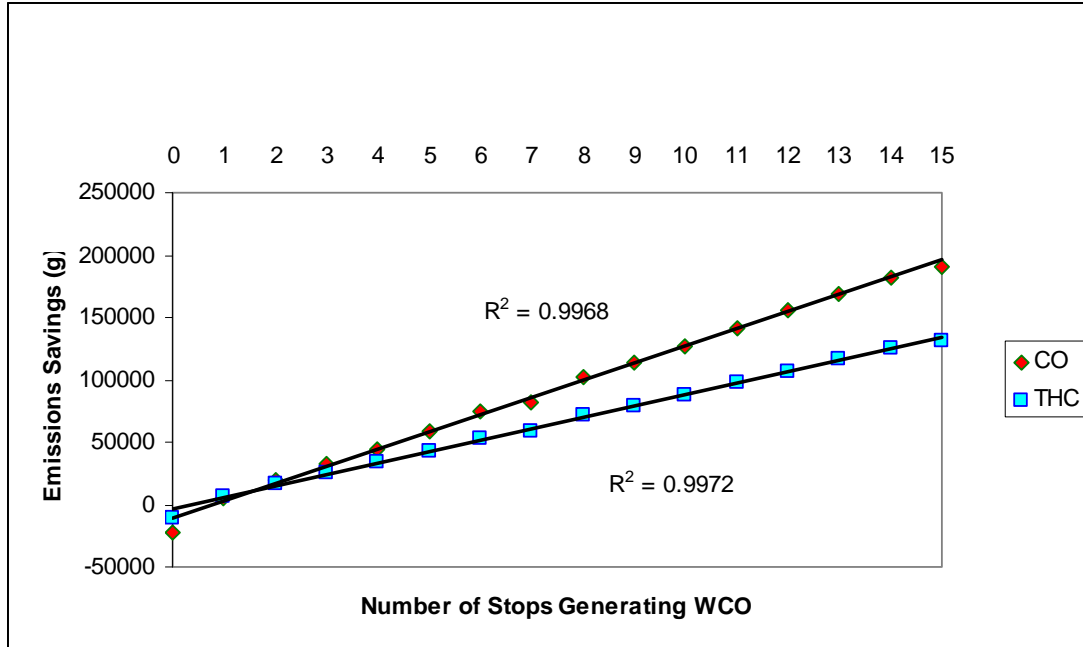


Figure 23. CO and THC Savings Vs Number of Stops Generating WCO out of 15 Total Stops

$$CO \text{ Savings} = \left(WCO \text{ Collected} \times \frac{MPG}{Avg \text{ Speed}} \times Truck \text{ HP} \times B20 \text{ Emissions Coefficient}_{CO} \right) - \left(\frac{Distance \text{ Traveled}}{Avg \text{ Speed}} \times Truck \text{ HP} \times Diesel \text{ Emissions Coefficient}_{CO} \right)$$

$$THC \text{ Savings} = \left(WCO \text{ Collected} \times \frac{MPG}{Avg \text{ Speed}} \times Truck \text{ HP} \times B20 \text{ Emissions Coefficient}_{THC} \right) - \left(\frac{Distance \text{ Traveled}}{Avg \text{ Speed}} \times Truck \text{ HP} \times Diesel \text{ Emissions Coefficient}_{THC} \right)$$

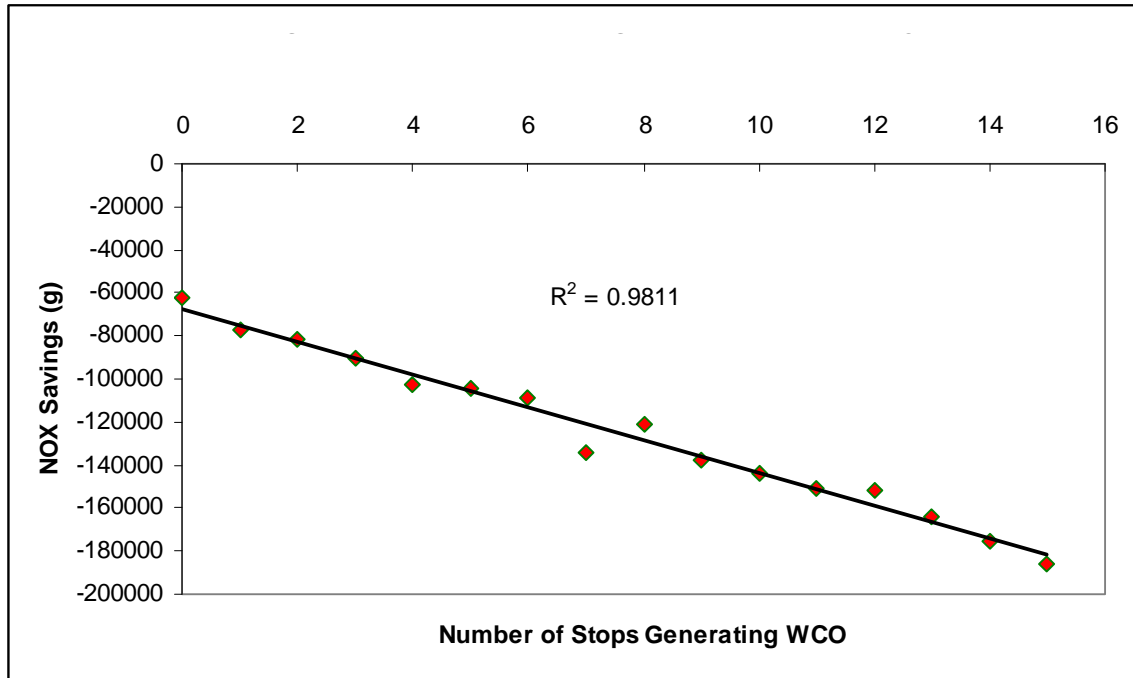


Figure 24. NO_x Savings Vs Number of Stops Generating WCO out of 15 Total Stops

$$NO_x \text{ Savings} = \left(WCO \text{ Collected} \times \frac{MPG}{Avg \text{ Speed}} \times Truck \text{ HP} \times B20 \text{ Emissions Coefficient}_{NOX} \right) - \left(\frac{Distance \text{ Traveled}}{Avg \text{ Speed}} \times Truck \text{ HP} \times Diesel \text{ Emissions Coefficient}_{NOX} \right)$$

Increasing stop density increases CO₂, CO, and THC emissions savings as shown in figures 22 and 23. The increase in emissions savings for these emissions can be noted by the increasing slope in figures 22 and 23. Therefore, it can be inferred that WCO should be collected from as many customers as possible, using the full piggy back system under these assumptions. NO_x savings is reduced with each additional WCO generating stop due to NO_x being emitted at a higher rate from biodiesel than regular diesel as shown by the downward slope in figure 24. All 0 stop values in figures 22-24 are negative due to

the fact that if no biodiesel is collected the emissions savings is zero and the resulting emissions that diesel emits is reported.

5.2 Full Piggy Back System Results for Cost and Service Level

The cost response to the full piggy back system is also largely controlled by the main effects as was revealed by comparing the F statistics in the ANOVA table in Table 7 above. The individual factors that have the most prevalent effect in order from, largest to smallest are stop density, diesel cost, and WCO collected as seen in the effects values in Table 12 and steep slopes in the effects plots of figure 25. A 25% change in these factors represents 282%, 280%, and 225% change in cost respectively, compared to the baseline full piggy back system. The other factors that are helping drive the cost response under these assumptions are distance, biodiesel cost, and stop time, they represent a 115%, 84%, 71% change in cost respectively compared to the baseline full piggy back system. The values associated with the change in cost associated with each factor are visually presents in the pareto diagram in figure 26. When looking at the interaction effects for cost under the full piggy back system, diesel cost*biodiesel cost, diesel cost*stop density, diesel cost*WCO, and diesel cost*distance are all significant and practically relevant as suggested by the large values associated with their effects in table 12. These interactions follow logical patterns that would be expected from this system, based upon the relevance of their main effects and that these factors are incorporated into the cost equations.

Cost of labor (L) = Time (T)*Wage (W)

Cost of Diesel Fuel (C_D) = $((0.8 * \text{Distance (D)}) / \text{Fuel Economy (E)}) * \text{Price of Diesel (F}_D)$

Cost of Additional Labor (L_A) = Additional Time (T_A) * Wage (W)

Cost of Additional Diesel (C_{DA}) = $((0.8 * \text{Additional Distance (D}_A)) / \text{Fuel Economy (E)}) * \text{Price of Diesel (F}_D)$

Total Cost of Route (CT) = $L + L_A + C_D + C_{DA} + C_B + C_{BA}$

Cost Savings from Trading all WCO for Biodiesel (S) = $((\text{Total WCO collected (G)} * .9) * \text{Price of Diesel (F}_D)) - ((\text{Total WCO collected (G)} * .9) * \text{Price of Biodiesel (F}_B))$

Total Cost of System after Savings (C_S) = $(L + L_A + ((D/E) * F_D) + ((D_A/E) * F_D)) - S$

For example, a WCO collection system would be expected to respond significantly to the amount of WCO collected and the cost of fuel. This is seen in the trend of diesel cost*stop density. The trend suggests that when diesel cost is high the saving from biodiesel happens at a greater rate, when collecting WCO from a low density of stops to a high density, than when diesel cost is low (Figure 27). This makes logical sense because the savings from the use of biodiesel is based on the difference in fuel costs and the amount of biodiesel that can be produced from the collected WCO. Therefore, if the cost of diesel is high and the number of stops with WCO goes from low to high you expect to see a large decrease in cost. Whereas, if diesel cost is low and the stop density goes from low to high you see a similar trend but a reduced slope signifying a smaller change in cost savings.

Table 12. Estimates Effects and Coefficients for Cost (2⁸⁻³)

Estimated Effects and Coefficients for Cost (coded units)					
Term	Effect	Coef	SE Coef	T	P
Constant		-467	0.5416	-862.86	0.000
diesel cost	-2625	-1313	0.5416	-2423.62	0.000
biodiesel cost	790	395	0.5416	729.08	0.000
Delay time	666	333	0.5416	614.47	0.000
Stop Density	-2644	-1322	0.5416	-2440.55	0.000
Distance	1082	541	0.5416	998.99	0.000
Packing percent	0	0	0.5416	0.00	1.000
WCO	-2106	-1053	0.5416	-1944.18	0.000
Product volume	-0	-0	0.5416	-0.00	1.000
diesel cost*biodiesel cost	-702	-351	0.5416	-648.01	0.000
diesel cost*Delay time	-0	-0	0.5416	-0.00	1.000
diesel cost*Stop Density	-790	-395	0.5416	-729.21	0.000
diesel cost*Distance	111	56	0.5416	102.93	0.000
diesel cost*Packing percent	-0	-0	0.5416	-0.00	1.000
diesel cost*WCO	-439	-219	0.5416	-405.06	0.000
diesel cost*Product volume	0	0	0.5416	0.00	1.000
biodiesel cost*Distance	0	0	0.5416	0.00	1.000
biodiesel cost*Product volume	-0	-0	0.5416	-0.00	1.000
Delay time*Stop Density	0	0	0.5416	0.00	1.000
Delay time*Distance	0	0	0.5416	0.00	1.000
Delay time*WCO	0	0	0.5416	0.00	1.000
Delay time*Product volume	-0	-0	0.5416	-0.00	1.000
Stop Density*Distance	-1	-0	0.5416	-0.54	0.592
Stop Density*Product volume	0	0	0.5416	0.00	1.000
Distance*Packing percent	-0	-0	0.5416	-0.00	1.000
Distance*WCO	-0	-0	0.5416	-0.00	1.000
Distance*Product volume	-0	-0	0.5416	-0.00	1.000
Packing percent*Product volume	-0	-0	0.5416	-0.06	0.956
WCO*Product volume	0	0	0.5416	0.00	1.000
S = 306.376 R-Sq = 98.31% R-Sq(adj) = 98.31%					

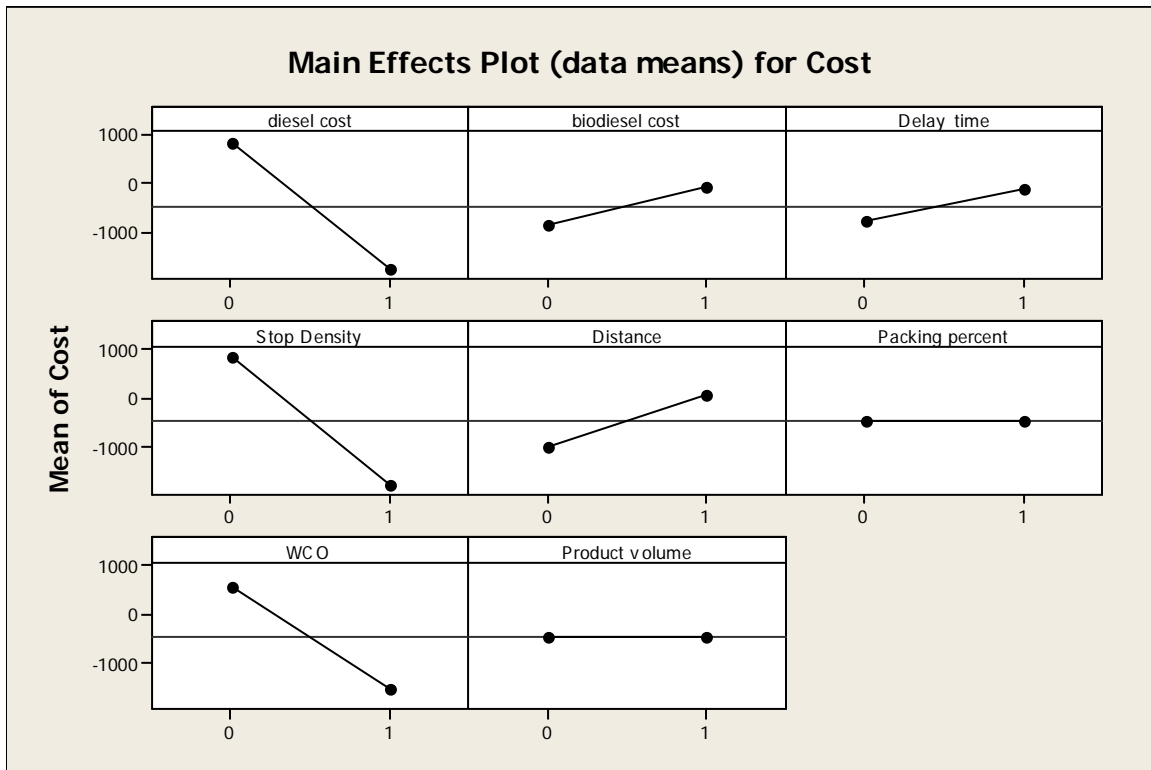


Figure 25. Main effects plot for cost (2^{8-3})

