Designing a Biodiesel Supply Chain in Mexico City

by

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Submitted to the System Design and Management Program
in Partial Fulfillment of the Requirements for the Degree of

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Abstract

Mexico City is a prime location to start a biodiesel enterprise due to its sizeable availability of waste vegetable oil (WVO) and biodiesel users. WVO is an extremely viable feedstock for producing biodiesel because of the similar functional properties compared to other feedstocks and low cost; collecting it for local reuse has enormous environmental savings potential. Supply chain design is essential for the success for this startup biodiesel enterprise.

The purpose of this thesis is to analyze a biodiesel enterprises value chain that uses feedstock as the primary performance area within the value chain. Second, this thesis will focus on optimizing the feedstock supply chain through a vehicle routing problem with time constraints in order to maximize the cost performance of the business.

TransCAD transportation planning software was used to solve the vehicle routing problem through different scenarios that included 263 WVO stops positioned randomly and clustered. The results reveal a logistics design model with optimized transportation cost providing insight into operating a successful start up biodiesel enterprise. Potential takeaways of these findings show that clustering is a necessary technique for optimizing transportation cost through managing vehicle fleet size, manpower, and vehicle scheduling.

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Dedication

I dedicate my thesis to Max. You are my encouragement, enthusiasm, future and love. Your spirit is rich with intellect and happiness. When I look into your eyes all my dreams come true. I love you more than you will ever know, now and for all eternity.

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Problem Statement

The Mexico City biodiesel industry will be explored specifically looking at how value can be captured and transferred from different entities in a supply chain. Mexico City lacks a recognized biodiesel company and there is no evidence of a biodiesel supply chain network. Accordingly, no benchmarking model exists in Mexico for establishing a robust biodiesel supply chain in a developing economy. As a result, a new, Mexico City, biodiesel company faces extensive challenges due to the complex urban environment and the impact of managing the total value chain from supply of the raw material (waste vegetable oil - WVO) to customers. Some challenges arise because of weak regulations and policies. Others are due to a lack of standards in WVO management. But, managing the collection of WVO is one of the most highlighted challenges for a biodiesel company. A company's supply chain is vital for operational efficiency and financial management. It provides a company's value chain with different attributes for competitive success.

This thesis focuses on the feedstock portion of a biodiesel supply chain. It also explores a vehicle routing problem in Mexico City. It further investigates a biodiesel enterprise that picks up WVO from restaurants and delivers it to a production facility location called a depot. It is imperative to manage the distribution operations efficiently to minimize operating costs and ensure a successful biodiesel supply chain. This vehicle routing problem is formulated as a Vehicle Routing Problem where demands are stochastic and a function of time or rate of consumption.

Motivation

Mexico, a developing country faces environmental challenges, oil and gas dependence, and health issues. Biodiesel is an alternative energy solution proven in other countries as a viable energy source with the potential to improve the Mexican energy sector with positive environmental implications. As a result, the motivation of this thesis is based around starting a successful biodiesel enterprise in Mexico City. This enterprise is a start up company with minimum capital and resources. High performance will be achieved on strategically managing different business operating components: Supply Chain, Production, Marketing, and Sales.

The focus of this thesis is the supply chain dimensions of the biodiesel enterprise. However, very little is known about the logistics practices of a biodiesel supply chain in Mexico City. Therefore, beyond the benefits for the startup, a model for a robust supply chain in Mexico City can be used as a foundation for other cities in Mexico and other developing countries.

Chapter 1 Literature Review

Biodiesel fuel is documented as an alternative fuel widely used from renewable resources. The fuel's benefits have driven the development of biodiesel businesses throughout the world. To inform this development, this review starts with an outline of a biodiesel company's supply chain. Next it focuses on the role of biodiesel feedstock. Following the discussion on feedstock, it shows research around the challenges related to collecting the feedstock through logistics analysis. Lastly, it focuses on supply chain logistics as an attribute that provides a competitive advantage for a biodiesel business, highlighting the limited literature on the logistics of collecting WVO.

A biodiesel supply chain can be divided into several valuable operating entities. According to Townley-Smith (2012), a supply chain generalization model identifies five major segments: 1) Feedstock Production, 2) Logistics, 3) Conversion, 4) Distribution, and 5) End Use Townley-Smith (2012). This model provides an overview on designing a biodiesel supply chain but the article assumes crops as the primary feedstock.

Research by Haas (2006) and Zhang (2003) found that the feedstock provides viable opportunities to minimize the overall cost of biodiesel. Moreover, other studies by Silvio Francisco dos Santos (2014), Demirbas (2008), and Radich (2004), show feedstock has the largest contribution to the overall cost of biodiesel, in some cases over 75% (Atabani, 2012; Luz del Carmen Díaz-Peña, 2013). This forces biodiesel companies to focus on feedstock cost reduction efforts.

Several feedstocks such as WVO, rapeseed, palm oil, soy, and canola oil have been researched for processing of biodiesel production (Fajman, 2011; Wesseler, 2007; Bender, 1999; Y. Zhang, 2003; Muley & Boldor, 2013). These studies examine the feasibility of using alternative feedstocks to produce biodiesel. It looks at optimum production settings to improve high biodiesel yield quantities and increased quality. They conclude that WVO is advantageous to straight vegetable oil (SVO) created from other feedstocks because of similar processing property characteristics. Also, it has lower costs because the primary feedstock production is in restaurants that discard the WVO. The major concern is how to collect the WVO in large quantities from restaurants at low cost.

One primary way to optimize feedstock cost is the improved efficiency of logistics. (Deniz Aksen, 2012; Pereira Ramosa, Gomes, & Barbosa-Póvoa, 2013) discuss the critical logistical decisions characterized by collecting WVO, which is route optimization, subject to constraints such as depot quantities, vehicle fleets characteristics, stochastic vs. deterministic demand, and time limitations. Further research of route optimization, by Figliozzi (2008b) and Daganzo (1984) investigated vehicle routing problems (VRP). Their research examined delivering products from a single location to many locations in order to estimate distances. Daganzo's and Figliozzi VRP models incorporate time window constraints, customer clustering, and vehicle capacity variables. These models all propose better distance approximations in order to minimize transportation costs. Araujo (2010) further explores a vehicle routing problem by specifically collecting WVO and analyzing the logistical costs.

Although, these articles examine delivery problems, their approach does not explore a vehicle routing problem such as that of Mexico City. The collection problem case examined in this thesis has many stops and will extend the research of a vehicle routing problem with stochastic demand to optimize transportation cost, thereby enabling biodiesel businesses to competitively structure operating costs.

Methodology

The literature review provides a framework to develop a supply chain for a biodiesel production enterprise in Mexico City. After the framework is established it focuses on a value specific area within the supply chain – feedstock logistics. This thesis identifies, measures and recommends logistic centric attributes that present a company's successful performance.

The data collection started with a population of 263 restaurants centralized in Mexico City. Each data point of restaurants contains location of restaurants, restaurant vegetable oil capacity, and quantity of waste vegetable oil produced. TransCAD, a Geographic Information System (GIS) software was used to conduct the initial data analysis. First, it used an origin and destination routing matrix to organize the location information. The other inputs were restaurant and biodiesel depot time constraints, specific routes, and vehicle capacity, speed, and cost.

This data uncovers the logistic challenges such as transportation scheduling for a biodiesel company. The vehicle routing problem has demand from several restaurant stops. Analysis of this problem will solve most cost and operational inefficiencies of a biodiesel company, and provide a useful model to other developing countries.

Energy Landscape

Today's demand for energy and a cleaner environment continues to grow rapidly as populations increase and nations deliver more energy-consuming products to the economy. Energy demand is met from established energy resources like coal, petroleum and natural gas (NG). For instance, in 2013, fossil fuel consisting of oil, natural gas, and coal constituted for 74% of the world energy source as seen below (U.S. Energy Information Administration (EIA), 2014). This demand continues to grow. EIA's recently released *International Energy Outlook 2013 (IEO2013)* and projects that world energy consumption will grow by 56% between 2010 and 2040.