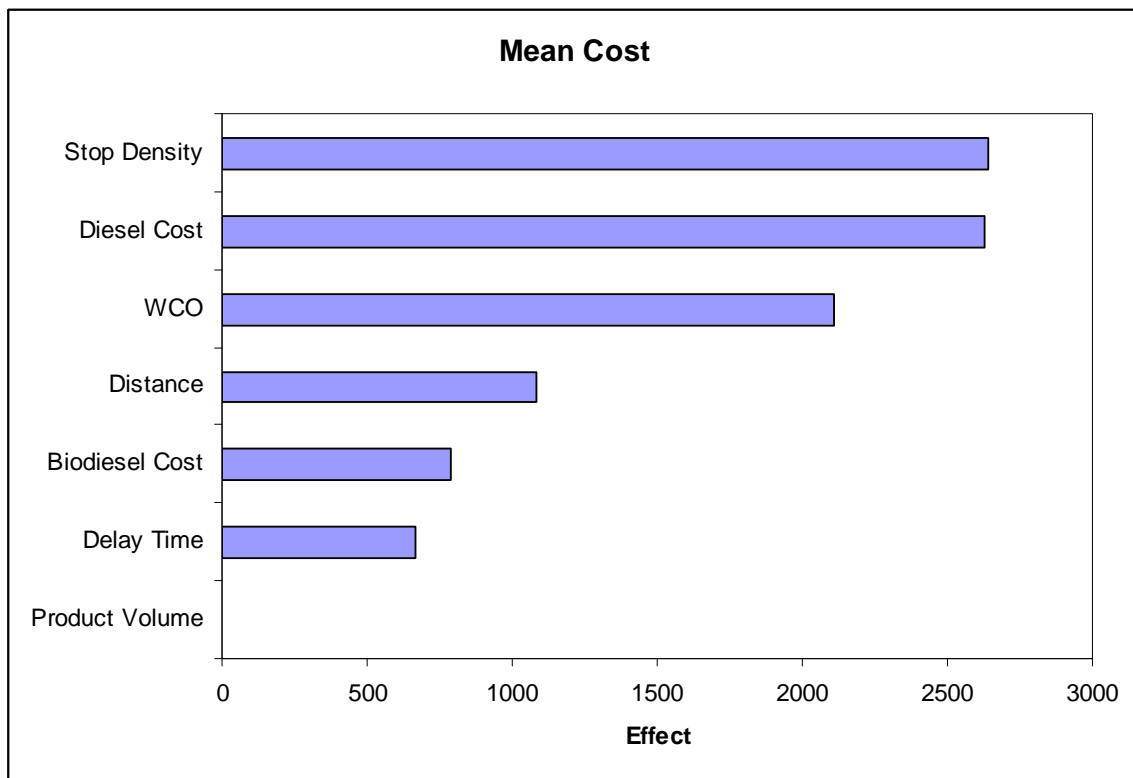


Figure 26. Pareto of Main Effects Response Values for Cost

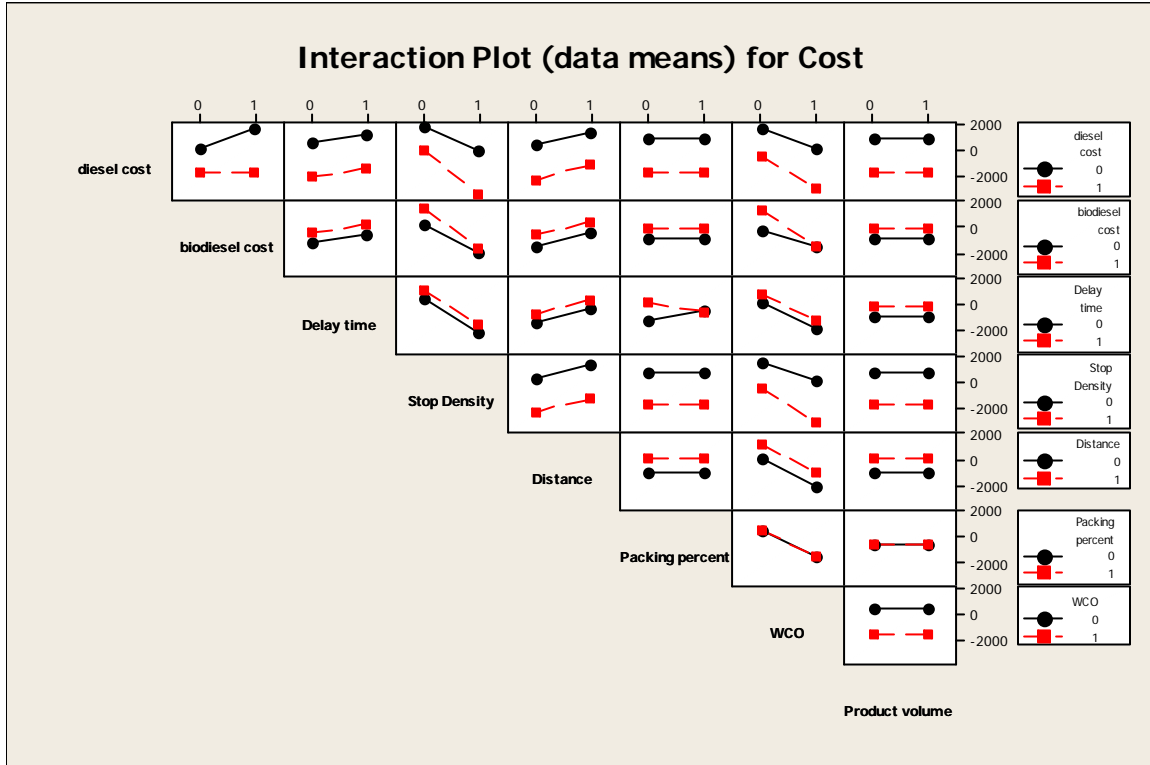


Figure 27. Interaction effects plot for Cost (2^{8-3})

Stop density was investigated more thoroughly because this factor had the largest effect on cost under these assumptions. All possible stop densities, with a total of 15 stops under the baseline values in table 3, were examined to understand the levels of cost that could be achieved under the full piggy back system as reported in Figure 28. The impacts to service level were also examined under this same experimental setup as depicted in Figure 29. Service level is described by the number of late deliveries in a route compared to the total number of deliveries in the route. It was assumed that all deliveries had to be complete within an eight hours window, otherwise it was deemed late.

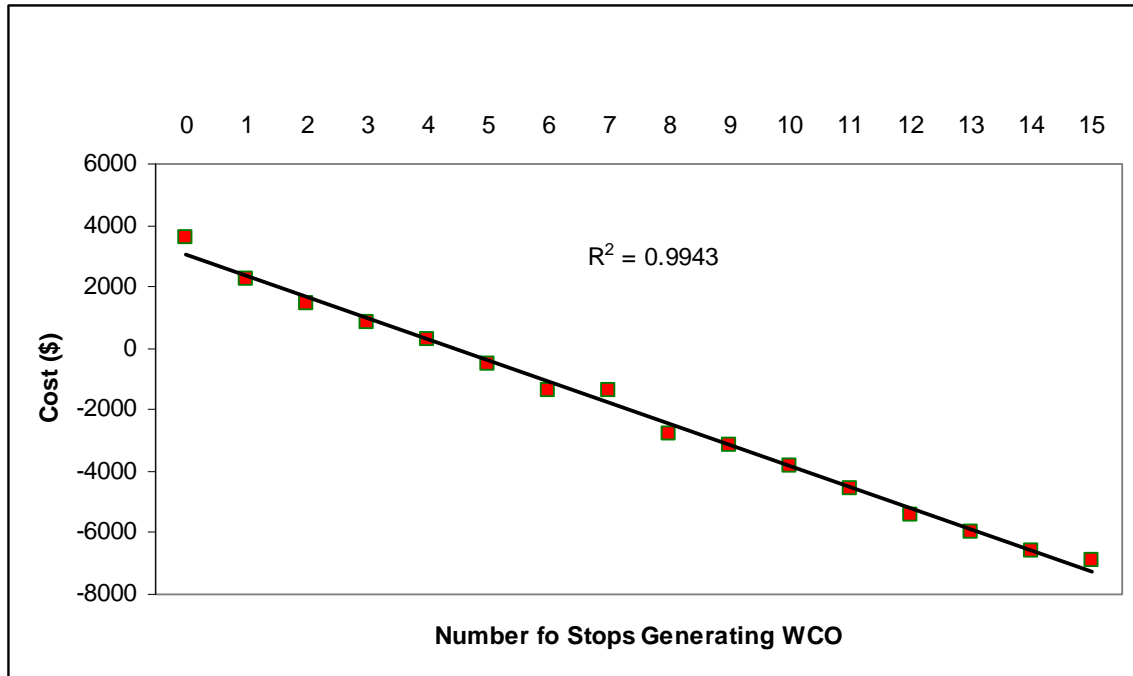


Figure 28. Cost Vs Number of Stops Generating WCO out of 15 Total Stops

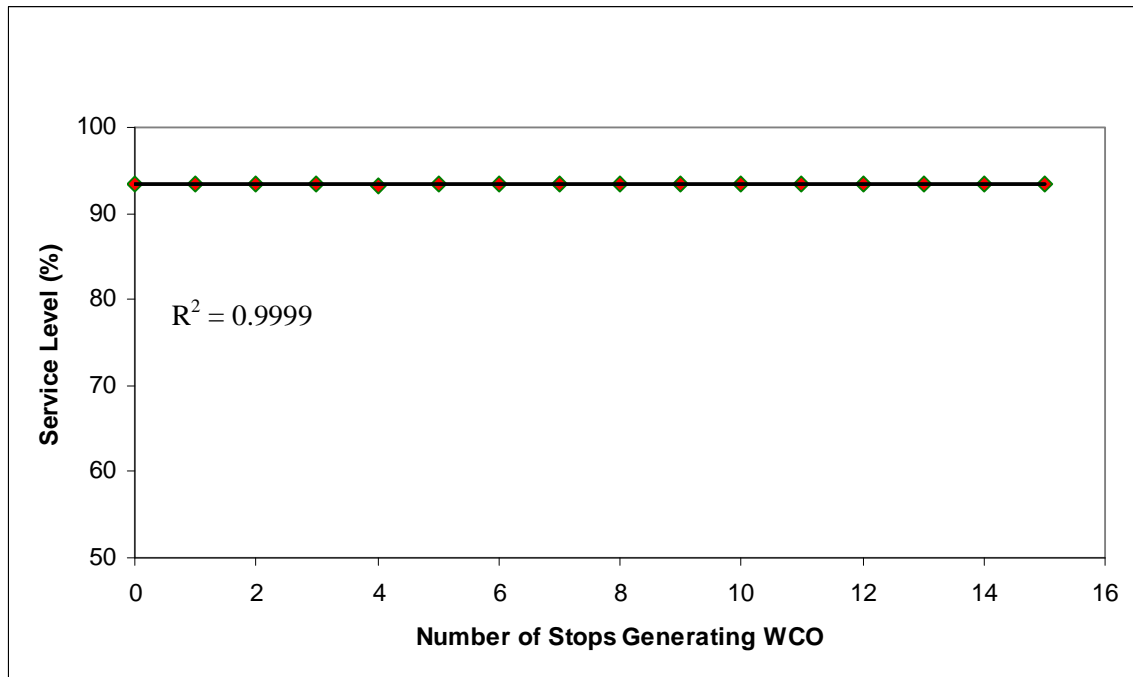


Figure 29. Service Level Vs Number of Stops Generating WCO out of 15 Total Stops

Increasing stop density reduces cost as shown by the negative slope in figure 28. Therefore, it can be inferred that WCO should be collected from as many customers as possible, using the full piggy back system under these assumptions. The stop density has no impact to the service level as depicted in figure 28 provided under the full piggy back system, this further supports the statement that all stops generating WCO should be collected from under these assumptions. Stop density not effecting service level seems unintuitive, it would be logical to assume that the added process would impair the ability to meet customers demand. It is possible that the system that was modeled, was not at full capacity and or that the assumed additional time for collection of five minute was underestimated.

5.3 Effects to the Full Piggy Back System from Changes in Total Number of Stops

The experimentation to this point had been based on the assumption that every route had 15 total customer stops. To determine whether the model outputs would hold true for different number of total stops, two single factor experiments were conducted with a total of 10 stops and 30 stops. Within each level of total stops, the stop density was varied between 20 and 80 percent in increments of 20 percent. The outcome of these experiments showed that the responses in both cost and CO₂ are similar for both 10 stops and 30 stops at the four levels of stop density (See Figures 30 - 31).

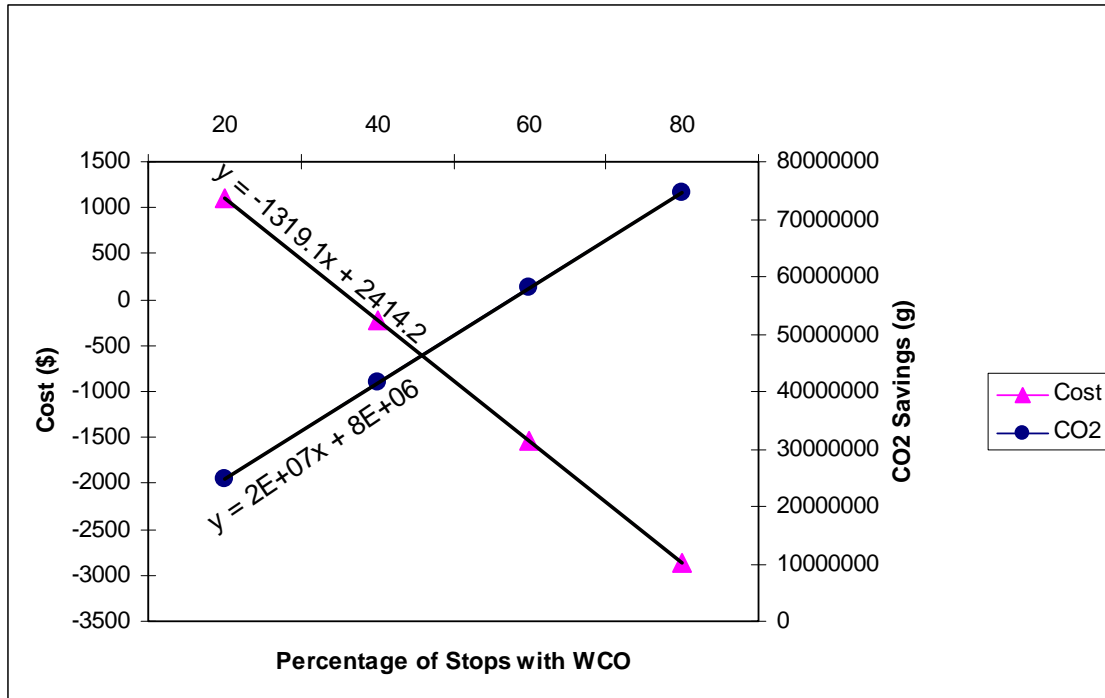


Figure 30. Response Plot for Cost and CO₂ Savings VS Density of Stops with WCO for 10 Total Stops

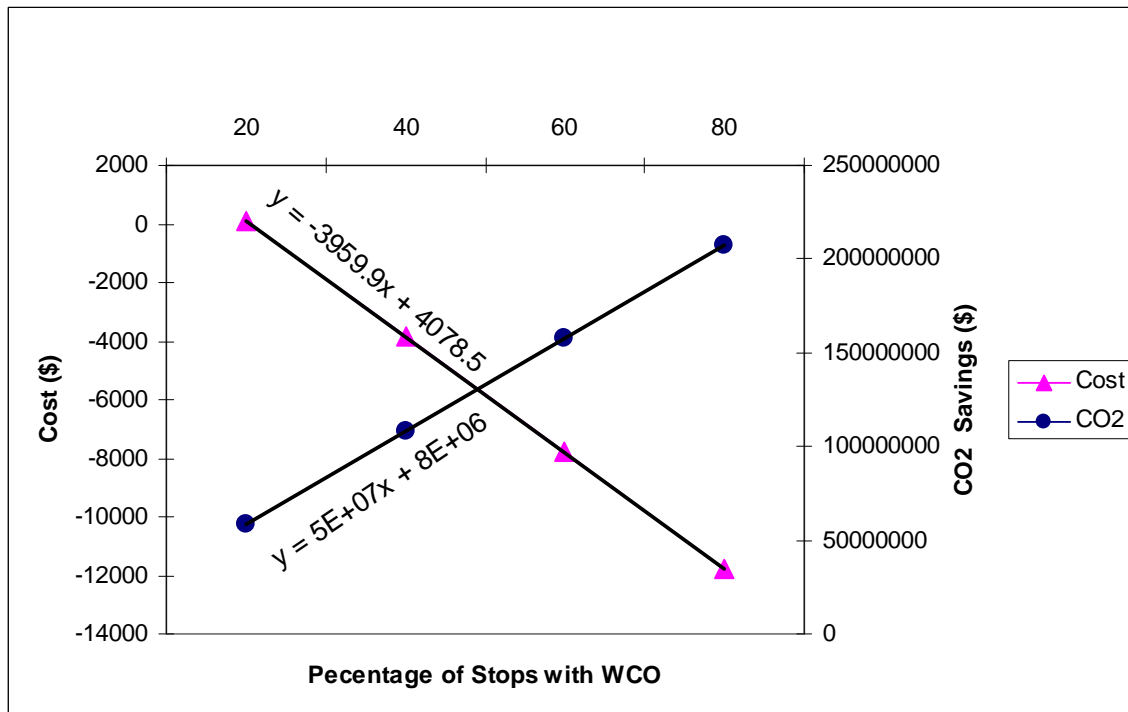


Figure 31. Response Plot for Cost and CO₂ Savings VS Density of Stops with WCO for 30 Total Stops

When comparing the responses from the different stop densities for 10 and 30 total stops in figures 30 and 31, it can be seen that they both follow similar trends for cost and CO₂ savings. However, when you look at the slope of the line from the equation, it can be seen that cost decreases and CO₂ savings increases at a rate three times more quickly for 30 stops than for 10 stops (Refer to Figures 30 – 31). This is explained by the fact that three times more stops are visited that generate WCO for a total of 30 stops, and the distance traveled is the same for both 10 and 30 total stops. The consistency of the results from these two experiments suggests that the model and conclusions are robust against the variation of total customer stops.

Total distance does not change based upon the number of stops in the route. The actual data from the F&B distributor showed no correlation between the number of stops and the distance traveled for that route as seen in Figure 32.

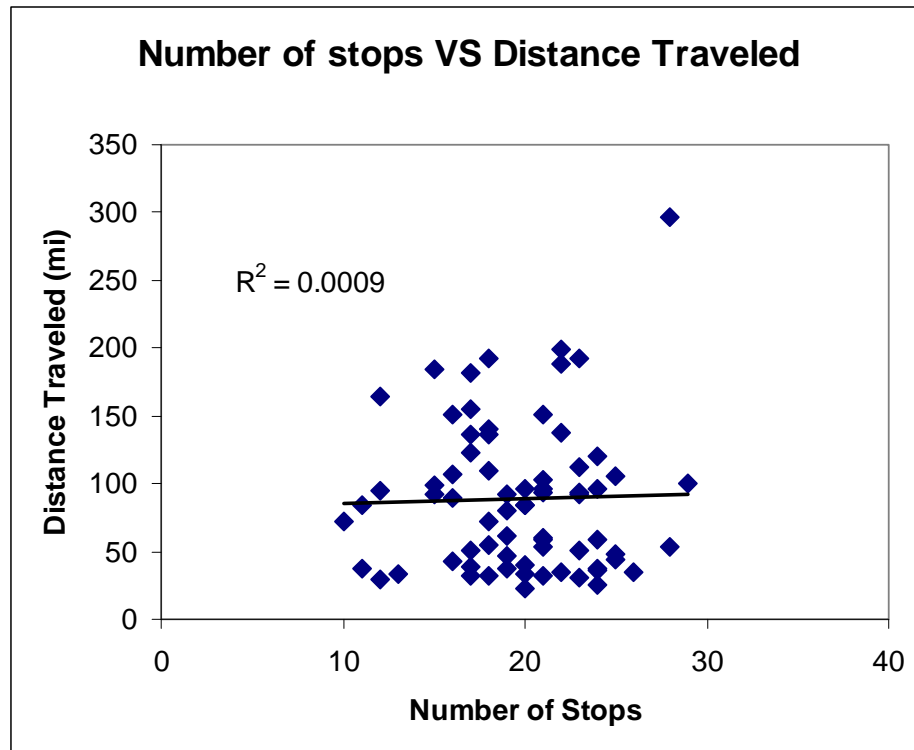


Figure 32. Actual Total Distance (Local Distributor) VS Number of Stops

6. Hybrid Piggy Back System Results

The hybrid piggy back system showed that the main effects were driving the system for both cost and CO₂ savings, under these assumptions. The F statistics for the main effects for both cost and CO₂ savings were at least an order of magnitude larger than the 2-way interaction effects as seen in tables 13 and 14.

Table 13. Hybrid Piggy Back System ANOVA Table for CO₂ Saving (2¹⁰⁻⁵)

Source	DF	Seq SS	Adj SS	Adj MS	F
Main Effects	10	2.95927E+20	2.95927E+20	2.95927E+19	6557389.90
2-Way Interactions	21	1.24785E+19	1.24785E+19	5.94214E+17	131670.59
Residual Error	319968	1.44398E+18	1.44398E+18	4.51288E+12	
Pure Error	319968	1.44398E+18	1.44398E+18	4.51288E+12	
Total	319999	3.09850E+20			

Table 14. Hybrid Piggy Back System ANOVA Table for Cost (2¹⁰⁻⁵)

Source	DF	Seq SS	Adj SS	Adj MS	F
Main Effects	10	2.94643E+12	2.94643E+12	2.94643E+11	2488242.69
2-Way Interactions	21	2.70866E+11	2.70866E+11	12898367078	108926.13
Residual Error	319968	37888656223	37888656223	118414	
Pure Error	319968	37888656223	37888656223	118414	
Total	319999	3.25518E+12			

6.1 Hybrid Piggy Back System Emissions Results

When analyzing the main and interactions effects on an individual level for CO₂ savings under the hybrid piggy back system, it can be seen that diesel cost, biodiesel cost, delay time, product volume, and packing percent have little effects, shown as a flat line, on the response as seen in the effects plots in figure 33 and by the values associated with their effects in table 15 and figure 34. These factors were selected for removal when analyzing CO₂ savings in order to get a cleaner look at the results. By removing these five factors, the experiment is reduced to a 2⁵ full factorial. Reducing the experiment to a 2⁵ full factorial produces no effects that are aliased.

Table 15. Estimates Effects and Coefficients for CO₂ Savings (2¹⁰⁻⁵)

Estimated Effects and Coefficients for CO2 Savings (coded units)					
Term	Effect	Coef	SE Coef	T	P
Constant		61508990	3755	16378.97	0.000
diesel cost	39	19	3755	0.01	0.996
biodiesel cost	-450	-225	3755	-0.06	0.952
delay time	1969	985	3755	0.26	0.793
stop density	37809168	18904584	3755	5034.02	0.000
distance	-4611519	-2305759	3755	-613.99	0.000
packing percent	-1379	-690	3755	-0.18	0.854
WCO	44873610	22436805	3755	5974.60	0.000
Product volume	70	35	3755	0.01	0.993
non-customers	12010183	6005092	3755	1599.07	0.000
additional distance	-9508206	-4754103	3755	-1265.95	0.000
diesel cost*biodiesel cost	-4080182	-2040091	3755	-543.25	0.000
diesel cost*delay time	-2193	-1097	3755	-0.29	0.770
diesel cost*stop density	70	35	3755	0.01	0.993
diesel cost*distance	2380	1190	3755	0.32	0.751
diesel cost*packing percent	39	19	3755	0.01	0.996
diesel cost*WCO	1947	974	3755	0.26	0.795
diesel cost*Product volume	-1367	-683	3755	-0.18	0.856
diesel cost*non-customers	39	19	3755	0.01	0.996
diesel cost*additional distance	9445634	4722817	3755	1257.62	0.000
biodiesel cost*delay time	70	35	3755	0.01	0.993
biodiesel cost*stop density	7079050	3539525	3755	942.53	0.000
biodiesel cost*distance	11866	5933	3755	1.58	0.114
biodiesel cost*packing percent	378	189	3755	0.05	0.960
biodiesel cost*WCO	-6634	-3317	3755	-0.88	0.377
biodiesel cost*Product volume	490	245	3755	0.07	0.948
delay time*stop density	2472	1236	3755	0.33	0.742
delay time*distance	70	35	3755	0.01	0.993
delay time*packing percent	499	250	3755	0.07	0.947
delay time*WCO	39	19	3755	0.01	0.996
stop density*distance	582	291	3755	0.08	0.938
stop density*packing percent	9169	4584	3755	1.22	0.222
S = 2124354 R-Sq = 99.53% R-Sq(adj) = 99.53%					

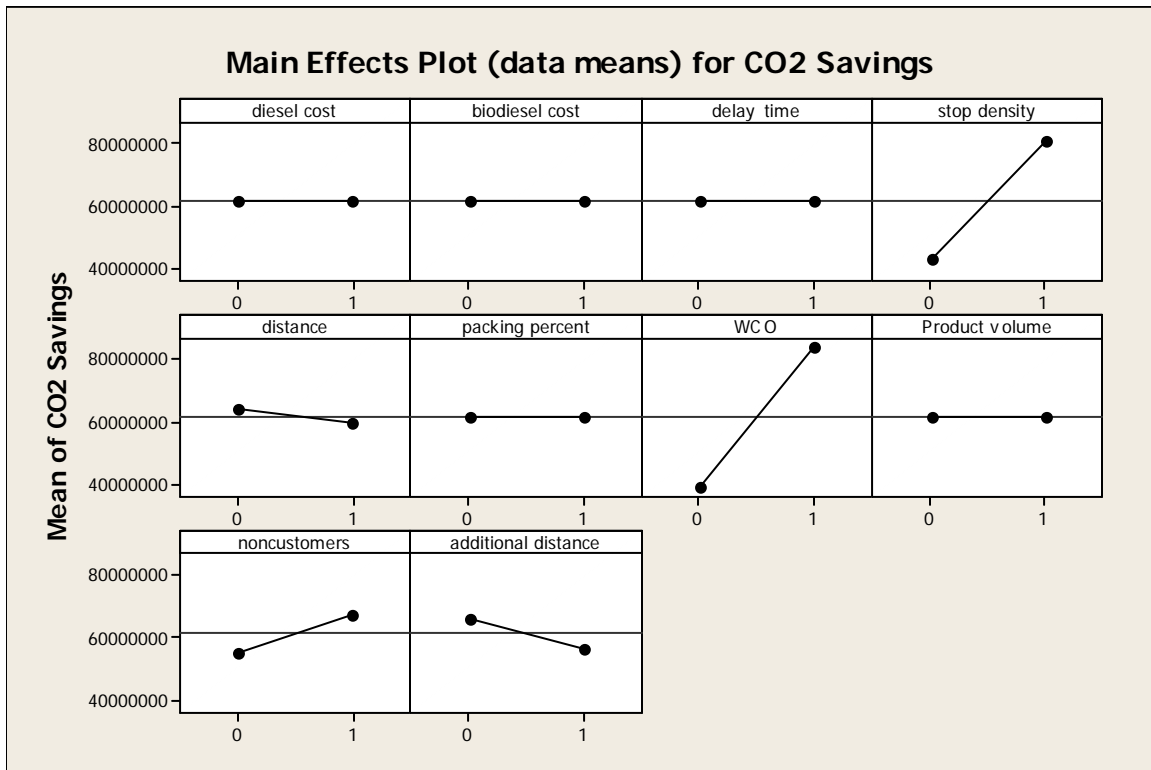


Figure 33. Main Effects plots for CO₂ Savings (2^{10-5})

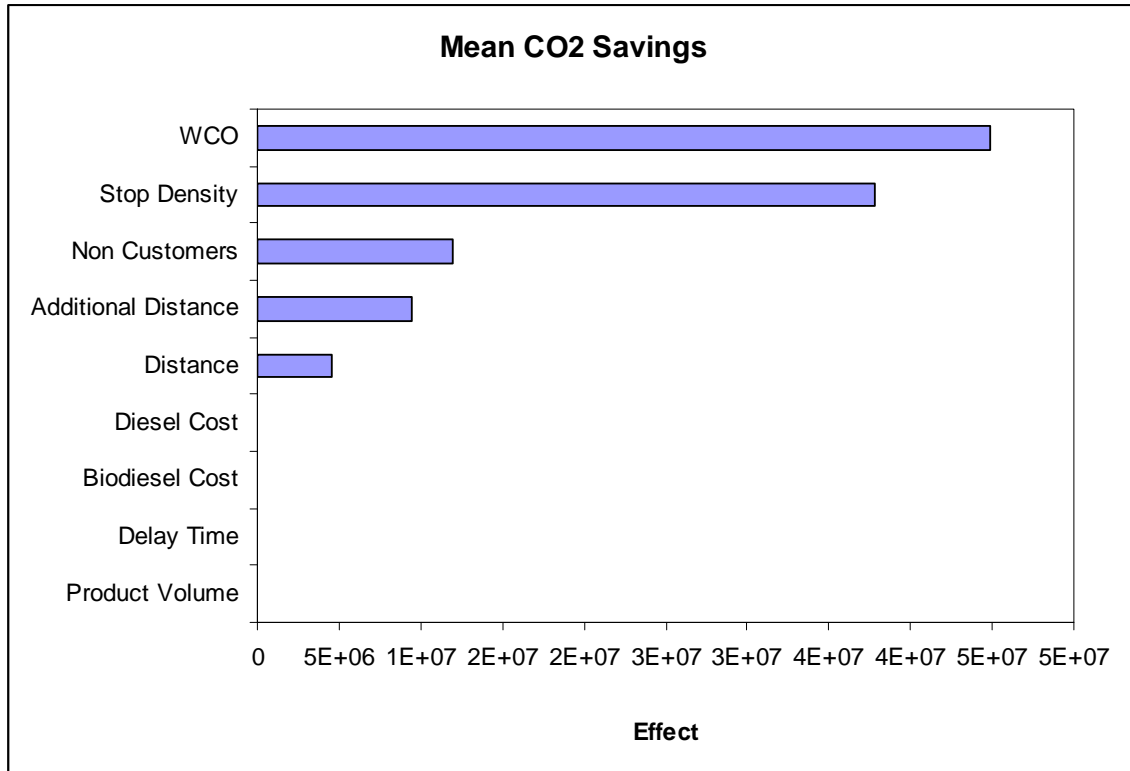


Figure 34. Pareto of Main Effects Response Values for CO₂ Savings

With the factorial reduced to a 2^5 design for CO₂ savings, the effects become clearer and easily analyzed. The ANOVA table for the reduced hybrid design still reports the main effects as driving the system as revealed by the relatively large F statistic reported for main effects as compared to interactions in table 16. When looking into the individual factors, all of them emerge as significant and relevant through the large values associated with their effects on CO₂ savings (Table 17). The main effects response plot confirms the relevance of the factors on CO₂ savings, these factors follow the logical patterns associated with this system under these assumptions in that all the factors have impacts to the amount of WCO collected or the distance traveled, which are driving the CO₂ savings equation. (Figure 35). The interaction effects associated with CO₂ savings also fit logically with how the system should work in that if the factor reduces the amount of

WCO collected or increases the distance the CO₂ savings is reduced and vice versa (Figure 37). For example, when stop density of customers generating WCO is high and the amount of WCO collected from each stops increases, CO₂ savings increase at a rate faster than when the stop density is low as seen in the effects plots in Figure 37. These logical findings help aid in verifying the logic of the model is correct.