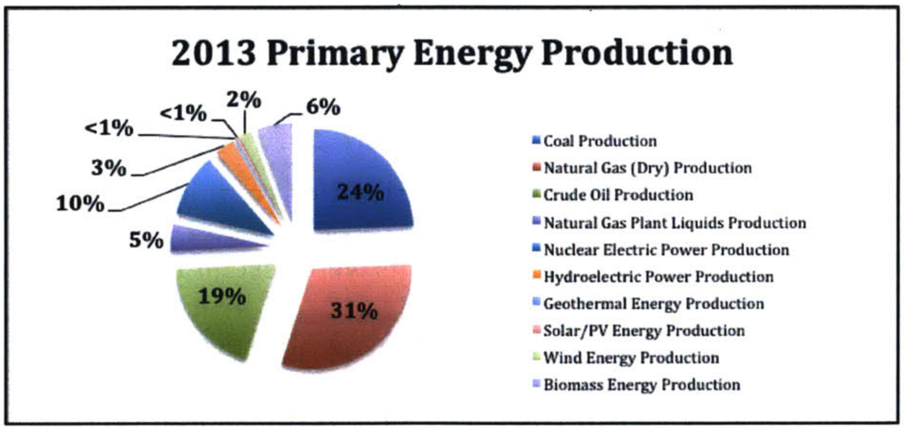


Figure 1: 2013 Primary Energy Production

Fossil fuels will continue to supply nearly 80% of the world's energy use through

2040. Renewable energy and nuclear power are the world's fastest-growing energy sources, each increasing 2.5% per year. These sources give rise to environmental and economic benefits such as no greenhouse gas emissions and reduced dependence on imported fuels. In 2012, the *Population Reference Bureau* reported that 6.85 billion people reside in developing countries (Haub, 2012), which account for some of the poorest populations in the world. These developing countries need energy independence because they already experience negative economic repercussions from sustained reliance on fossil fuels because of the inability to produce an alternative energy source.

Specifically, in Mexico, the need for an alternative energy source has increased because of insufficient economic progress due to its reliance on fossil fuels. Over the past 10 years, Mexico's oil production has been in a constant decline as shown in the Figure 2 (Yo, 2014).

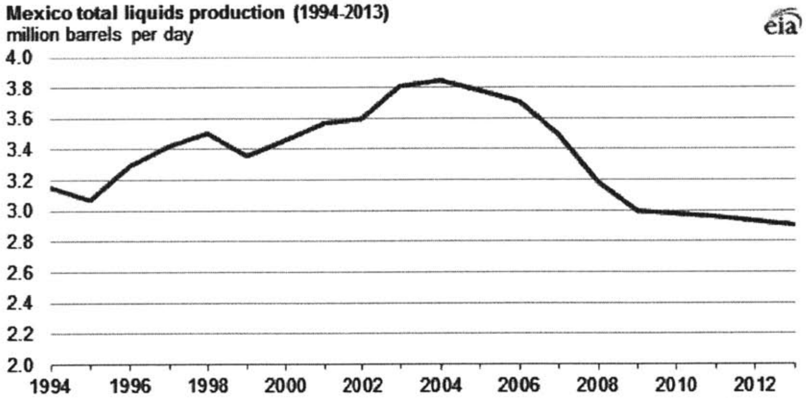


Figure 2: Mexico Total Liquids Production, 1994-2013 (Yo, 2014)

One potential solution to address the declining fossil fuels production in Mexico is the alternative fuel - biofuel.

Biofuel is created from a biomass conversion process, which converts vegetable and animal oils and fats into fuel. Biodiesel is one type of biofuel. It is an alternative fuel for diesel engines. Worldwide, biofuel production has increased. Biofuel in Mexico has been on an upward trajectory throughout the last decade, and soared 276.9% in 2013 over 2012 as shown in Figure 3 (*BP Statistical Review of World Energy*, 2014). This trajectory is in line with Mexico's desire to change the negative economic and environmental affects seen throughout the different communities. In addition, environmental awareness has been growing throughout Mexico as efforts are made to preserve water supply, improve air quality, increase renewable energy production, and protect endangered species (2014 Green Cities Campaign, 2014).

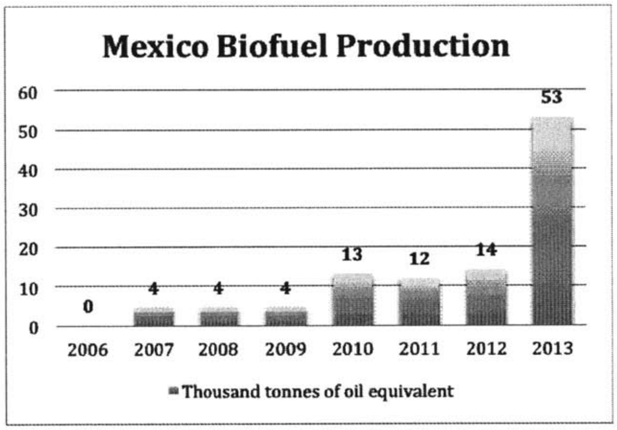


Figure 3: Mexico Biodiesel Production

As a result, the largest city in Mexico, Mexico City is moving toward a more improved international image. Research in Mexico has started to grow in the field of biofuels. The largest university in Mexico City, Universidad Nacional Autonoma de

Mexico has constructed a prototype facility to produce biodiesel from WVO collected from restaurants. This was done as an attempt to promote solutions around the economic and environmental crisis in Mexico. Consequently, a biodiesel company introduced in Mexico City directly benefits from the research efforts. More importantly, a company that is sustainable with financial stability improves the foundation of a successful business. Thus, a company's core competency increases with further understanding of its different business components, as well as the history of biodiesel, the design, and utility, which helps drive the sustainability and financial health.

Biofuels Background

Engines

Internal Combustion Engines have existed for over a century providing mechanical power and transportation. The diesel engine, developed by Rudolf Diesel, immediately differentiated itself from other engines. The diesel engine's performance was achieved by compressing air in a cylinder. Unlike gasoline engines, diesel engine's power was driven by pressure, which ignited the fuel as opposed to a spark. Typical diesel versus petrol engine data presented in the early 20th century showed diesel engines had a higher fuel to air mixture compression ratio, yielding larger amounts of power. Table 1 (Barry F. Wellington, 1995) shows specific diesel versus petrol engine performance data.

Table 1: Diesel vs. Petro Engine Performance

	Diesel Engine	Petrol Engine
Compression Ratio	14:1 to 24:1	7:1 to 10:1
Thermal Efficiency	35% to 43%	25% to 30%
RPM	2500 to 5000	4000 to 6000

Diesel engines found a place in several applications including industrial generators, large ships, locomotives, and trucks. These applications demonstrated the engine's advantages over the petrol combustion engine. A few highlights reported from the truck transportation industry include:

- Advantages are fuel-efficiency, engine torque, component longevity, and increased residual value.
- Disadvantages are engine horsepower, noise, higher engine price tag, and fuel cost per liter. (Autos.com Editor, 2013)

Fuel

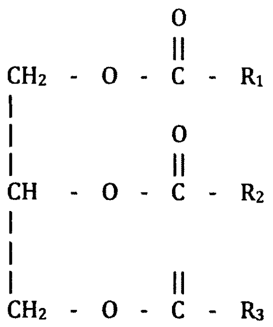
The evolution of the internal combustion engine gave rise to a variety of energy sources. Engines initially experimented with several diverse fuel options such as a mixture of coal dust and moss spores wood, peat, and several vegetable oils. In 1912, R. Diesel stated: "The use of vegetable oils for engine fuels may seem insignificant today. But such oils may become in the course of time as important as petroleum and the coal tar products of the present time" (F.D. Gunston, 2001). Today the most prominent transportation fuels are petrol/gasoline – mostly used in passenger vehicles and diesel – widely used in commercial transportation. However, just as Diesel predicted in 1912, the evolution continues with alternative fuels such as Liquid Petroleum (also known as propane) – clean fuel alternative to petroleum, Ethanol – biofuel alternative to gasoline, and Biodiesel – biofuel alternative to diesel can power many of the motor vehicles.