Table 16. Hybrid Piggy Back System ANOVA for CO₂ Saving (2⁵)

Source	DF	Seq SS	Adj SS	Adj MS	F
Main Effects	5	2.95927E+20	2.95927E+20	5.91855E+19	13115315.14
2-Way Interactions	10	1.24785E+19	1.24785E+19	1.24785E+18	276519.25
Residual Error	319984	1.44399E+18	1.44399E+18	4.51270E+12	
Lack of Fit	16	1.32592E+13	1.32592E+13	8.28702E+11	0.18
Pure Error	319968	1.44398E+18	1.44398E+18	4.51288E+12	
Total	319999	3.09850E+20			

Table 17. Estimates Effects and Coefficients for CO₂ Savings (2⁵)

Estimated Effects and Coefficients for CO ₂ Savings (coded units)						
Term	Effect	Coef	SE Coef	T	P	
Constant		61508990	3755	16379.31	0.000	
stop density	37809168	18904584	3755	5034.13	0.000	
distance	-4611519	-2305759	3755	-614.00	0.000	
WCO	44873610	22436805	3755	5974.72	0.000	
non-customers	12010183	6005092	3755	1599.10	0.000	
additional distance	-9508206	-4754103	3755	-1265.98	0.000	
stop density*distance	582	291	3755	0.08	0.938	
stop density*WCO	9445634	4722817	3755	1257.64	0.000	
stop density*non-customers	-6634	-3317	3755	-0.88	0.377	
stop density*additional distance	1947	974	3755	0.26	0.795	
distance*WCO	9169	4584	3755	1.22	0.222	
distance*non-customers	378	189	3755	0.05	0.960	
distance*additional distance	39	19	3755	0.01	0.996	
WCO*non-customers	7079050	3539525	3755	942.54	0.000	
WCO*additional distance	70	35	3755	0.01	0.993	
non-customers*additional distance	-4080182	-2040091	3755	-543.26	0.000	
S = 2124311 R-Sq = 99.53% R-Sq(adj) = 99.53%						

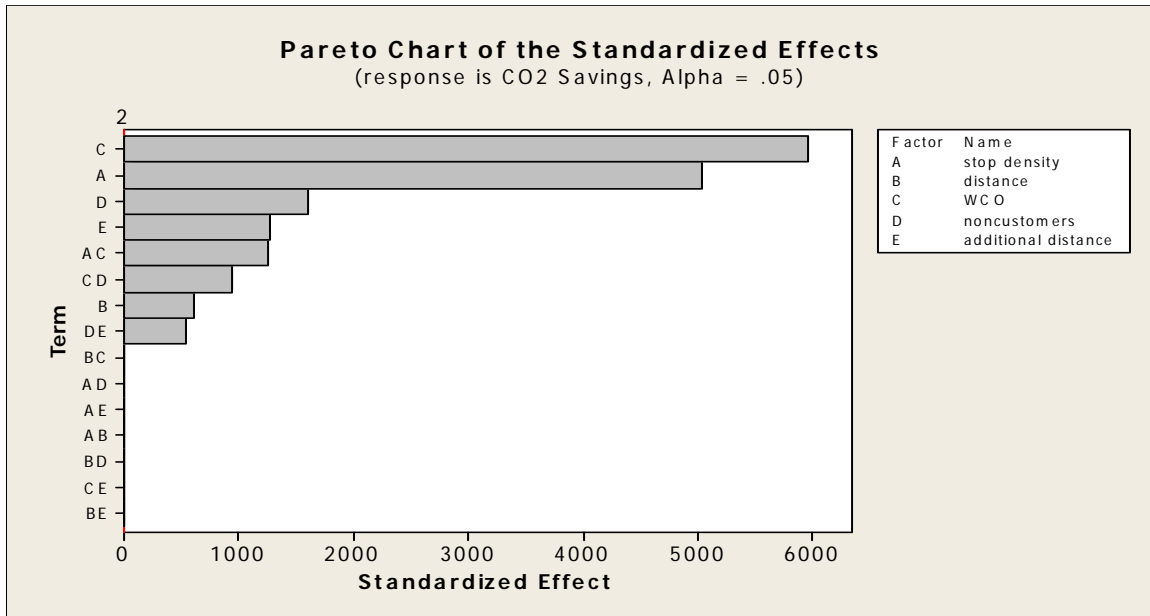


Figure 35. Pareto Chart of the Standardized Effects for CO₂ Savings (2⁵)

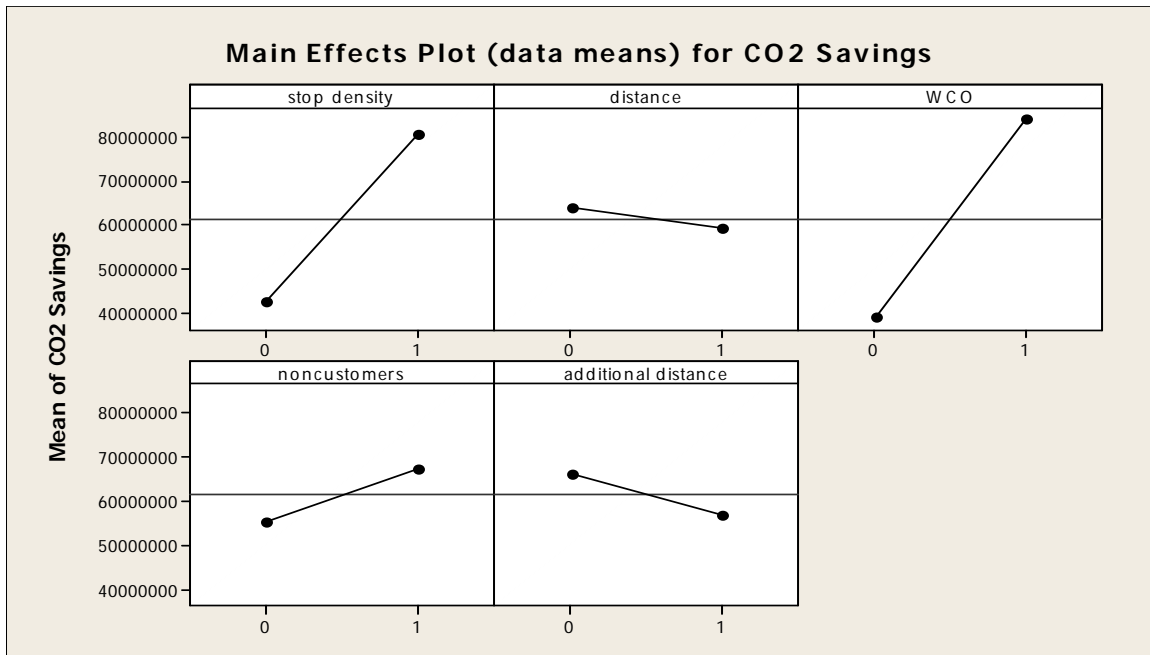


Figure 36. Main Effects plots for CO₂ Savings (2⁵)

Each main effect has physical meaning. As stop density increases the amount of WCO that is collected increases. The larger amounts of collected WCO become increased amounts of biodiesel that can be used in place of petroleum based diesel, therefore

reducing CO₂ emissions. The total distance traveled impacts CO₂ in that as larger distances are traveled more CO₂ is emitted through the combustion of fuel. Similar to stop density, as the volume of collected WCO is increased the more biodiesel and subsequent emissions reduction increase. The same is true for high number of noncustomers providing WCO. The increase in locations providing WCO, the more biodiesel and emissions reductions can be realized. The additional distances traveled however reduces the CO₂ saving, based on emissions generated to collect the WCO.

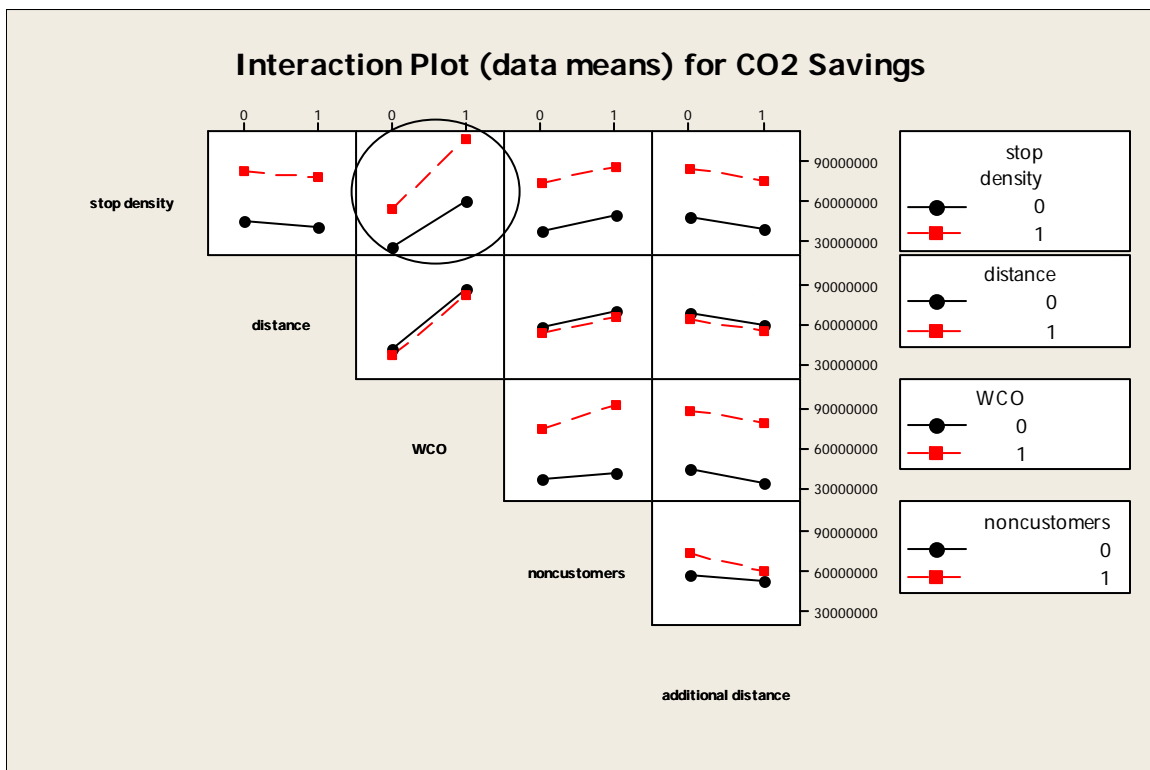


Figure 37. Interaction Effects plots for CO₂ Savings (2⁵)

6.2 Hybrid Piggy Back System Results for Cost

This same experimental reduction method that was conducted for reducing the experiment for CO₂ was done for cost. The main effects plots show no change or a flat response in the cost response from packing percent or product volume, so they were

selected for removal from the analysis (See Figure 38). The new experimental design for cost was reduced to a 2^{8-3} , providing a cleaner yet still aliased look into the effects of these eight factors on cost for the hybrid piggy back system.

Table 18. Estimates Effects and Coefficients for Cost (2^{10-5})

Estimated Effects and Coefficients for Cost (coded units)					
Term	Effect	Coef	SE Coef	T	P
Constant		-300	0.6083	-492.78	0.000
diesel cost	-3638	-1819	0.6083	-2990.07	0.000
biodiesel cost	1766	883	0.6083	1451.41	0.000
delay time	811	406	0.6083	666.65	0.000
stop density	-2580	-1290	0.6083	-2120.61	0.000
distance	1081	540	0.6083	888.26	0.000
packing percent	0	0	0.6083	0.36	0.721
WCO	-3335	-1667	0.6083	-2741.16	0.000
Product volume	0	0	0.6083	0.02	0.983
non-customers	236	118	0.6083	194.34	0.000
additional distance	905	452	0.6083	743.77	0.000
diesel cost*biodiesel cost	501	251	0.6083	411.90	0.000
diesel cost*delay time	0	0	0.6083	0.34	0.735
diesel cost*stop density	-1053	-527	0.6083	-865.92	0.000
diesel cost*distance	111	56	0.6083	91.35	0.000
diesel cost*packing percent	0	0	0.6083	0.05	0.962
diesel cost*WCO	-1251	-625	0.6083	-1027.93	0.000
diesel cost*Product volume	1	1	0.6083	1.20	0.229
diesel cost*non-customers	-395	-198	0.6083	-324.92	0.000
diesel cost*additional distance	-209	-104	0.6083	-171.77	0.000
biodiesel cost*delay time	-0	-0	0.6083	-0.18	0.861
biodiesel cost*stop density	-175	-87	0.6083	-143.57	0.000
biodiesel cost*distance	-1	-0	0.6083	-0.74	0.459
biodiesel cost*packing percent	-0	-0	0.6083	-0.16	0.871
biodiesel cost*WCO	419	209	0.6083	344.02	0.000
biodiesel cost*Product volume	62	31	0.6083	51.25	0.000
delay time*stop density	-0	-0	0.6083	-0.20	0.839
delay time*distance	0	0	0.6083	0.13	0.898
delay time*packing percent	-197	-99	0.6083	-162.18	0.000
delay time*WCO	-0	-0	0.6083	-0.25	0.804
stop density*distance	-1	-0	0.6083	-0.55	0.585
stop density*packing percent	-2	-1	0.6083	-2.01	0.044
S = 344.113 R-Sq = 98.84% R-Sq(adj) = 98.84%					

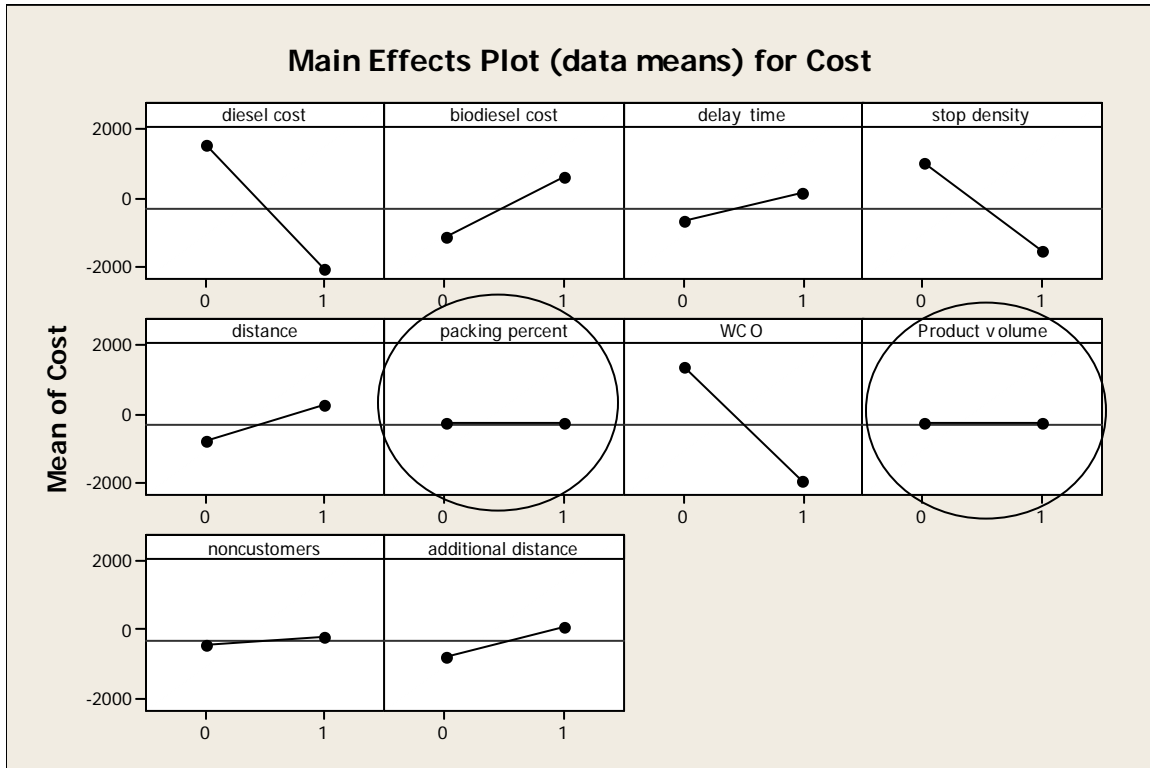


Figure 38. Main Effects plots for Cost (2^{10-5})

The 2^{8-3} design for cost shows a less aliased set of responses than the resolution IV 2^{10-5} design; however it is still aliased under the structure provided in table 5. The results of the 2^{8-3} still suggest that the main effects for cost are driving the system. This can be confirmed when looking at the scale of the main effects as compared to the interactions in the pareto and main effects plots in Figures 39 and 40 respectively. All the responses for cost under the hybrid piggy back scenario seem to follow how the system would perform logically, except one. The cost response for the hybrid piggy back system was thought to be based upon the cost of fuel, time, distance, and the amount of WCO collected. This can be seen in the main effects plots in figure 40. An increase in the difference in cost between diesel and biodiesel, diesel cost increasing while biodiesel cost is decreasing, and an increase in the amount of WCO collected, there should be a decrease in cost.

Whereas with a decrease in distance and time it was expected that cost would decrease with them. These responses are reflected in the main effects plots in figure 40. One of the factors effects on the cost responses seems counterintuitive. Logically it would seem that with each additional non-customer stop (non-customers), the cost would decrease. This decrease would stem from the additional savings associated with the additional WCO that is collected from the non-customers and used as biodiesel. However, this is not the case. The response plot for non-customers shows a direct correlation between cost and non-customer stops as seen by the increasing slope in the plot in figure 40. This increasing trend shows through in all the interaction effects associated with non-customer stops as well (See interaction effects plots in Figure 41). The other interaction effects associated with cost seem to follow logical patterns suggested above, under these assumptions. For example, when stop density is high and the route distance moves from low to high, cost increases at the same rate as when stop density is low, however cost is less with a high level of stop density.