Biodiesel Evolution

The concept of using straight vegetable oil (SVO) was used in engine functionality tests during the early 1900s. G. Knothe and R. Dunn (2001), in *Biofuels Derived From Vegetable Oils And Fats* reference R. Diesel's statements to the French government about finding an abundant source of power that is also easily grown and cultivated in colonies, enabling a sustainable cycle for harnessing power. This concept, immediately met with barriers, from the French government stunt its continued exploration.

Common barriers, during the exploration of SVO are the high viscous chemical properties, reactivity to oxygen, and the high cloud point (Further barriers are outlined in the Appendix titled "Engine Fuel: Straight Vegetable Oil – Barriers to Usage."). In short-term operations, diesel engines using SVO provide satisfactory power and emissions performance. However, during long-term operations, usage of SVO can lead to engine functionality and durability deterioration. As a result, these barriers prevent SVO from becoming a viable energy solution; but innovations develop a functional and sustainable alternative energy source. Biodiesel fuel was an output of SVO, which provided superior long-term performance properties for diesel engines.

Unlike diesel fuel, a hydrocarbon (C_8-C_{25}) liquid fuel manufactured by fractional distillation from petroleum, biodiesel is the mono-alkyl esters of free fatty acids, converted from SVO or animal fat. The primary component of SVO, fats, or recycled restaurant grease is a triglyceride molecule. The chemical structure of a triglyceride molecule is shown below in Figure 4.



$$\begin{array}{lcccccc} & & & & O & & \\ & & & & \| & & \\ CH_2 & - & O & - & C & - & R_1 \\ | & & & & & & \\ | & & & & O & & \\ | & & & & \| & & \\ CH & - & O & - & C & - & R_2 \\ | & & & & & & \\ | & & & & & & \\ | & & & & \| & & \\ CH_2 & - & O & - & C & - & R_3 \end{array}$$

Figure 4: Triglyceride Molecule

Biodiesel Processing

Four chemical processes solve the high viscosity problem of triglycerides, a main component of SVO: dilution, microemulsification, pyrolysis (thermal cracking), and transesterification. The most commonly used chemical process to produce biodiesel is transesterification. It is the most economical process demanding low operating temperatures and pressures and producing a high conversion yield. Transesterification is the chemical process of reacting a triglyceride molecule plus excess alcohol in the presence of a catalyst to produce fatty esters and glycerol. The fatty ester molecules produced from the process are more commonly called biodiesel. The below Figure 5 shows the approximate stoichiometric transesterification reaction, a triglyceride molecule plus methanol converting to a fatty ester mixture and glycerol.

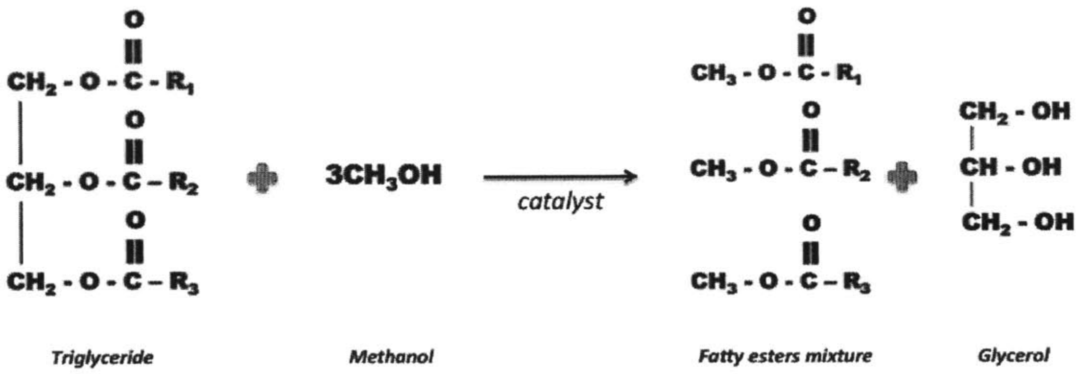


Figure 5: Transesterification Chemical Reaction

In this diagram, R1, R2, and R3 refer to the hydrocarbon chains of the fatty acyl group of the triglyceride; when methanol is used in the reaction, the fatty ester mixture yields methyl ester. The approximate biodiesel reaction ratios are shown in Table 2. The conversion shows a rough estimate of 1:1 feedstock to biodiesel. The chemical reaction is robust and produces a viable alternative fuel for engines.

Table 2: Biodiesel Production Stoichiometric Ratio

Triglyceride				Mixture		
Feedstock	+	Alcohol	->	Fatty Esters	+	Glycerol
100 kg of oil	+	10 kg of alcohol	->	100 kg of Biodiesel	+	10 kg of glycerol

Requirements, Standards and Specifications

After successful production, fuel performance and quality is monitored and maintained by proper standards. These standards allow customers to feel safe and satisfied about fuel usage during engine operation. Fuel characteristics are aligned with the designing and manufacturing of engines. These characteristics, within the United States follow the American Society for Testing and Materials (ASTM) but have also been adopted worldwide. Following standards authored by the ASTM assures customer will be provided high quality fuel and subsequently quality engine performance.

Diesel engines function with both diesel and biodiesel fuels and thus follow established, internationally recognized standards. First, the diesel fuel specification defines how to ensure satisfactory operational performance and function of the vehicle and engine. ASTM **D975 specification** follows seven grades of diesel fuel oils: Three Grades within Classification No. 1-D (S15, S500, S5000), Three Grades within No. 2-D (S15, S500, S5000), and One Grade No. 4-D. ASTM lists the following specifications, for fuel use in diesel engine applications, in the *Book of Standards Volume 05.01,* shown in Table 3 below:

Table 3: Diesel Fuel Specifications for Engine Application

<table>
<tr><th></th><th>Grade</th><th>Description</th></tr>
<tr><td colspan="3">A special-purpose, light middle distillate fuel for use in diesel engine applications requiring the following:</td></tr>
<tr><td>1</td><td>Grade No. 1-D S15</td><td>15 ppm sulfur (maximum)</td></tr>
<tr><td>2</td><td>Grade No. 1-D S500</td><td>500 ppm sulfur (maximum)</td></tr>
<tr><td>3</td><td>Grade No. 1-D S5000</td><td>5,000 ppm sulfur (maximum)</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td colspan="3">A general purpose, middle distillate fuel. Suitable for varying speed and load conditions for use in diesel engine applications requiring the following:</td></tr>
<tr><td>4</td><td>Grade No. 2-D S15</td><td>15 ppm sulfur (maximum)</td></tr>
<tr><td>5</td><td>Grade No. 2-D S500</td><td>500 ppm sulfur (maximum)</td></tr>
<tr><td>6</td><td>Grade No. 2-D S5000</td><td>5,000 ppm sulfur (maximum)</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td colspan="3">A heavy distillate fuel, or a blend of distillate and residual oil for use in the following applications involving predominantly constant speed and load:</td></tr>
<tr><td>7</td><td>Grade No. 4-D</td><td>Low- and Medium-speed diesel engines</td></tr>
</table>

Like diesel fuel, biodiesel is fully compatible with diesel engines and has its own recognized ASTM standards/specifications. Biodiesel does not have to be altered for engine function; therefore, this transparency provides increased benefits for biodiesel fuel adaption. It can be used as a 100% stand alone fuel (called B100) or a blend with standard diesel fuel in several ratios, the most common of which is B20 (20% biodiesel and 80% petroleum diesel). Common ASTM biodiesel specifications are D7467 for biodiesel blends 6%-20%, and D396 & D975 for blends of biodiesel 5% or under, and D6751 for B100. Thus, ASTM D6571 assures biodiesel has the following diesel engine functionality: ignition, proper energy discharge, appropriate density (energy/liter), low temperature operation, corrosion resistant, absence of particles that plug holes or cause wear, and safe for operating conditions. Testing against these ASTM specifications ensure a high quality product.

Mexico lacks a local biodiesel standard and uses the ASTM standard to certify any biodiesel-produced fuels. These requirements and specifications allow for structure and quality to facilitate the successful introduction of biodiesel fuel usage in existing and new diesel engines, in today's consumer and industrial markets. More importantly, the fuel specifications and standards integrated within a biodiesel company ensure the effective operations within a biodiesel fuel.

Chapter 2 Biofuel in Mexico

Introduction

For a new biodiesel company reassurance in the successful production of biodiesel can be globally seen in several models. The *International Energy Statistics,* shown below in Figure 6, presents Europe as well as Central & South America as the worlds leading producers of biodiesel.

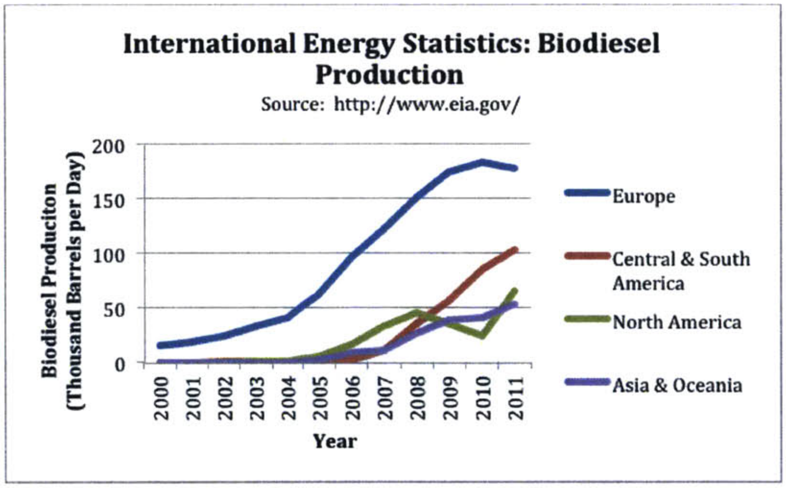


Figure 6: International Energy Statistics: Biodiesel Production

More specifically, the top 10-biodiesel producing countries are listed in Figure 7. The U.S. as well as EU and S.A. countries have legislation in place to promote subsidies to increase capacity and biodiesel production, which further improves the success of a companies operation.

However, countries without these subsidies or incentives have a hard time establishing a successful biodiesel business. Mexico is number 48, prior to 2007 had no legislation support for biodiesel production. Moreover, Mexico has not invested significant time or resources in the development of biodiesel to compete internationally. "In 2007 Mexico passed the Law on the Promotion and Development of Bioenergy, which purpose is to encourage the use and production of bioenergy as a key step to achieving national energy self-sufficiency and sustainable development." (Guerrero, 2008)

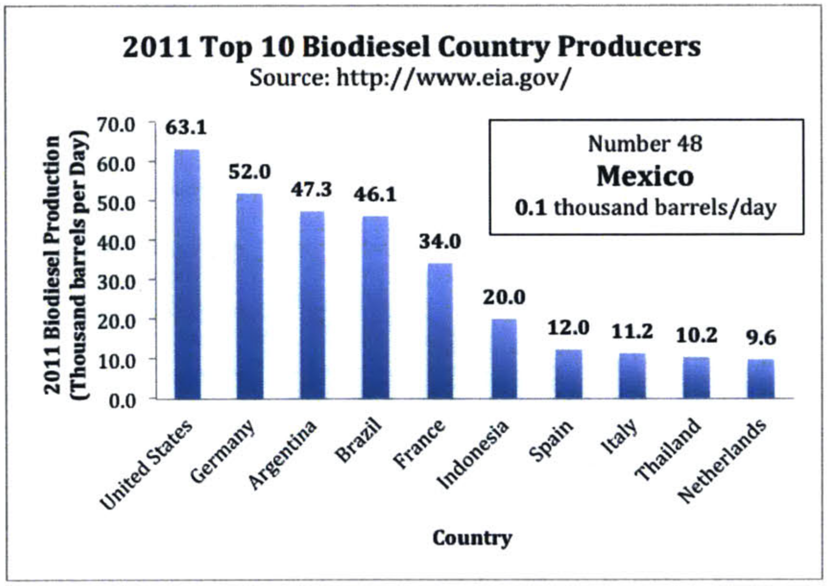


Figure 7: 2011 Top 10 Biodiesel Country Producers

The only Mexican petroleum company is *Petróleos Mexicanos*, also known as PEMEX. This state oil company is involved in the exploration, production, transportation, refining, storage and sale of fuel. But, no alternative fuels exist in this company's product portfolio. The primary products of Pemex are petrochemical, natural gas, liquid gas, sulphur, gasoline, kerosene, and diesel.

Mexico Legislation

PEMEX's Mexico monopoly on the oil and gas industry poses barriers to market entry of alternative fuel products, such as biodiesel. Raul Felix, coordinator of the Climate Change & Renewable Energy Practice in Mexico for Baker & McKenzie spoke about the agriculture ministry pushing to use bio blends beginning in 2010; but when PEMEX called for bids on supply no company provided a low enough price. This barrier forces businesses to design low cost operations in order to be competitive.

"In December 2013, Mexico's government approved constitutional amendments that would alter the 1938 nationalization of the energy sector, effectively ending the 75-year monopoly of state-owned Petróleos Mexicanos (Pemex) and allowing for more foreign investment in the oil sector." (U.S. Energy Information Administration, 2014) This policy does not specifically promote biodiesel but indicates some sensitivity to alternative energy. Discussed in an article by (Furlow, 2014), six takeaways from this new policy include:

1. It ends the Pemex monopoly and opens the upstream oil and gas sector to private investment and competition;
2. Introduces a new contractual framework in which private parties can be awarded exploration & production (E&P) contracts (licenses, production-sharing and profit-sharing contracts);
3. Allows joint ventures with Pemex;

4. Opens midstream and downstream to private sector participation;
5. Ends the ban on the "booking of reserves";
6. Exploration & Production Companies will be subject to Local Content Requirements.

The policy removes the constitutional limitations by allowing private businesses to participate in Mexico's upstream oil and gas industry through the granting of exploration and production (E&P) contracts or joint ventures with Pemex. This newly signed law by Mexican President Enrique Peña Nieto shows an acceptance of competition. It also provides opportunities and decreases barriers to market entry. Finally, a new biodiesel business has a landscape to design a scalable and sustainable value chain.

Chapter 3 Biodiesel Value Chain

Overview

A biodiesel business starts by understanding the value chain associated with its enterprise. This value chain analysis provides a framework that can optimize operational areas to improve efficiencies and financial health. Michael Porter, in his book *Competitive Advantage: Creating Sustaining Superior Performance* (1985) discusses value chains.

> 'The value chain analysis describes the activities the organization performs and links them to the organization's competitive position. Value chain analysis describes the activities within and around an organization, and relates them to an analysis of the competitive strength of the organization. Therefore, it evaluates which value each particular activity adds to the organization's products or services."
>
> (Dagmar Recklies, 2001)

The Michael Porter Value Chain framework differentiates among primary and supportive activities. **The primary activities** represent the development and supply of a product or service. They are Inbound Logistics, Operations, Outbound logistics, Marketing and sales, and Service. **The four main support activities are:** Procurement, Technology development, Human Resource Management, and Infrastructure (systems for planning, finance, quality, information management, etc.). These primary and support activities can be seen in the below Value Chain Model shown in Figure 8.