Table 19. Hybrid Piggy Back System ANOVA Table for Cost (2^{8-3})

Source	DF	Seq SS	Adj SS	Adj MS	F
Main Effects	8	2.94642E+12	2.94642E+12	3.68303E+11	2874060.47
2-Way Interactions	20	2.67751E+11	2.67751E+11	13387547813	104469.99
Residual Error	319971	41003423721	41003423721	128147	
Lack of Fit	3	3114767498	3114767498	1038255833	8768.02
Pure Error	319968	37888656223	37888656223	118414	
Total	319999	3.25518E+12			

Table 20. Hybrid Piggy Back System Estimated Effects and Coefficients for Cost (2⁸⁻³)

Estimated Effects and Coefficients for Cost (coded units)					
Term	Effect	Coef	SE Coef	T	P
Constant		-300	0.6328	-473.70	0.000
diesel cost	-3638	-1819	0.6328	-2874.27	0.000
biodiesel cost	1766	883	0.6328	1395.20	0.000
delay time	811	406	0.6328	640.83	0.000
stop density	-2580	-1290	0.6328	-2038.48	0.000
distance	1081	540	0.6328	853.86	0.000
WCO	-3335	-1667	0.6328	-2635.00	0.000
Non-customers	236	118	0.6328	186.81	0.000
additional distance	905	452	0.6328	714.97	0.000
diesel cost*biodiesel cost	501	251	0.6328	395.95	0.000
diesel cost*delay time	0	0	0.6328	0.33	0.745
diesel cost*stop density	-1053	-527	0.6328	-832.38	0.000
diesel cost*distance	111	56	0.6328	87.82	0.000
diesel cost*WCO	-1251	-625	0.6328	-988.12	0.000
diesel cost*non-customers	-395	-198	0.6328	-312.34	0.000
diesel cost*additional distance	-209	-104	0.6328	-165.12	0.000
biodiesel cost*delay time	-0	-0	0.6328	-0.17	0.866
biodiesel cost*stop density	-175	-87	0.6328	-138.01	0.000
biodiesel cost*distance	-1	-0	0.6328	-0.71	0.476
biodiesel cost*WCO	419	209	0.6328	330.70	0.000
delay time*stop density	-0	-0	0.6328	-0.19	0.845
delay time*distance	0	0	0.6328	0.12	0.902
delay time*WCO	-0	-0	0.6328	-0.24	0.811
delay time*non-customers	62	31	0.6328	49.27	0.000
delay time*additional distance	1	1	0.6328	1.16	0.248
stop density*distance	-1	-0	0.6328	-0.52	0.600
distance*WCO	-2	-1	0.6328	-1.93	0.053
distance*non-customers	-0	-0	0.6328	-0.16	0.876
distance*additional distance	0	0	0.6328	0.05	0.963
S = 357.977 R-Sq = 98.74% R-Sq(adj) = 98.74%					

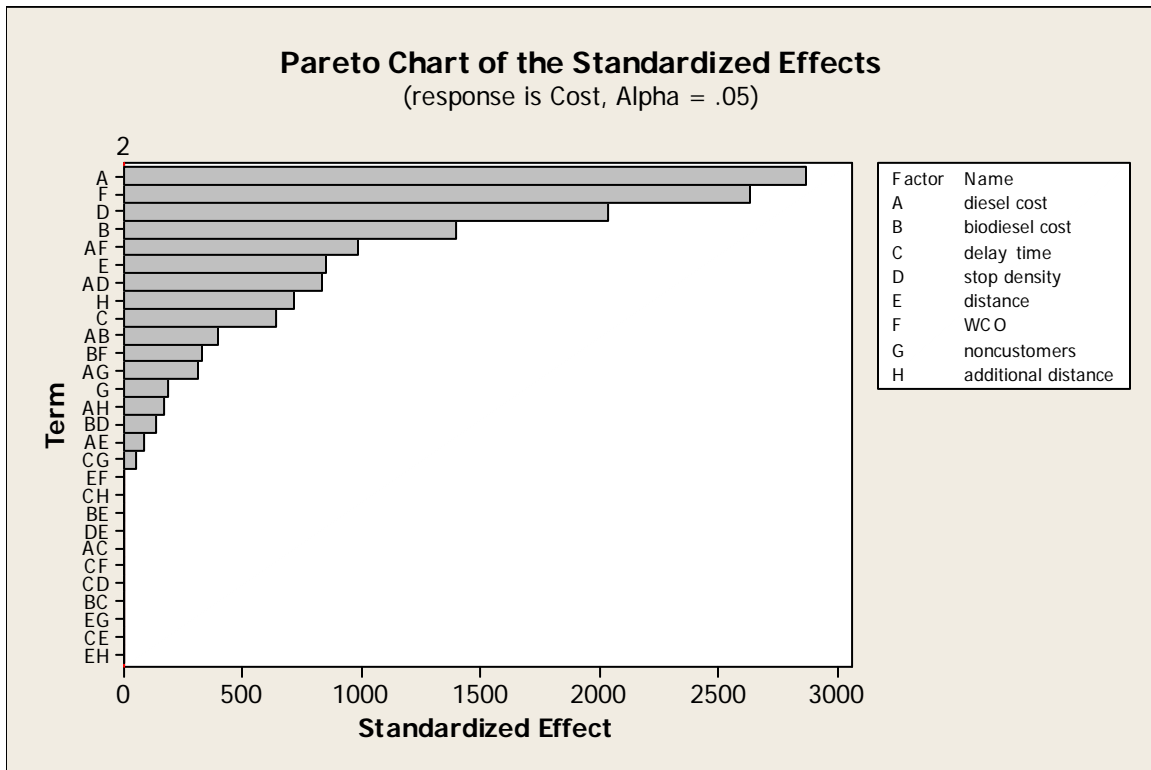


Figure 39. Pareto Chart of the Standardized Effects for Cost (2^{8-3})

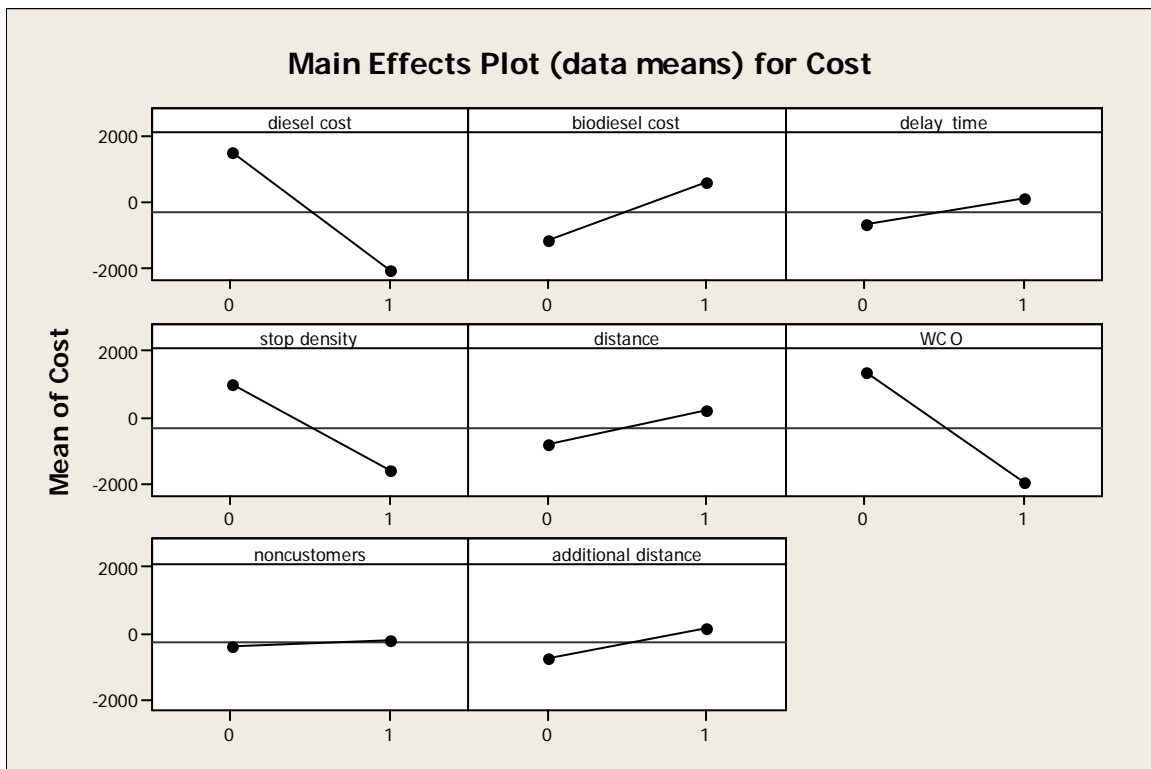


Figure 40. Hybrid Piggy Back System Main Effects Plots for Cost (2^{8-3})

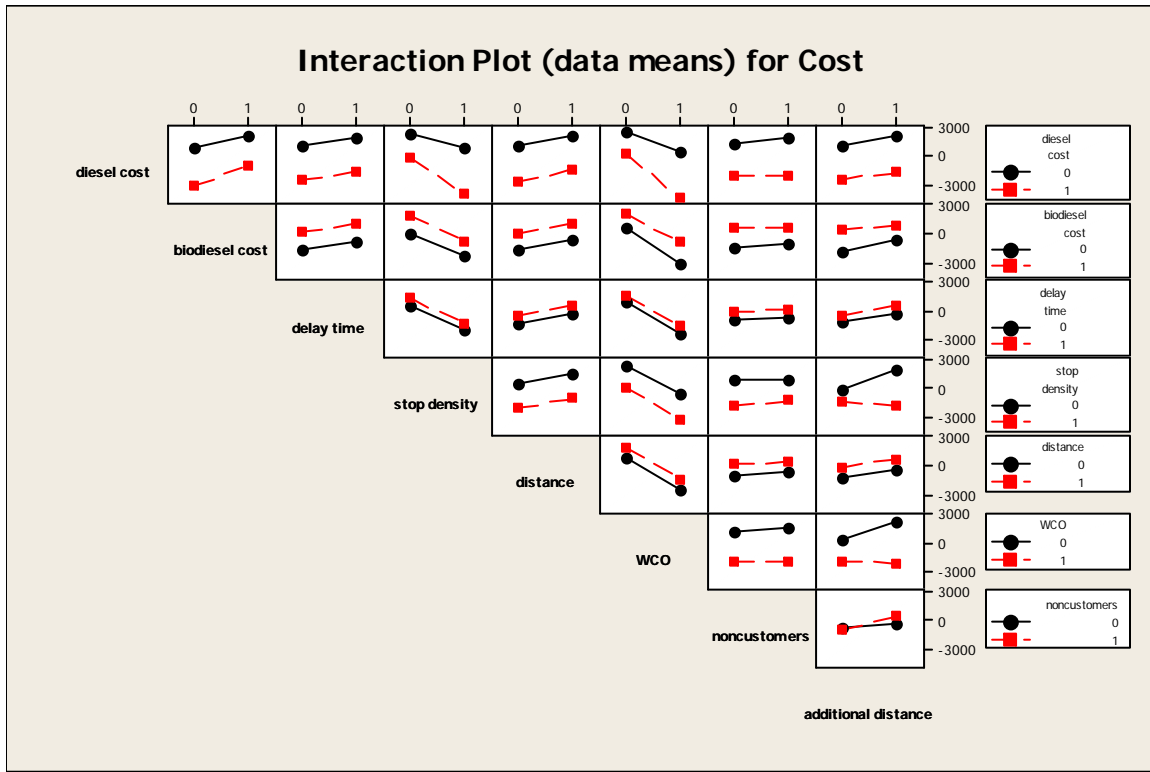


Figure 41. Hybrid Piggy Back System Interaction Effects plots for Cost (2^{8-3})

The non-customers effect requires further investigation to determine the cause of the direct correlation to cost. It was thought that the increase in cost could be attributed to the distance being traveled and extra time necessary to collect the WCO from the non-customers. In other words the cost associated with driving to the additional stops and the time to pick up the WCO was larger than the saving achieved from using the WCO as biodiesel. In order to investigate the effects of additional non-customer stops to the model, experiments were conducted that placed the additional non-customer stops at locations requiring a maximum additional distance from 1 to 20 miles off the route, in increments of 1 mile. The actual distance from the route is based upon the uniform distribution, allowing for equal likelihood that the stop be anywhere from 0 to the max distance away from the route deviation point (UNIF(0, Max deviation distance)). The

uniform distribution was chosen because it would not be likely for only stops at the max distance to be visited. It was assumed that the closest stops would be chosen before stops at a farther distance from the route. Within these setups, four levels of non-customer stops were added to the route. The four levels were set at 2, 4, 6, and 8 additional non-customer stops. This setup was used to determine the distance from the route that was too far, based on cost, to travel for collecting the WCO from non-customer under this design. The results of this experiment are visually depicted in Figure 42. Looking at the 3-D response surface for cost, it can be seen that below the threshold of 9 miles roundtrip on the distance axis, the cost decreases as the number of additional stops increase. Whereas, above the 9 mile threshold, or the inflection point, the cost increases as the number of additional stops increase. This reversal in trends can be attributed to the cost associated with the extra travel distance and time associated with additional non-customer stops. At and below a maximum deviation distance of 9 miles per stop, the cost savings from using WCO as biodiesel outweighs the cost incurred by labor and fuel to travel the additional distance. Whereas, at and beyond a maximum deviation distance of 10 miles per stop the cost incurred by labor and fuel outweigh the savings from collecting the WCO and using it as biodiesel. The total cost of the system is still below the cost under current practices at the 10 mile maximum deviation distance. This change in relationship just points out the distance at which the cost incurred for collection outweighs the cost savings for collecting WCO for use as biodiesel, not accounting for the cost associated with impacts to customer service levels.

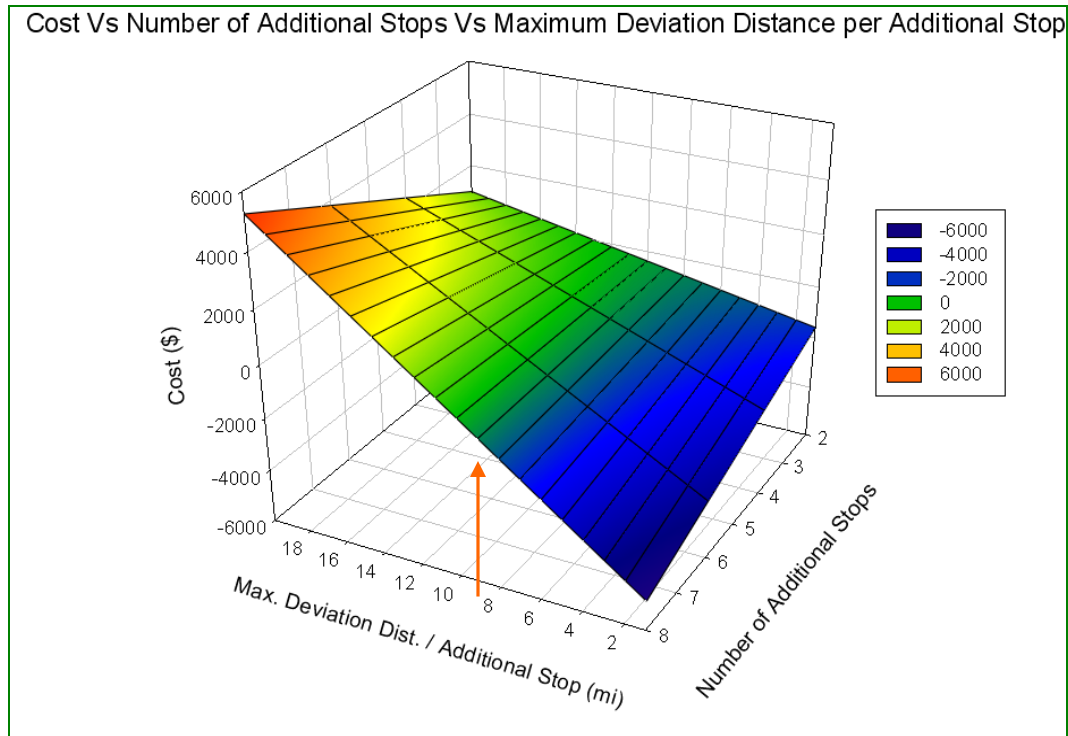


Figure 42. 3-D Response Surface for Cost Vs Additional Non-Customer Stops Vs Additional Travel Distance per Additional Stop

Upon discovering this dynamic trend for cost, it was inferred that the same would hold true for CO₂, CO, and THC. This experiment setup was used to determine the max distances at which the savings for CO₂, CO, and THC were no longer greater than the respective emissions caused by traveling the additional distance. NO_x is the only emission that does not generate a positive savings from biodiesel use, therefore the shortest distance traveled will always produce the least amount of NO_x emissions as seen in Figure 46.