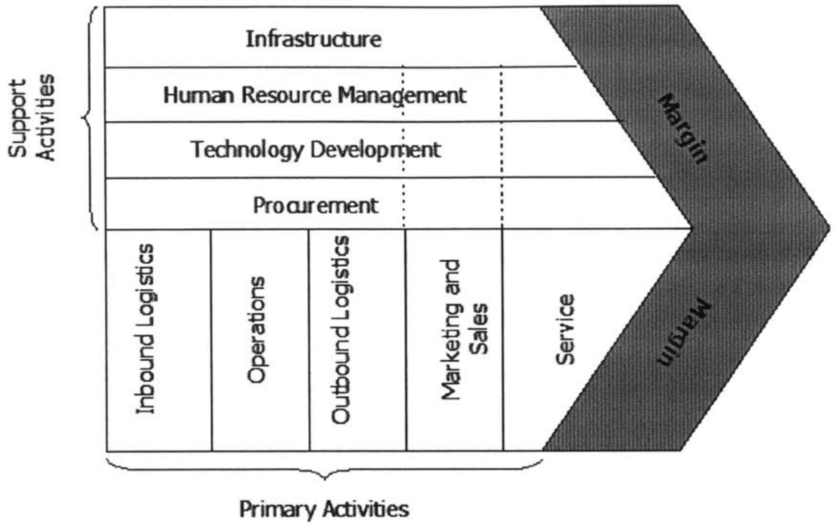


Figure 8: Basic Porter Value Chain Model; Source: (Dagmar Recklies)

A Biodiesel Value Chain in Mexico City

Mexico does not have a dominant biodiesel business framework. As a result, a model cannot be leveraged for a new biodiesel business that wants to create value by capturing market share and generating profitable operations. Porter's value chain concept is adapted to a biodiesel company that collects WVO in Mexico City. This adaptation provides the necessary structure during the development stages of a biodiesel business.

The primary activities in this value chain starts with the **Inbound Logistics.** Here, **Inbound Logistics** is the collection and storage of feedstock. Two main factors are considered when structuring the logistics component: the number of suppliers per production facility and the average distance between supplier and production facility. Also there are several collection and delivery strategies that can be implemented for collecting feedstock. The different strategies are direct collection from suppliers, direct delivery (supplier to production facility), and Milk-Run supplier collection. Each strategy has their own benefits, but for the purposes of this thesis, we will focus on a milk-run supplier collection strategy, where routes are designed based on customer demand. This approach is also commonly done at less than truckload (LTL), which does not require a full truck trailer.

Mexico City has a road network with common big-city transport problems. Some of the several problems described in (Turblog, 2011) are listed below:

- Jammed roadways
- Insufficient and poor quality public passenger transport, which motivates individuals to have their own vehicle.
- Long journey times
- 24-hour "peak hour"
- Air stagnation, thermal inversion, radiation, and ozone problems.

These problems are pervasive throughout urban densely populated cities and effect the performance of collection. Vehicle travel speeds and wait times are primary effects that result in optimal **Inbound Logistic** performance. After **Inbound Logistics** is complete, feedstock can be sent to the operations department.

Next is **Operations**, the production process. This segment processes the feedstock into a customer, valued product. Other critical areas within the **Operations segment** are production facility location, equipment for feedstock processing, labor, and overall system processes including quality control and continuous improvement.

The third component of this value chain is **Outbound Logistics**, the distribution of a product to the end user customers. The main goals for this segment start with increased efficiency, which decreases potential inventory and overhead cost. Next goal is increased sales. Managing storage levels and timely shipments allows for optimized sales and capturing existing or future product orders. Finally, better relationships are enables the transportation of products is the last interaction with the customer, which ensures a positive business relationship.

The last value chain activity is **Marketing, Sales and Service**, which guide the development of products and services. It establishes, who and where to sell the product, along with price setting. Lastly, service ensures that customers are happy, to prevent business losses. These value chain components provide the necessary framework to further emphasize the necessary segments of a new or growing business.

A Mexico City Biodiesel Start Up Company

Strategically, a new biodiesel company has many business areas that are important to develop. Each value chain segment is a viable area to develop the business for optimal profitability potential. Before, a company invests precious capital and resources, it should develop a strategic approach for what business segment is most valuable to understand and solve.

Chapter 4 Designing a Biodiesel Supply Chain

Overview

Strategically, a new biodiesel company has many business areas that are important to develop. Each value chain segment is a viable area to develop the business for optimal profitability potential. Before, a company invests precious capital and resources it should develop a strategic approach on what is most valuable to understand and solve. Common questions a company can ask to assist in the development of a strategic approach are listed in Bill Aulet's book, *Discipline Entrepreneurship*. The main questions outlined in (Aulet, 2013) are who is your customer, what can you do for your customer, how does your customer acquire your product, how do you make money off your product, how do you design and building your product, and how do you scale your business? These questions align a biodiesel business to ensure thoroughness is taken throughout the value chain. Thus focusing on these questions prompts necessary data to be collected around suppliers, customers, and production.

A Biodiesel Company's Market Opportunity in Mexico City

Mexico City has approximately 21 million residents, 5 million vehicles, 50,000 industrial plants and it is continually growing (GARCÍA, 2013). It is also host to approximately 39,000 restaurants (Instituto Nacional de Estadística y Geografía , 2011) and 38,000 diesel buses owned by the private and public sector (Secretaría de Comunicaciones y Transportes, 2013). These local factors demonstrate that there is a prime target market opportunity for biodiesel in Mexico City given the large quantity of restaurants that use vegetable oil, in relation to biodiesel-capable vehicles, which is a large customer base - the public and private bus transportation industry.

A Biodiesel Company's Feedstock in Mexico City

There are two biodiesel feedstocks predominantly considered for a newly established biodiesel company: the availability of agricultural feedstock and restaurant waste vegetable oil (WVO). Agricultural feedstock options such as soybean, rapeseed, sunflower, corn, safflower, cottonseed, peanut, and tallow have been studied and used in many countries because those options support production of an abundant amount of feedstock. However, these feedstock options are costly because of their effect on food prices, the energy density, the acreage of land that must be devoted to the feedstock, and the costs required to grow and process the feedstock.

Alternatively, restaurants and other cooking establishments frequently dispose of WVO making it a viable source for biodiesel production. New York City (NYC), New York, USA, one of the largest cities in the U.S., has several policies to address and manage WVO. In fact, "Improper disposal of WVO violates New York City's Sewer Use Regulations and carries monetary penalties of up to $10,000 per violation." (New York Times, 2008) Also, NYC has a *New York City Commercial Fats, Oil and Grease (FOG) Program* designed to help restaurants and other food service establishments with the approved handling and disposal of FOG. In contract however, Mexico presents an especially viable case for the use of WVO because of the absence of regulations and laws addressing waste oil collection or city sewage standards. In Mexico City, no regulations, ordinances, or programs that manage or eliminate the improper discharge of WVO. Thus, WVO collection for a biodiesel company in Mexico City provides an opportunity to capture value through the availability of a plentiful low-cost feedstock.

A Biodiesel Company's Production in Mexico City

Earlier, transesterification was discussed, which is the chemical reaction of converting triglyceride molecules into biodiesel. The process uses existing, mature technology to create the final product through a production process. There are two types of biodiesel production processes: Batch & Continuous. Batch processing utilizes a finite quantity of feedstock over a limited time. In contrast, continuous processing allows the feedstock to be sent continuously through a series of equipment that individually performs a single operation, over potentially an infinite amount of time. The use of a continuous process enables the reduction of time and cost, thereby, optimizing the production yield quantities and company profits. Time and cost are primarily reduced by large quantities of feedstock, continuous operation, which is driven by a more automated setup, and lower labor costs because more fuel can be produced per unit of labor. On the other hand, the use of a batch process enables flexibility. This process provides the opportunity of same equipment usage, seasonal operational patterns, smaller feedstock quantities, and better control over processing parameters. For a new biodiesel company, establishing a foundation in Mexico City, batch processing is most advantageous.

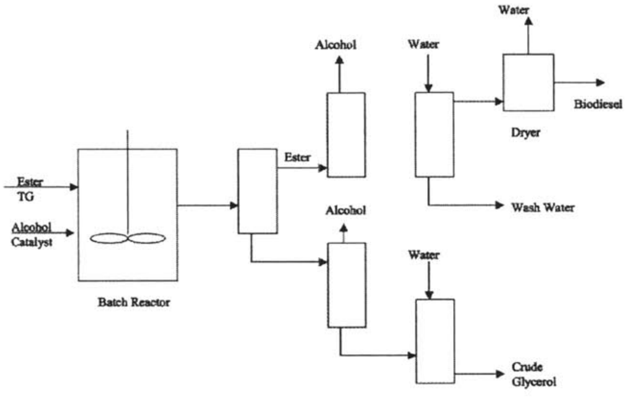


Figure 8: Biodiesel Batch Process Flow Diagram; (Van, 2006)

It allows the most benefit for collecting small quantities of feedstock. Also, it provides less capital cost due to large process and automated equipment. Batch processing is more labor intensive but without feedstock you will not able to extract the necessary value from the continuous operation. The process flow diagram in Figure 9 depicts a batch process commonly used to produce biodiesel. The flow diagram shows a feedstock called Ester or WVO entering into a batch reactor along with alcohol and a catalyst. Through several separation processes, biodiesel and glycerol emerge as the final products. Nonetheless, these steps provide context on creating value when collected WVO is returned to the main production facility.

A Biodiesel Company's Distribution & Sales in Mexico City

Relationships are the major contributor in building a distribution channel for sales to the end consumer. As a model, in the U.S., biodiesel distribution has followed the same model as the petroleum fuel industry. Producers connect with third party distribution companies, providing a wholesale product that in turn is bought by customers. This model enables high volume sales but limits customer interaction. In Mexico, building a customer base is rooted in relationships and leveraging the existing distribution infrastructure. This customer base is essential for business growth and long-term financial sustainability.

In Mexico City however, the diesel buses, owned by the private and public sector are the primary target market – end user customers and currently have no dominant infrastructure available for the delivery of biodiesel. Single or multiple pumping stations are not available, so designing a distribution channel is essential for the delivery and customer acquisition.

One proposal is to mix and fill biodiesel at the bus depot facility, allowing an initial benefit of low capital investment due to avoiding the construction of fuel pumping stations. Another proposal, as sales volume increases, leveraging the existing petro-fuel infrastructure will enable more efficient distribution. Currently, either mixing on-site or constructing a fuel pumping station would be two primary distribution options but further research needs to be explored within Mexico.

A Biodiesel Company's Market Place Position

A biodiesel company exists in a two-sided market. The first are the producers of WVO (i.e. restaurants and other establishments) and the second, consumers (public & private bus industry) that buy biodiesel. "Broadly speaking, a two-sided market is one in which two sets of agents interact through an intermediary or platform and the decisions of each set of agents affects the outcomes of the other set of agents, typically through an externality." (Rysman, 2009) Thus, the ability to increase the supply of WVO will directly affect a businesses ability to provide biodiesel to customers. However, when optimizing a two-sided enterprise, between restaurants and consumers, a new biodiesel business's resources can be constrained and performance can be hindered resulting in financial losses. Thus, selecting one side to focus on optimizes resources, timing, and finances.

An economic assessment of a biodiesel company provides data to select the primary side a business should focus on to optimize performance. Several articles such as (Demirbas, 2008; Perimenis, 2011; Radich, 2004; Silvio Francisco dos Santos, 2014) have analyzed the cost components of a biodiesel business and have found that the **Inbound Logistics** segment within the value chain provides the optimal performance and long-term benefits. As a result, focusing on the collection of WVO throughout Mexico City will be the primary focus in order to achieve an optimal approach to collecting WVO and beneficial financial performance to operating a business.

Chapter 5 Data Collection & Analysis

Logistics Theory

Approaches used to solve the traveling salesman problem (TSP) can be used to design biodiesel collection in Mexico. The TSP is a sequencing problem, which sequences through restaurants back to the original depot location. The demands at each stop are fixed and known. However, the TSP is a particular case of the VRP, where the quantity of vehicles is one, there is only one route, and the capacity of the vehicles is infinite. Several restaurant collection sites and one central facility location present a classic vehicle routing problem (VRP). The VRP will encompass identifying a group of vehicle routs with minimized cost. It will be modeled such that first, each route starts and ends at the production depot, second, each restaurant is visited only once by one vehicle, third, total demand per route does not exceed vehicle capacity, fourth, total time duration does not exceed specified time limits, and fifth, the total transportation cost is minimized.

This thesis will focus on a VRP one-to-many collection method. A good approximation in calculating the VRP distance in a one-to-many system is referenced from Figliozzi (2008b) in the equation: $\text{VRP}(n) \approx \text{k}\frac{n-m}{n} * \sqrt{An} + m2r$.

Where,

- A = Area of a cluster
- n = number of restaurant stops in a cluster
- m = number of routes

- $\delta = density$ (Number of stops per area)
- $k = VRP\ network\ factors$

The major difference with a VRP approach is the introduction of stochastic demand at each restaurant stop. The above approximation equation allows for a good initial analysis with minimal data collection. This method, however, with the complexity of stochastic demand, needs a stronger model to perform the necessary calculations. Thus, TransCAD software is used for modeling and analyzing the related VRP problem.

TransCAD Modeling Software

In this study, TransCAD software is used to analyze the VRP. TransCAD is the first and only Geographic Information System (GIS) created to store, present, manage, and analyze transportation data. The software also integrates in a single platform GIS and transportation modeling capabilities. Adopted from the *The Routing and Logistics with TransCAD Users' Guide, the following* procedure was used to obtain the data for modeling and analyzing the vehicle routing problem:

- Prepare Depot (biodiesel production facility) and Restaurant Stop Data
- Create a vehicle routing matrix
- Create a vehicle table
- Solve the vehicle routing problem

Depot and Restaurant Stop Data Overview

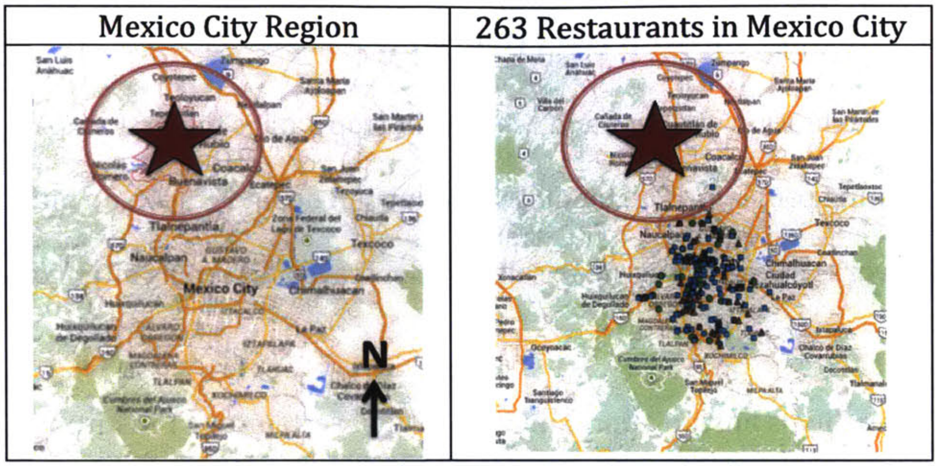
The preparation of depot and restaurant stop data is the first step to solving a vehicle routing problem. The biodiesel production depot is the main hub of the routing network. The depot is where all vehicles leave and return after collecting WVO.

Mexico City is host to approximately 39,000 restaurants (Instituto Nacional de Estadística y Geografía , 2011). These consist of small street vendors as well as major international franchise enterprises. For the purposes of this study, a collection of random restaurant franchises were selected and mapped through editing specific geographic information systems (GIS) data available in the I*nstituto Nacional de Estadística y Geografía* (INEGI) database. This data provided specific latitude and longitude location information. The restaurants were filtered down to 263 locations with the following segmentation for stops listed in Table 4.