When observing the trend of CO₂ savings versus number of additional stops at given distances under the same experimental setup, the same dynamic relationship is seen under these assumptions. Figure 43 shows that below the threshold of 17 miles on the distance axis, the CO₂ savings increase as the number of additional stops increase. Whereas,

above the 17 mile threshold, or the inflection line, the CO₂ savings decrease as the number of additional stops increase. This means that at the threshold of 17 miles per additional stop, regardless of the number stops, the saving will be equal. This relationship infers that the CO₂ emitted during travel to the additional stops beyond the threshold is larger than the savings that can be gained from using the biodiesel. The opposite would be true for maximum deviation distances below the inflection point. Like cost, CO₂ savings at its threshold distance still outperforms the current system. However it does not make logical sense to continue collecting WCO from additional stops beyond this threshold, on the basis of CO₂ savings. Experimental runs were conducted beyond the maximum deviation distance of 20 miles for CO₂, in order to provide a more clear representation of the dynamic trend occurring between the maximum deviation distance and CO₂ Savings.

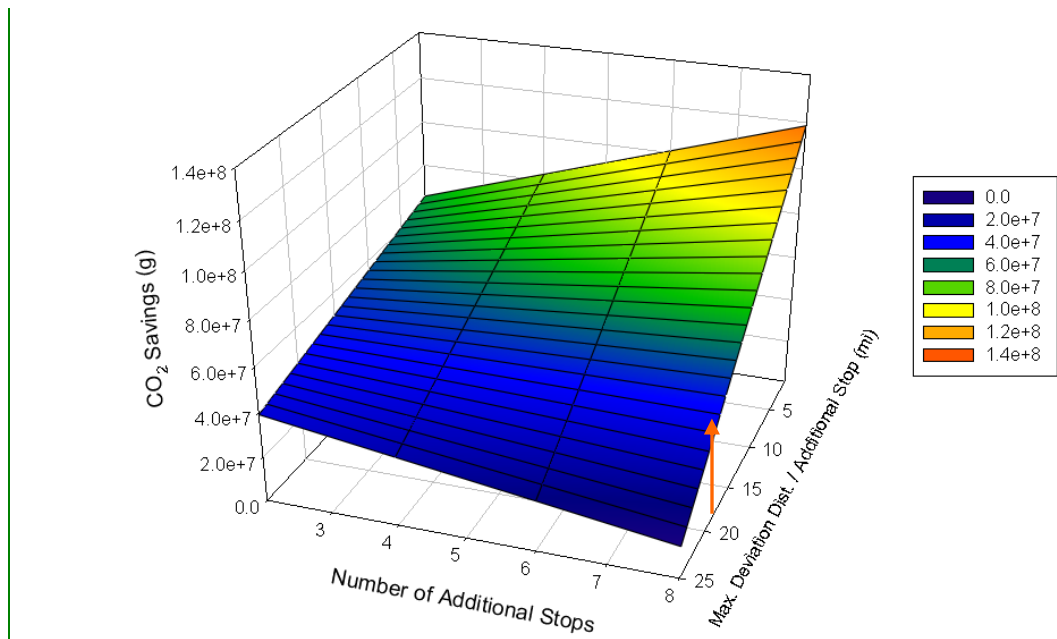


Figure 43. CO₂ Savings versus Additional Non-Customer Stops Vs Additional Travel Distance per Additional Stop

Figure 44 shows that below the threshold of 10 miles on the distance axis, CO savings increase as the number of additional stops increase. Whereas, above the 10 mile threshold, or the inflection line, CO savings decrease as the number of additional stops increase. This means that at 10 mile round trip distances, regardless of the number of additional stops, the CO saving remains the same. This relationship infers that the CO emitted during travel to the additional stops beyond the 10 mile threshold is larger than the savings that can be gained from using the biodiesel collected on that loop. The opposite would be true for maximum deviation distances below the inflection point.

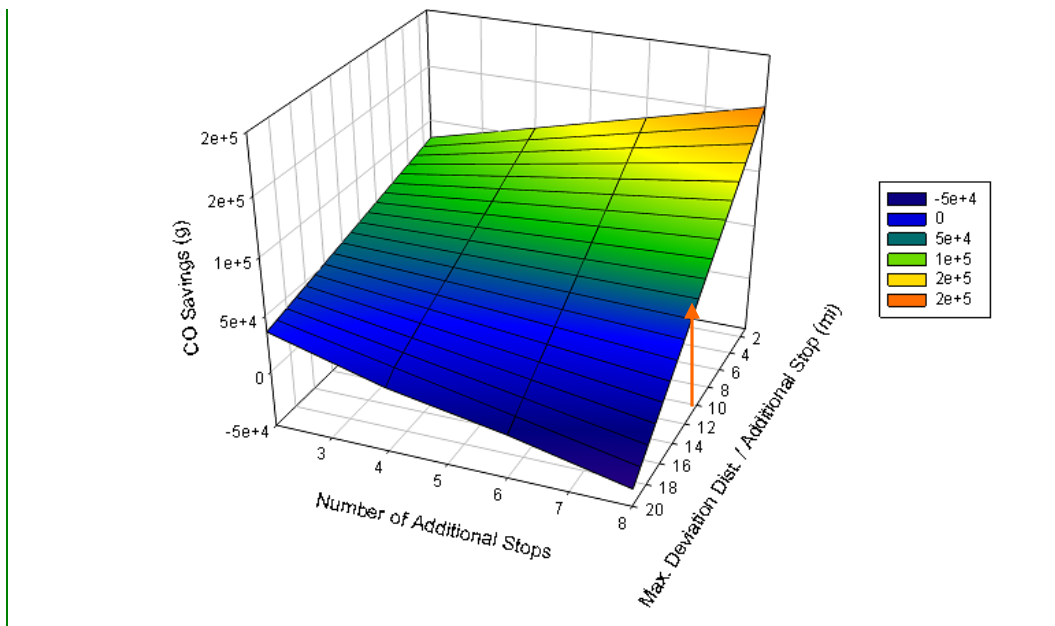


Figure 44. CO Savings versus Additional Non-Customer Stops Vs Additional Travel Distance per Additional Stop

Figure 45 shows that below the threshold of 14 miles on the distance axis, THC savings increase as the number of additional stops increase. Whereas, above the 14 mile threshold, or the inflection line, the THC savings decrease as the number of additional stops increase. This means that at a round trip distance of 14 miles, regardless of the

number of additional stops, the THC savings are equal. This relationship infers that the THC emitted during travel to the additional stops beyond the threshold is larger than the savings that can be gained from using the biodiesel. The opposite would be true for maximum deviation distances below the inflection point.

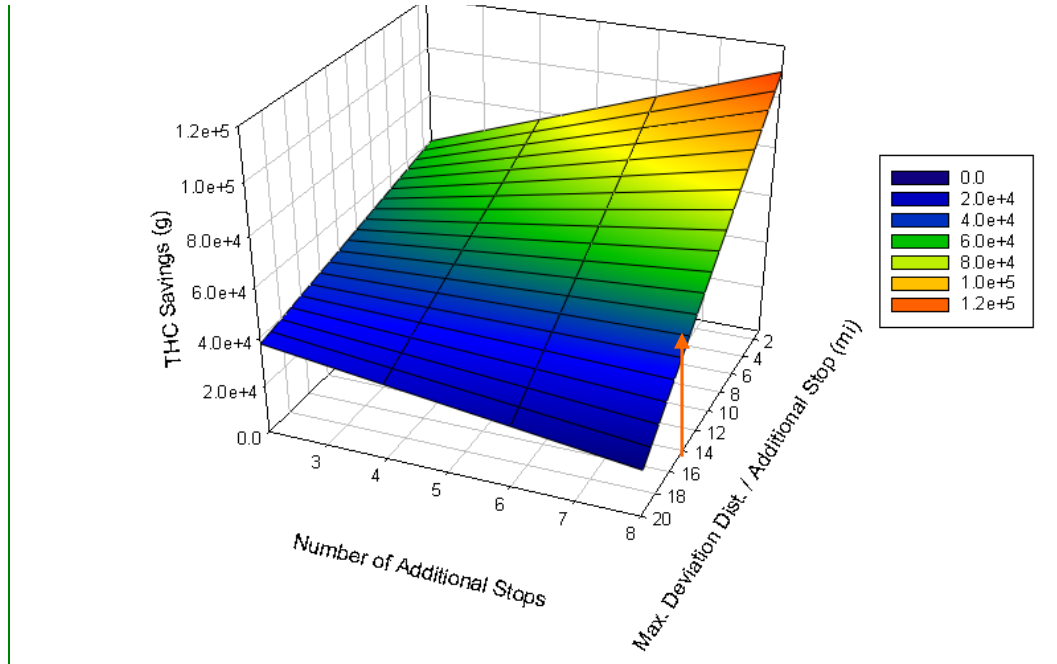


Figure 45. THC Savings versus Additional Non-Customer Stops Vs Additional Travel Distance per Additional Stop

It was hypothesized that NO_x would not follow the same patterns as cost and the other emissions. Since NO_x is emitted at higher rates with the use of biodiesel, NO_x can only be limited by reducing the distance traveled and the amount of biodiesel used. The graph in Figure 46 visually confirms that there is no inflection point at which it makes environmental sense to collect WCO under the hybrid piggy back scenario. This 3-D surface depicts the idea that NO_x savings decrease, or NO_x emissions increase, with increases in both the number of stops and the additional distance traveled per stop. This

decrease in savings is accelerated with a combined increase in both number of stops and distance.

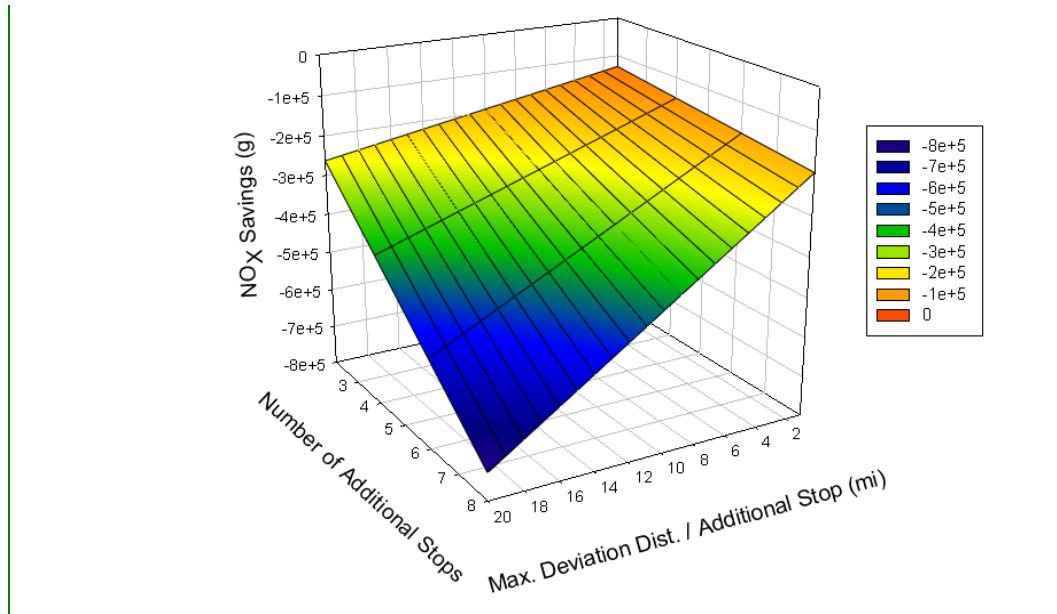


Figure 46. NO_x Savings versus Additional Non-Customer Stops Vs Additional Travel Distance per Additional Stop

At any maximum deviation distance farther than 17 miles per stop, additional stops that are visited will decrease the CO₂, CO, THC, and NO_x savings. At this threshold the cost for the additional distances traveled and time spent have increased the total cost to near or above the current cost of the system depending on the number of additional stops visited. Therefore, no stops should be visited beyond the maximum deviation distance of 17 miles for either environmental or economic benefit, under these assumptions. The maximum deviations distance thresholds for cost and emissions savings are only sensitive to the additional distance traveled for each additional stop.

By collecting WCO for use as biodiesel the F&B distributor is benefiting in both its cost and environmental impact at the expense of on-time deliveries to its customers. This reduction in customer service could potentially pose a threat to the core business, which is providing customers with food and beverages. To understand the impact of additional stops to service levels, the number of on-time customer deliveries was tracked over varying levels of additional customers at varying maximum deviation distances. The 3-D response surface for service level depicts that an increase in either the number of additional stops or the maximum deviation distance per additional stops a decrease in service level occurs as seen in Figure 47. The combination of increased stops and distance result in a more severe loss of service level. This data provided insight into what level of hybridization could be achieved at different service levels. Service level was defined as a percentage representing the average number of on-time deliveries at the 15 total customers per route. On-time being defined as stopping at all customers within an eight hour window.

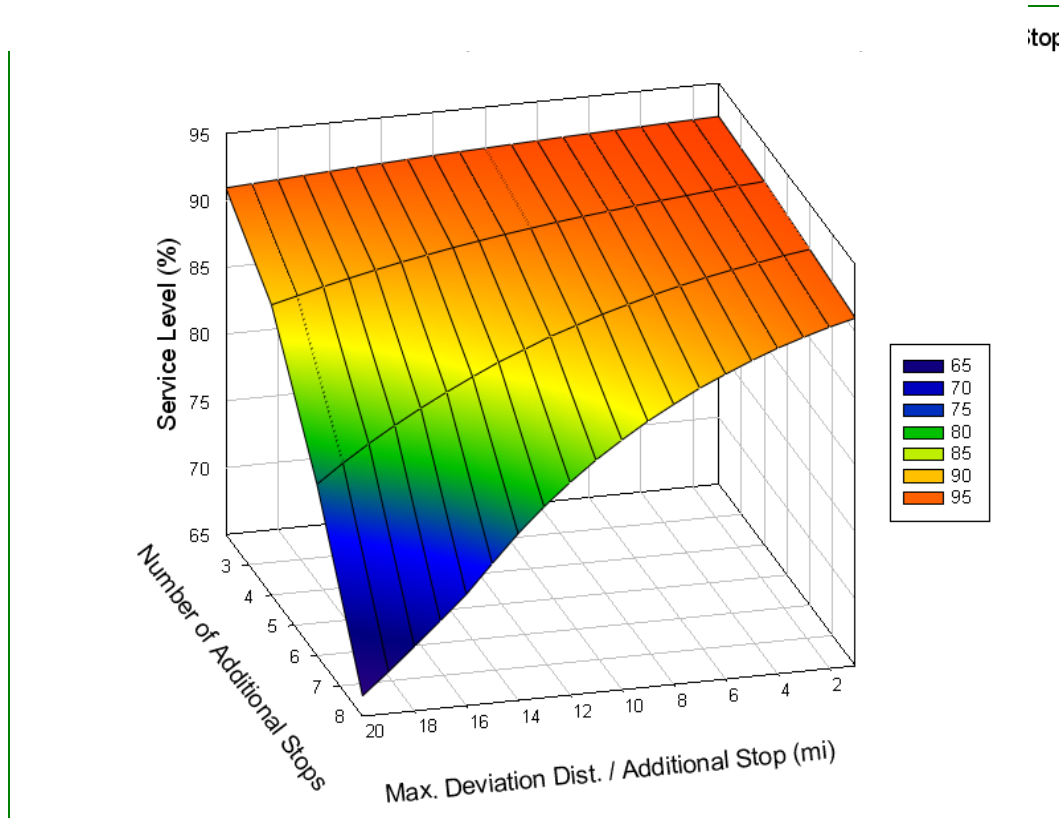


Figure 47. Service Level versus Additional Non-Customer Stops Vs Additional Travel Distance per Additional Stop

7. Conclusions

With the thresholds at which cost and emissions become infeasible, guidelines were constructed in order to provide F&B distribution companies with an aid in the decisions making process for determining the level to which they would hybridize the piggy back system under these assumptions. The heuristics were based upon the companies' culture, route demographics, and the level of service deemed acceptable. Company culture refers to the valuation of economics versus environmental impacts within the company, whereas route demographics refer to the number of non-customer WCO generating locations within the threshold proximity to the route in question. Due to the fact that visiting additional stops will reduce the service level of the company, an acceptable service level needs to be established in order to continue meeting the current customer's needs.