Table 4: WVO Restaurants and Quantities

Restaurant Description	**Restaurant Quantities**	**Color Key**
Restaurant Group 1	42	Green
Restaurant Group 2	68	Orange
Restaurant Group 3	44	Red
Restaurant Group 4	12	Yellow
Restaurant Group 5	97	Purple
Total	**263**	

The biodiesel production (depot) is located by a red star and restaurants are distributed throughout the Mexico City region, as seen in Figure 10.


Mexico City Region

263 Restaurants in Mexico City

Figure 9: GIS Located Restaurant Stops in Mexico City

The main production depot processes WVO collected weekly (7 day week) from the 263 restaurants scattered throughout the Mexico City region. Finalizing the design layers for the depot and restaurant stops saw the following input fields identified and populated:

Table 5: Depot Operating Time

Depot		
Input Field	Description	Time
Opening Time	Earliest time vehicles can be dispatched from the depot	0:00
Close Time	Latest time that vehicles can return to the depot	24:00

The depot has a time window of 24-hours because the facility will operate on a 24-hour biodiesel batch process production schedule. This allows for the collected WVO to be processed without delays within the operations.

Table 6: Restaurant Operating Time

Restaurant Stops		
Input Field	Description	Time (military format)
Open Time	Earliest time vehicles can be dispatched	08:00
Close Time	Latest time that a stop can be serviced	18:00

WVO Collection Volume

The quantity of waste vegetable oil produced by Mexican franchise restaurants is proprietary information and treated as a company's competitive knowledge. As a result, the Mexican demand used in the analysis was adopted from an interview with Daniel Camacho Gonzalez, CEO of Transforma Industries, a Mexican energy company, in December 2014. They found that on average restaurants produce approximately 18 liters per month. To present a realistic representation of the stochastic nature of restaurant WVO production, a Normal (Gaussian) distribution was used.

The normal distribution's first quartile in Table 7 shows no WVO production represents the poor practices of restaurants in Mexico City, which involves selling oil to illegal business enterprises. A black market is a major threat to a biodiesel business and a major deterrent to the establishment of a scalable biodiesel business. In Mexico City, illegal businesses collect WVO from restaurants, filter impurities, and resell the filtered WVO for usage in restaurants. Other common practices that affect the volume of WVO collected include re-using cooking oil beyond safe food standards or dumping the oil into sewers.

This lack of WVO production from restaurants presents a limitation to the TransCAD software because it cannot model restaurants with zero demand. So, in order to capture the real nature of the potential for collection in Mexico City these restaurants were assigned a value of 0.07L's representing the absences of WVO produced during a seven-day time period. This provides a scenario where vehicles need to make a stop but will not be allotted significant time or capacity due to no available supply or demand.

Table 7 shows 263 restaurants producing an average of 4.62L of WVO per day with a standard deviation of 5L at a total collection demand capacity of 1214L.

Table 7: WVO Volume Distribution over 263 Restaurants

Statistics

Variable	N	Mean	SE Mean	StDev	Sum	Minimum	Q1	Median	Q3	Maximum	Range
Demand	263	4.616	0.31	5.05	1214.08	0.07	0.07	2.80	7.91	24.78	24.71

This distribution of data was used in populating the TransCAD input field for restaurant demand.

Service Time

The range of fixed service time from 6-27 minutes represents the monitoring, with a stopwatch, of a normal worker getting out of a vehicle and collecting WVO. The minimum limit of six minutes represents a person leaving the collection vehicle and affirming zero WVO to collect. The maximum limit of 27 minutes represents a person leaving the collection vehicle, assessing quantity of WVO to collect, retrieving the WVO, and leaving the premises.

Equation 1 represents the amount of time it takes to service a stop:

Equation 1

$$Service\ time\ =\ (fixed\ time) +\ (number\ of\ units) x\ (time\ per\ unit)$$

Service time is a variable component in managing the routing to collect WVO. Rarely is service time constant due to many variables, including, different quantities of WVO available for pick up, lack of a loading dock, and location of WVO container on the restaurants premises. The variable Fixed Time is represented in the following histogram, mapped over 263 restaurants:

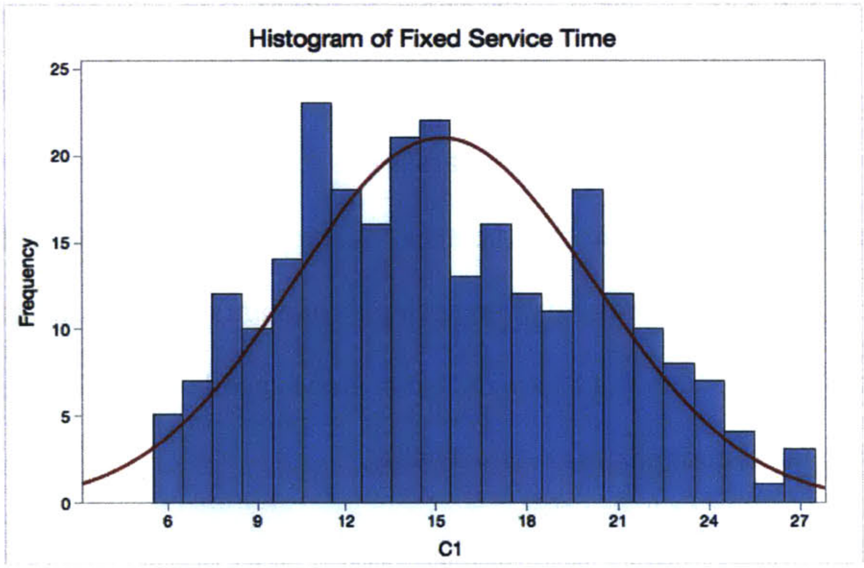


Figure 10: Histogram of Service Time

The time per unit element follows a normal distribution curve with the following descriptive statistics:

Descriptive Statistics

N	Mean	StDev	Minimum	Maximum
263	0.447217	0.102774	0.155871191	0.719177181

Both sample sizes of data were used to perform a stochastic approach to evaluate a company's collection vehicle service time operating pattern.

Vehicle Routing Matrix

The vehicle routing matrix comprises of the distance and travel times between each depot and restaurants. Distances and times were computed using a straight-line method between restaurants. Transcad uses a straight-line method to calculate the distances between points and a circuity factor of 1.3. Travel times between points were assessed between city and highway driving.

Mexico City has a road network with common big-city transport problems. Several problems such as jammed roadways and long journey times result in poor vehicle travel speeds. "Speed limits for cars are as follows: main roads, 70 km/h and pedestrian zones, 20 km/h, and built up areas, 40 km/h." (AngloINFO, 2014) Thus, for this model, the travel times between each pair of points is estimated at an approximate speed of 30 mph (48 km/h); an average speed of mixed minimal highway commuting and maximum city driving.

Vehicle Information Table

Trucks, with a fixed capacity leave the depot, travel to restaurants, and return to the main depot for WVO conversion into biodiesel fuel. The vehicle information table contains the necessary information about the fleet of vehicles available at the depot that are dispatched for WVO collection in table XX.

Physical dimensions and total restaurant demand drive truck selection. This study looked at three types of vehicles: Ford Transit, Ford Transit Connect, and the

Nissan Compact. Due to cost, size, and capacity the Ford Transit Connect was identified as the optimal vehicle for collecting WVO.

Table 8: Vehicle

Vehicle Truck Type	Capacity (L)	Wheelbase Size (m)	Vehicle Cost
Ford Transit	6994	3.3	$29, 735
Ford Transit Connect	**1134**	**2.6**	**$22, 075**
Nissan Compact	2268	2.9	$20, 720

Total Restaurant demand is 1214 L per 7-day week as shown in Table 7 with 1134 L capacity is a good fit for the Ford Transit Connect. The Ford Connect has 93% total demand capacity utilization versus the Ford Transit with 576%. The larger capacity of the Ford Transit would be wasteful based on the available restaurant demand landscape represented in the model. Furthermore, each vehicle carries 60-liter UN polycompsite (reduced top for stacking) drums, which account for the 1134 L total volume contained in each vehicle.