The level of hybridization of the piggy back model should not reduce the service level below the percentage deemed acceptable. WCO collection is a secondary service that needs to give way for the core business to be accomplished. With a chosen service level, the ability to collect WCO should then be based upon the number of locations that generate WCO in proximity to the route in question. Using the thresholds for cost and emissions, a F&B distributor can determine what the cut off limit should be for deciding which additional stops to visit. This decision should be based upon the perceived value of cost and environmental impact. If the company does not value the environment, the decision should be based purely upon the cost savings. For example, if the company decides that 90% service level is the lowest acceptable value and cost is the only metric, no additional stops at or beyond 9 miles should be visited. The number of sites that will actually be visited will be dictated by the available WCO generation stops within 9 miles of the route. Similarly, if the company does value its environmental impact, the threshold for additional stops distances will become increased. In this case, cost is still well below the current cost therefore achieving the higher environmental gains are still within economically sound reasoning. If total emissions are to be reduced the threshold is moved to 10 miles. However if CO₂ is the main emissions to be valued, the threshold can be increased to 18 miles. Again, the number of additional stops to be visited would depend on the available number of WCO generating stops within the threshold of the given route and the service level deemed acceptable. With the number of additional stops determined, the stops should be chosen, in order, from closest to farthest away from the route. This will allow for maximum reductions in cost and emissions.

Table 21. Maximum Deviation Distances for Cost, CO, THC, CO₂, and NO_x

Response	Maximum Deviation Distance
Cost	9 miles
CO Savings	10 miles
THC Savings	14 miles
CO ₂ Savings	17 miles
NO _x Savings	Minimize

By collecting WCO, the food and beverage industry can feasibly reduce its cost and environmental impact compared to current practices. The levels of reductions are based upon the factors underlying their routes and the method chosen. Provided that the F&B distributor's demographics fit alongside the assumptions in this model, the savings under the full piggy back scenario will be dictated by the density of customers generating WCO, the cost of diesel, and the amount of WCO being generated at each stop. The density of customers generating WCO will vary based upon the surrounding demographics of any given route; therefore the levels of savings will be different for each company and between routes. In general, the greater the percentage of customers that generate WCO, the larger the cost and emissions savings will be. The full piggy back scenario does not affect the service level of the company at a total of 15 stops per route. The cost and emissions savings associated with the hybrid piggy back scenario are more complex to understand and evaluate. Under this scenario tradeoffs have to be made. In order to reduce cost while increasing emissions savings, service levels have to be sacrificed. In general, cost will decrease up to a maximum deviation distance of 9 miles

per stop, CO savings will increase up to a maximum deviations distance of 10 miles, THC savings will increase up to a maximum deviation distance of 14 miles, and CO₂ savings will increase up to a maximum deviation distance of 17 miles. NOX will increase based up n the distances traveled. Therefore, the shorter the distance traveled the lower the NOX emitted. Service level will also decrease as deviation distances increase and the number of additional stops increase.

Food and beverage distributors can reduce their operations cost while reducing emissions by collecting waste cooking oil from their customers to use as biodiesel under this localized strategy. Both the full and hybrid piggy back system will provide beneficial results in terms of economics and the environment.

8. Future Work

The model and subsequent analysis of the F&B based WCO collection system for the production and use of biodiesel provides insight into the feasibility of closing this material loop in a sustainable manner. This study was the first pass at determining feasibility. The model could be expanded to include the impacts to fuel consumption and emissions generation from the varying load of the truck. Also, determining the quality and consistency of the WCO produced by different restaurant types would aid in the decision on which stops to visit. The heuristics here could then be expanded to include the restaurant types that provide the best quality or most consistent WCO, in terms of it free fatty acid content. The scale of the F&B distributor could be looked at more thoroughly as well. This model only investigated a local distribution network. Other F&B distribution networks are national in scale. There could be possibilities for such a network and economies of scale to have local pick up routes that feed a centralized

biodiesel plant. Other models like this one could be built to further investigate different material streams to understand if they too could be closed in a sustainable manner.

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Appendix A. Simulation Code: SIMAN

```
;
;
;   Model statements for module:  Create 1
;

80$      CREATE,      1,DaysToBaseTime(1),Entity
1:DaysToBaseTime(1),1:NEXT(81$);

81$      ASSIGN:      Create Truck.NumberOut=Create Truck.NumberOut +
1:NEXT(0$);

;
;
;   Model statements for module:  Assign 2
;
0$      ASSIGN:      Picture=Picture.Truck:
                        Capacity=567000:
                        Truck HP=277:
                        MPG=6:
                        Fuel Capacity=100:
                        Method=Method:
                        Diesel Cost=Diesel Cost:
                        Biodiesel Cost=Biodiesel Cost:
                        Total Biodiesel=0:
                        Total Cost=0:
                        Max Time=Max time:
                        Max Distance=Fuel Capacity*MPG:
                        BMIX=BMIX:
                        Delay Time=Delay Time:
                        Total Additional Cost=0:NEXT(12$);

;
;
;   Model statements for module:  Separate 2
;
12$      DUPLICATE,      100 - 0:
                        1,86$,0:NEXT(85$);

85$      ASSIGN:      Create Refueling Control Entity.NumberOut
Orig=Create Refueling Control Entity.NumberOut Orig + 1
                        :NEXT(13$);

86$      ASSIGN:      Create Refueling Control Entity.NumberOut
Dup=Create Refueling Control Entity.NumberOut Dup + 1
                        :NEXT(56$);

;
;
;   Model statements for module:  Hold 10
;
13$      QUEUE,      Wait for Next Refueling Signal.Queue;
WAIT:      1:NEXT(10$);
```

```

;
;
;   Model statements for module:  Assign 26
;
10$      ASSIGN:      Biodiesel Used=MIN(((BMIX/100)*(total
distance/MPG)), Total Biodiesel):
                        Diesel Used=(Total Distance/MPG):
                        Total biodiesel Used=Total Biodiesel Used +
Biodiesel Used *.0001:
                        Total Diesel Used=Total Diesel Used + Diesel Used:
                        Diesel Fuel Cost=Total Diesel Used * Diesel Cost:
                        Potential Biodiesel Savings=(Total Biodiesel *
diesel cost) - (total biodiesel * biodiesel cost)
                        :NEXT(19$);

;
;
;   Model statements for module:  Assign 37
;
19$      ASSIGN:      Biodiesel savings=(Total Biodiesel Used * diesel
cost) - (total biodiesel used * biodiesel cost):
                        Total Cost=(Cumulative Route Times*.416) + (Diesel
Fuel Cost):
                        Total Additional Cost=
                        (Total Pick Time *0.461) + ((Total additional
Distance/mpg)*(BMIX/100)*(Biodiesel Cost)) + ((Total additional
Distance/mpg)*(1-(BMIX/100))*(diesel Cost)) + (Cumulative additional
Time*0.461):
                        Collection Cost=
                        (Total Pick Time *0.461) + ((Total additional
Distance/mpg)*(BMIX/100)*(Biodiesel Cost)) + ((Total additional
Distance/mpg)*(1-(BMIX/100))*(diesel Cost)) + (Cumulative additional
Time*0.461)
                        :NEXT(13$);

;
;
;   Model statements for module:  Station 20
;

56$      STATION,      Routing;
89$      DELAY:        0.0,,VA:NEXT(17$);

;
;
;   Model statements for module:  Assign 32
;
17$      ASSIGN:      Number of Stop 1=Percent Stop 1:
                        Number of stop 2=Percent Stop 2:
                        Number of Stops=Number of Stop 1 + Number of Stop
2:
                        Distance=22 + 275 * BETA(0.896, 2.77):
                        Added Distance per Stop=Added Distance Per Stop:
                        Number of Stop 3=Number of Stop 3:
                        Time remaining=Max Time:
                        Total Distance=0:
                        Biodiesel=0:
                        uti=TRIA(0.3, 0.951, 1):
                        RemCap=capacity-(capacity*(uti)):
                        Total Pick=0:

```

```

Timein=TNOW:
Total time=0:
Y=0:
Number of Stops Made=0:
Stop Type 1=0:
Stop Type 2=0:
Stop Type 3=0:
previous stop location=0:
Time in route=0:
Number late=0:
Route pick=0:
Total Additional Pick=0:NEXT(26$);

;
;
;   Model statements for module:  Assign 43
;
26$      ASSIGN:      Route CO Emissions=0:
                        Route CO Emissions10=0:
                        Route CO Emissions20=0:
                        Route CO Emissions30=0:
                        Route CO Emissions40=0:
                        Route CO2 Emissions=0:
                        Route CO2 Emissions10=0:
                        Route CO2 Emissions20=0:
                        Route CO2 Emissions30=0:
                        Route CO2 Emissions40=0:
                        Route NOX Emissions=0:
                        Route NOX Emissions10=0:
                        Route NOX Emissions20=0:
                        Route NOX Emissions30=0:
                        Route NOX Emissions40=0:
                        Route THC Emissions=0:
                        Route THC Emissions10=0:
                        Route THC Emissions20=0:
                        Route THC Emissions30=0:
                        Route THC Emissions40=0:
                        Route CO Savings=0:
                        Route CO2 Savings=0:
                        Route NOX Savings=0:
                        Route THC Savings=0:
                        Additional Route CO Savings=0:
                        Additional Route CO2 Savings=0:
                        Additional Route NOX Savings=0:
                        Additional Route THC Savings=0:NEXT(47$);

;
;
;   Model statements for module:  Decide 16
;
47$      BRANCH,      1:
                        If,Number of Stop 1==0,90$,Yes:
                        Else,91$,Yes;
90$      ASSIGN:      Are there and Pickup and Delivery Stops.NumberOut
True=
                        Are there and Pickup and Delivery Stops.NumberOut
True + 1:NEXT(48$);
91$      ASSIGN:      Are there and Pickup and Delivery Stops.NumberOut
False=

```

```

Are there and Pickup and Delivery Stops.NumberOut
False + 1:NEXT(29$);

;
;
;   Model statements for module:  Decide 17
;
48$          BRANCH,          1:
                                If,Number of stop 2==0,92$,Yes:
                                Else,93$,Yes;
92$          ASSIGN:          Are there any delivery only stops.NumberOut True=
                                Are there any delivery only stops.NumberOut True +
1:NEXT(49$);

93$          ASSIGN:          Are there any delivery only stops.NumberOut False=
                                Are there any delivery only stops.NumberOut False
+ 1:NEXT(31$);

;
;
;   Model statements for module:  Decide 18
;
49$          BRANCH,          1:
                                If,Number of Stop 3==0,94$,Yes:
                                Else,95$,Yes;
94$          ASSIGN:          Are there any noncustomer stops.NumberOut True=Are
there any noncustomer stops.NumberOut True + 1
                                :NEXT(50$);

95$          ASSIGN:          Are there any noncustomer stops.NumberOut
False=Are there any noncustomer stops.NumberOut False + 1
                                :NEXT(33$);

;
;
;   Model statements for module:  Route 30
;
50$          ROUTE:          0.0000000000000000,Dispatch;

33$          ASSIGN:          Y=Y+1:
                                DD(Y,1)=UNIF(0, Distance):
                                DD(Y,2)=3:
                                Stop Type 3=Stop Type 3+1:NEXT(32$);

;
;
;   Model statements for module:  Decide 11
;
32$          BRANCH,          1:
                                If,Stop Type 3>=Number of stop 3,96$,Yes:
                                Else,97$,Yes;
96$          ASSIGN:          Are all noncustomer stops created.NumberOut True=
                                Are all noncustomer stops created.NumberOut True +
1:NEXT(50$);

97$          ASSIGN:          Are all noncustomer stops created.NumberOut False=
                                Are all noncustomer stops created.NumberOut False
+ 1:NEXT(33$);

```

```

31$          ASSIGN:      Y=Y+1:
                                DD(Y,1)=UNIF(0, Distance):
                                DD(Y,2)=2:
                                Stop Type 2=Stop Type 2+1:NEXT(30$);

;
;
;   Model statements for module:  Decide 10
;
30$          BRANCH,      1:
                                If,Stop Type 2>=Number of stop 2,98$,Yes:
                                Else,99$,Yes;
98$          ASSIGN:      Are all delivery only stops created.NumberOut
True=
                                Are all delivery only stops created.NumberOut True
+ 1:NEXT(49$);

99$          ASSIGN:      Are all delivery only stops created.NumberOut
False=
                                Are all delivery only stops created.NumberOut
False + 1:NEXT(31$);

29$          ASSIGN:      Y=Y+1:
                                DD(Y,1)=UNIF(0, Distance):
                                DD(Y,2)=1:
                                Stop Type 1=Stop Type 1+1:NEXT(27$);

;
;
;   Model statements for module:  Decide 9
;
27$          BRANCH,      1:
                                If,Stop Type 1>=Number of stop 1,100$,Yes:
                                Else,101$,Yes;
100$         ASSIGN:      Are all the pickup and delivery stops
created.NumberOut True=
                                Are all the pickup and delivery stops
created.NumberOut True + 1:NEXT(48$);

101$         ASSIGN:      Are all the pickup and delivery stops
created.NumberOut False=
                                Are all the pickup and delivery stops
created.NumberOut False + 1:NEXT(29$);

;
;
;   Model statements for module:  Station 1
;

1$           STATION,      Stop 1;
104$         DELAY:        0.0,,VA:NEXT(5$);

;
;
;   Model statements for module:  Assign 15
;
5$           ASSIGN:      Drop AMnt=1.26e+004 + 7.67e+004 * BETA(0.404,
1.25):
                                RemCap=RemCap+drop amnt:

```

```

                                Time in route=Time in route + (((Stop Location -
previous stop location)/35)*60)+delay time):
                                Total Drop Time=Total Drop Time + Delay Time:
                                previous stop location=Stop Location:NEXT(63$);

;
;
;   Model statements for module:  Decide 19
;
63$           BRANCH,          1:
                                If,Time in route  <=  Max time,105$,Yes:
                                Else,106$,Yes;
105$          ASSIGN:          Was The Delivery Late.NumberOut True=Was The
Delivery Late.NumberOut True + 1:NEXT(70$);

106$          ASSIGN:          Was The Delivery Late.NumberOut False=Was The
Delivery Late.NumberOut False + 1:NEXT(64$);

;
;
;   Model statements for module:  Assign 46
;
70$           ASSIGN:          Pick Amnt1=min((RemCap*.004329), UNIF(16,23)):
                                Number of containers=pick amnt1/5:
                                RemCap=RemCap-(number of containers*(5*231)):
                                Total Pick=total pick + pick amnt1:
                                Pick Time=5:
                                Total time=Total time + Pick time + delay time:
                                Total Pick Time=Total Pick Time + Pick time:
                                Route pick=Route Pick + Pick amnt1:NEXT(2$);

;
;
;   Model statements for module:  Route 7
;
2$           ROUTE:            0.0000000000000000,Dispatch;

;
;
;   Model statements for module:  Assign 44
;
64$          ASSIGN:          Number late=Number late + 1:NEXT(70$);

;
;
;   Model statements for module:  Station 11
;
3$           STATION,          Warehouse;
109$         DELAY:            0.0,,VA:NEXT(16$);

;
;
;   Model statements for module:  Assign 31
;
16$          ASSIGN:          Total Distance=Distance + Total Additional
Distance:

```



```

Total time=Total Time + ((Distance/35)*60):
Biodiesel=Total pick *.90:
Total Biodiesel=Total biodiesel + Biodiesel:
Biodiesel Production Cost=Total Biodiesel *

Biodiesel Cost:
Cumulative Route Times=Cumulative Route Times +
Total Time:NEXT(15$);

;
;
;   Model statements for module:  Signal 1
;
15$           SIGNAL:           1:NEXT(20$);

;
;
;   Model statements for module:  Decide 8
;
20$           BRANCH,           1:
                                If,Bmix>0 && Bmix<=10,24$,Yes:
                                If,Bmix > 10  && Bmix <= 20,23$,Yes:
                                If,Bmix > 20  && Bmix <= 30,22$,Yes:
                                If,BMIX > 30  && BMIX <=40,21$,Yes:
                                Else,25$,Yes;

;
;
;   Model statements for module:  Assign 42
;
25$           ASSIGN:           Route THC Savings=(Route Pick*mpg/35*Truck
HP*.72*.67) - (distance/35*Truck HP *.72):
                                Route NOX Savings=(Route Pick*mpg/35*Truck
HP*4.23*(-.1)) - (distance/35*Truck HP*4.23):
                                Route CO Savings=(Route Pick*mpg/35*Truck
HP*1.51*.48) - (distance/35*Truck HP*1.51):
                                Route CO2 Savings=((Route Pick*mpg/35)*(Truck
HP*654*.78)) - ((distance/35)*Truck HP*654):
                                Total Route CO2 Savings=Total Route CO2 Savings +
Route CO2 Savings:
                                Total Route CO Savings=Total Route CO Savings +
Route CO Savings:
                                Total Route NOX Savings=Total Route NOX Savings +
Route NOX Savings:
                                Total Route THC Savings=Total Route THC Savings +
Route THC Savings:
                                Route CO Emissions=(Truck HP)*(Total
Distance/35)*(1.51):
                                Route NOX Emissions=(Truck HP)*(Total
Distance/35)*(4.23):
                                Route THC Emissions=(Truck HP)*(Total
Distance/35)*(.72):
                                Route CO2 Emissions=(Truck HP)*(Total
Distance/35)*(654):
                                Total CO Emissions=Total CO Emissions + Route CO
Emissions:
                                Total NOX Emissions=Total NOX Emissions + Route
NOX Emissions:
                                Total THC Emissions=Total THC Emissions + Route
THC Emissions:
                                Total CO2 Emissions=Total CO2 Emissions + Route
CO2 Emissions:

```

```

CO Emissions Savings=
Total CO Emissions - (Total CO Emissions10 +
Total CO Emissions20 + Total CO Emissions30 + Total CO Emissions40):
NOX Emissions Increase=
(Total NOX Emissions10 + Total NOX Emissions20 +
Total NOX Emissions30 + Total NOX Emissions40) - Total NOX Emissions:
THC Emissions Savings=
Total THC Emissions - (Total THC Emissions10 +
Total THC Emissions20 + Total THC Emissions30 + Total THC Emissions40):
CO2 Emissions Savings=
Total CO2 Emissions - (Total CO2 Emissions10 +
Total CO2 Emissions20 + Total CO2 Emissions30 + Total CO2 Emissions40):
Additional Route CO2 Savings=
(Total Additional Pick*mpg/35*Truck HP*654*.78) -
(Total additional distance/35*Truck HP*654):
Additional Route CO Savings=
(Total Additional Pick*mpg/35*Truck HP*1.51*.48) -
(Total additional distance/35*Truck HP*1.51):
Additional Route NOX Savings=
(Total Additional Pick*mpg/35*Truck HP*4.23*(-.1))
- (Total additional distance/35*Truck HP*4.23):
Additional Route THC Savings=
(Total Additional Pick*mpg/35*Truck HP*.72*.67) -
(Total additional distance/35*Truck HP*.72):
Total Additional CO2 Savings=Total additional CO2
Savings + Additional Route CO2 Savings:
Total Additional CO Savings=Total Additional CO
Savings + Additional Route CO Savings:
Total Additional NOX Savings=Total Additional NOX
Savings + Additional Route NOX Savings:
Total Additional THC Savings=Total Additional THC
Savings + Additional Route THC Savings:
Total CO2 Savings=Total Route CO2 Savings + Total
Additional CO2 Savings:
Total CO Savings=Total Route CO Savings + Total
Additional CO Savings:
Total NOX Savings=Total Route NOX Savings + Total
Additional NOX Savings:
Total THC Savings=Total Route THC Savings + Total
Additional THC Savings:NEXT(46$);

;
;
;   Model statements for module:  Decide 15
;
46$      BRANCH,      1:
                If,Method==0,112$,Yes:
                Else,113$,Yes;
112$      ASSIGN:      Decide 15.NumberOut True=Decide 15.NumberOut True
+ 1:NEXT(51$);

113$      ASSIGN:      Decide 15.NumberOut False=Decide 15.NumberOut
False + 1:NEXT(43$);

;
;
;   Model statements for module:  Record 3
;
51$      TALLY:      AVG Total Cost,(Total Cost),1:NEXT(52$);

```

```

;
;
;   Model statements for module:  Record 4
;
52$           TALLY:           Avg Biodiesel Savings,Potential Biodiesel
Savings,1:NEXT(55$);

;
;
;   Model statements for module:  Record 7
;
55$           TALLY:           Cost after Savings,Total Cost - Potential
Biodiesel Savings,1:NEXT(53$);

;
;
;   Model statements for module:  Record 5
;
53$           TALLY:           WCO collected,Total Pick,1:NEXT(54$);

;
;
;   Model statements for module:  Record 6
;
54$           TALLY:           CO Emissions,CO Emissions Savings,1:NEXT(58$);

;
;
;   Model statements for module:  Record 8
;
58$           TALLY:           THC Savings,THC Emissions Savings,1:NEXT(59$);

;
;
;   Model statements for module:  Record 9
;
59$           TALLY:           CO2 Savings Tonnes,CO2 Emissions
Savings/(1000*1000),1:NEXT(60$);

;
;
;   Model statements for module:  Record 10
;
60$           TALLY:           NOX Increase,NOX Emissions Increase,1:NEXT(61$);

;
;
;   Model statements for module:  Record 11
;
61$           TALLY:           Trucks fueled,total biodiesel/(total biodiesel
used +1),1:NEXT(69$);

;
;
;   Model statements for module:  Record 14

```

```

;
69$          TALLY:          biodiesel created,biodiesel,1:NEXT(62$);

;
;
;   Model statements for module:  Record 13
;
62$          TALLY:          Total biodiesel loop cost,Total Additional
Cost,1:NEXT(11$);

;
;
;   Model statements for module:  Delay 10
;
11$          DELAY:          1440,,Other:NEXT(57$);

;
;
;   Model statements for module:  Route 32
;
57$          ROUTE:          0.000000000000000,Routing;

;
;
;   Model statements for module:  Decide 14
;
43$          BRANCH,          1:
                                If,
                                Total Time < Max Time && Total Additional Cost
< Potential Biodiesel Savings && RemCap >= 0,
                                114$,Yes:
                                Else,115$,Yes;
114$          ASSIGN:          Decide 14.NumberOut True=Decide 14.NumberOut True
+ 1:NEXT(44$);

115$          ASSIGN:          Decide 14.NumberOut False=Decide 14.NumberOut
False + 1:NEXT(45$);

;
;
;   Model statements for module:  Record 1
;
44$          COUNT:          Good,1:NEXT(51$);

;
;
;   Model statements for module:  Record 2
;
45$          COUNT:          Bad,1:NEXT(51$);

;
;
;   Model statements for module:  Assign 41
;
24$          ASSIGN:          Route CO Emissions10=(Truck
HP)*(Distance/35)*(1.43):

```

```

Route NOX Emissions10=(Truck
HP)*(Distance/35)*(4.38):
Route THC Emissions10=(Truck
HP)*(Distance/35)*(.63):
Route CO2 Emissions10=
((Truck HP)*(Distance/35)*(657)) - ((Truck
HP)*(Distance/35)*(657)*(.10)*(.78)):
Total CO Emissions10=Total CO Emissions10 + Route
CO Emissions10:
Total NOX Emissions10=Total NOX Emissions10 +
Route NOX Emissions10:
Total THC Emissions10=Total THC Emissions10 +
Route THC Emissions10:
Total CO2 Emissions10=Total CO2 Emissions10 +
Route CO2 Emissions10:NEXT(25$);

;
;
;   Model statements for module:  Assign 40
;
23$      ASSIGN:      Route CO Emissions20=(Truck
HP)*(Distance/35)*(1.32):
Route NOX Emissions20=(Truck
HP)*(Distance/35)*(4.46):
Route THC Emissions20=(Truck
HP)*(Distance/35)*(.56):
Route CO2 Emissions20=
((Truck HP)*(Distance/35)*(657)) - ((Truck
HP)*(Distance/35)*(657)*(.20)*(.78)):
Total CO Emissions20=Total CO Emissions20 + Route
CO Emissions20:
Total NOX Emissions20=Total NOX Emissions20 +
Route NOX Emissions20:
Total THC Emissions20=Total THC Emissions20 +
Route THC Emissions20:
Total CO2 Emissions20=Total CO2 Emissions20 +
Route CO2 Emissions20:NEXT(25$);

;
;
;   Model statements for module:  Assign 39
;
22$      ASSIGN:      Route CO Emissions30=(Truck
HP)*(Distance/35)*(1.14):
Route NOX Emissions30=(Truck
HP)*(Distance/35)*(4.8):
Route THC Emissions30=(Truck
HP)*(Distance/35)*(.54):
Route CO2 Emissions30=
((Truck HP)*(Distance/35)*(685)) - ((Truck
HP)*(Distance/35)*(685)*(.30)*(.78)):
Total CO Emissions30=Total CO Emissions30 + Route
CO Emissions30:
Total NOX Emissions30=Total NOX Emissions30 +
Route NOX Emissions30:
Total THC Emissions30=Total THC Emissions30 +
Route THC Emissions30:
Total CO2 Emissions30=Total CO2 Emissions30 +
Route CO2 Emissions30:NEXT(25$);

```

```

;
;
;   Model statements for module:  Assign 38
;
21$           ASSIGN:           Route CO Emissions40=(Truck
HP)*(Distance/35)*(1.07):
                                Route NOX Emissions40=(Truck
HP)*(Distance/35)*(4.86):
                                Route THC Emissions40=(Truck
HP)*(Distance/35)*(.43):
                                Route CO2 Emissions40=
                                ((Truck HP)*(Distance/35)*(684)) - ((Truck
HP)*(Distance/35)*(684)*(.40)*(.78)):
                                Total CO Emissions40=Total CO Emissions40 + Route
CO Emissions40:
                                Total NOX Emissions40=Total NOX Emissions40 +
Route NOX Emissions40:
                                Total THC Emissions40=Total THC Emissions40 +
Route THC Emissions40:
                                Total CO2 Emissions40=Total NOX Emissions40 +
Route NOX Emissions40:NEXT(25$);

;
;
;   Model statements for module:  Station 16
;

6$           STATION,           Stop 2;
118$          DELAY:            0.0,,VA:NEXT(8$);

;
;
;   Model statements for module:  Assign 19
;
8$           ASSIGN:           Drop AMnt=1.26e+004 + 7.67e+004 * BETA(0.404,
1.25):
                                RemCap=REmCap+Drop Amnt:
                                Time in route=Time in route + (((Stop Location -
previous stop location)/35)*60)+delay time):
                                Total Drop Time=Total Drop Time + delay Time:
                                Total time=Total Time + Delay Time:
                                previous stop location=Stop Location:NEXT(65$);

;
;
;   Model statements for module:  Decide 20
;
65$           BRANCH,           1:
                                If,Time in route <= Max Time,119$,Yes:
                                Else,120$,Yes;
119$          ASSIGN:           Was delivery late? 2.NumberOut True=Was delivery
late? 2.NumberOut True + 1:NEXT(7$);

120$          ASSIGN:           Was delivery late? 2.NumberOut False=Was delivery
late? 2.NumberOut False + 1:NEXT(66$);

;
;
;   Model statements for module:  Route 17

```

```

;
7$          ROUTE:          0,Dispatch;

;
;
;   Model statements for module:  Assign 45
;
66$          ASSIGN:          Number late=Number late + 1:NEXT(7$);

;
;
;   Model statements for module:  Station 17
;

9$           STATION,        Stop 3;
123$          DELAY:          0.0,,VA:NEXT(18$);

;
;
;   Model statements for module:  Assign 35
;
18$           ASSIGN:          Additional Distance=UNIF(0,Added Distance Per
Stop):
                                Total Additional Distance=Total Additional
Distance + Additional Distance:
                                Additional Time=((Added Distance Per
Stop)/35)*60) + Delay time:
                                Time in route=Time in route + additional time:
                                Total Additional Time=Total Additional Time +
Additional Time:NEXT(71$);

;
;
;   Model statements for module:  Assign 47
;
71$           ASSIGN:          Additional Pick=min((RemCap*.004329), UNIF(16,
23)):
                                Number of containers=additional pick/5:
                                RemCap=RemCap-(number of containers*(5*231)):
                                Total Additional Pick=Total Additional Pick +
Additional Pick:
                                Total Pick=total pick + Additional Pick:
                                Total time=Total Time + Additional Time:
                                Cumulative Additional Time=Cumulative Additional
Time + Additional Time:NEXT(28$);

;
;
;   Model statements for module:  Route 26
;
28$           ROUTE:          0.000000000000000,Dispatch;

;
;
;   Model statements for module:  Station 19
;

```

```

36$          STATION,          Dispatch;
126$         DELAY:           0.0,,VA:NEXT(67$);

;
;
;   Model statements for module:  Decide 21
;
67$          BRANCH,          1:
                                If,Number of Stops Made==0,127$,Yes:
                                Else,128$,Yes;
127$          ASSIGN:         Decide 21.NumberOut True=Decide 21.NumberOut True
+ 1:NEXT(38$);

128$          ASSIGN:         Decide 21.NumberOut False=Decide 21.NumberOut
False + 1:NEXT(68$);

38$          ASSIGN:         Number of Stops Made=Number of Stops Made + 1;
34$          FINDJ,          1,Number of Stops + Number of Stop 3:Min(DD(J,1));
35$          ASSIGN:         Stop Location=DD(J,1):
                                Stop Type=DD(J,2):NEXT(42$);

;
;
;   Model statements for module:  Decide 13
;
42$          BRANCH,          1:
                                If,Number of Stops Made>Number of Stops + Number
of stop 3 + 1,129$,Yes:
                                Else,130$,Yes;
129$          ASSIGN:         Decide 13.NumberOut True=Decide 13.NumberOut True
+ 1:NEXT(41$);

130$          ASSIGN:         Decide 13.NumberOut False=Decide 13.NumberOut
False + 1:NEXT(37$);

;
;
;   Model statements for module:  Route 29
;
41$          ROUTE:           0.000000000000000,Warehouse;

;
;
;   Model statements for module:  Decide 12
;
37$          BRANCH,          1:
                                If,Stop Type==1,4$,Yes:
                                If,Stop Type==2,39$,Yes:
                                Else,40$,Yes;

;
;
;   Model statements for module:  Route 28
;
40$          ROUTE:           0.000000000000000,Stop 3;

;
;

```



```

;      Model statements for module:  Route 15
;
4$      ROUTE:          0,Stop 1;

;
;
;      Model statements for module:  Route 27
;
39$      ROUTE:          0.0000000000000000,Stop 2;

68$      ASSIGN:        Number of Stops Made=Number of Stops Made + 1:
                        DD(J,1)=100*Max time:NEXT(34$);

;
;
;      Model statements for module:  Create 2
;

133$      CREATE,        1,MinutesToBaseTime(TFIN),Entity
1:MinutesToBaseTime(TFIN),1:NEXT(134$);

134$      ASSIGN:        Create 2.NumberOut=Create 2.NumberOut +
1:NEXT(72$);

;
;
;      Model statements for module:  ReadWrite 1
;
72$      WRITE,          biodiesel data:
                        Total Cost - Potential Biodiesel
savings:NEXT(74$);

;
;
;      Model statements for module:  ReadWrite 2
;
74$      WRITE,          CO2 data:
                        Total CO2 Savings:NEXT(75$);

;
;
;      Model statements for module:  ReadWrite 3
;
75$      WRITE,          CO data:
                        Total CO Savings:NEXT(76$);

;
;
;      Model statements for module:  ReadWrite 4
;
76$      WRITE,          NOX Data:
                        Total NOX Savings:NEXT(77$);

;
;
;      Model statements for module:  ReadWrite 5

```

```

;
77$      WRITE,      THC Data:
                        Total THC Savings:NEXT(78$);

;
;
;      Model statements for module:  ReadWrite 6
;
78$      WRITE,      Trucks Data:
                        Total biodiesel/(total biodiesel used):NEXT(79$);

;
;
;      Model statements for module:  ReadWrite 7
;
79$      WRITE,      Number late data:
                        Number late:NEXT(73$);

;
;
;      Model statements for module:  Dispose 1
;
73$      ASSIGN:      Dispose 1.NumberOut=Dispose 1.NumberOut + 1;
137$     DISPOSE:      Yes;

```