Table 9: Vehicle Input Field Description

Input Field	Description	Input
Capacity	Capacity of vehicle	*1134 L*
Number of Vehicles	Quantity of vehicles at the depot	*Variable*
Cost	Purchase Cost of each vehicle	*$22, 075*

The drums allow for easy storage and transport of WVO. Each collection stop is very different due to loading dock design, quantity of WVO, and pick up location. The restaurant decants old oil into the same containers the WVO was originally delivered in. The collection containers hold approximately 20 liters.

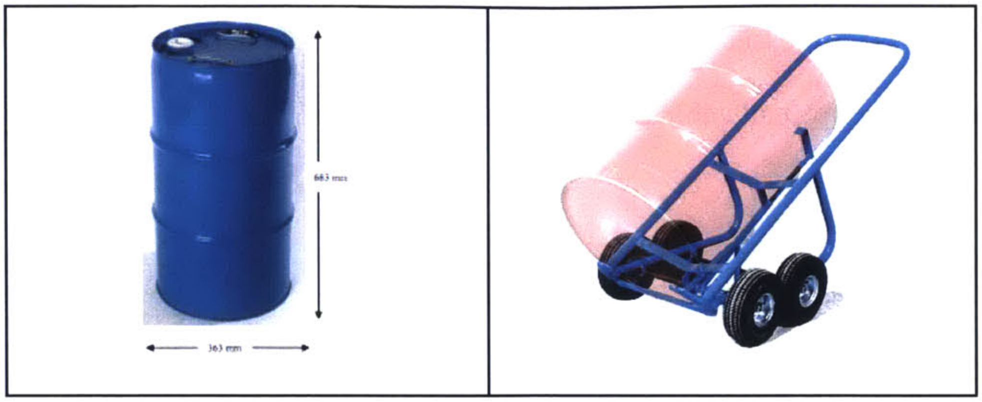


Figure 11: 60L UN Polycompsite Drum and Truck Drum Carrier, (Interstate Products, Inc, 2015)

The drum will be transported to and from the collection vehicles depending on the quantity of WVO. The model is designed to service demand greater than 1 L of WVO.

Cluster Analysis

Collecting WVO from 263 restaurants dispersed throughout Mexico City is a complex task. Clustering is a strategic way to create homogeneity for optimal logistic operations to improve WVO collection results. Clustering enables increased collection speeds through close proximity of restaurants and improved supplier relationships due to improved information flow or knowledge sharing. If clustering were not an option, the approach to collecting WVO would create waste in terms of vehicle fleet size selection, vehicle travel time per distance, and vehicle utilization.

The most common approaches to cluster design are hierarchical, partitioning/k-means, and two-step clustering. A hierarchical clustering method was used to determine homogeneous groups. The final cluster analysis steps, based on (Sarstedt, 2011) are as follows:

1. Select clustering variable: Distance
2. Select a clustering method: Hierarchical, Partitioning, or two step
3. Hierarchical Method
4. Choose a measure of homogeneity
5. Choose a clustering algorithm
6. Select an appropriate number of clusters
7. Validate and interpret the cluster solution

A hierarchical method with distance as the similarity characteristic was chosen for the clustering algorithm. Distance was calculated from the GIS longitudinal and latitudinal data through the following Haversine Equation based on the following formulas from (Veness, 2007; C. A. Cassa, 2005) as shown in Table 10.

Table 10: *Haversine* Distance Equations

$$a = \sin^2(\Delta lat/2) + \cos(lat1)*\cos(lat2)*\sin^2(\Delta long/2) \tag{2}$$

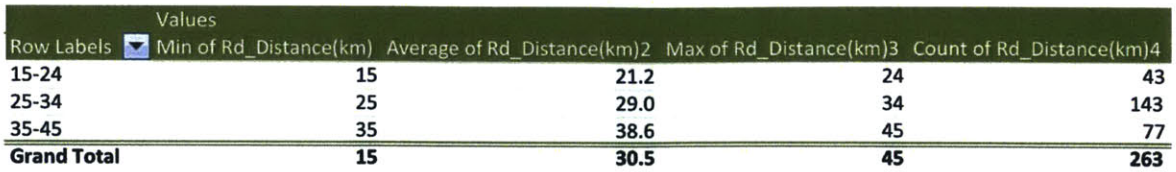
$$c = 2*atan2(\sqrt{a}, \sqrt{(1-a)}) \tag{3}$$

$$d = R*c, \tag{4}$$

Where d is the distance and R is the Earth's Radius.

Next, a hierarchal grouping function was used to differentiate restaurant locations. A three and four cluster approach was chosen to model the VRP. First, the three-cluster approach shown in Table 11 was used to segment the restaurants into three groups totaling 43, 143, and 77, respectively.

Table 11: Three-Cluster Approach



Row Labels	Values Min of Rd_Distance(km)	Average of Rd_Distance(km)2	Max of Rd_Distance(km)3	Count of Rd_Distance(km)4
15-24	15	21.2	24	43
25-34	25	29.0	34	143
35-45	35	38.6	45	77
Grand Total	**15**	**30.5**	**45**	**263**

In Figure 13, the depot is positioned at the red "X" and the three restaurant clusters are color coded blue, green, and brown.

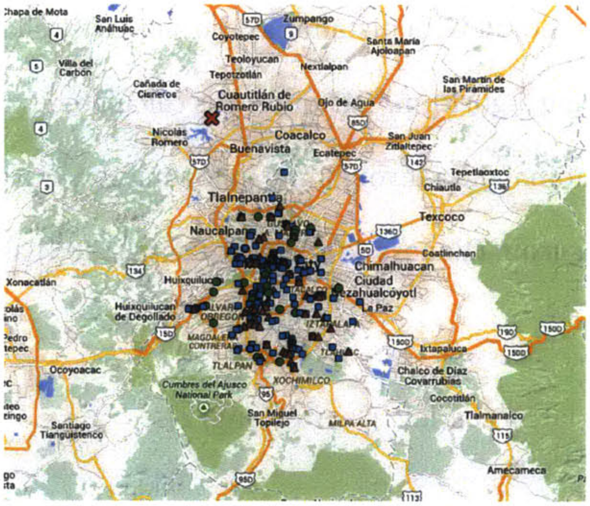
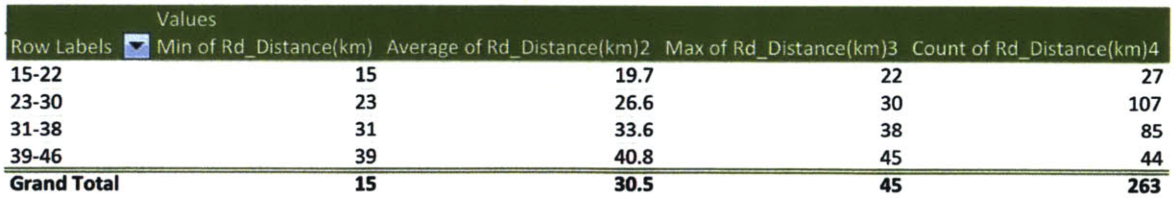


Figure 12: Three Cluster Graphical Representation

Second, the four-cluster approach shown in Table 12 was used to segment the restaurants into four groups totaling 27, 107, 85, and 44, respectively.

Table 12: Four-Cluster Approach



Row Labels	Values Min of Rd_Distance(km)	Average of Rd_Distance(km)2	Max of Rd_Distance(km)3	Count of Rd_Distance(km)4
15-22	15	19.7	22	27
23-30	23	26.6	30	107
31-38	31	33.6	38	85
39-46	39	40.8	45	44
Grand Total	**15**	**30.5**	**45**	**263**

In Figure 14, the depot is positioned at the red "X" and the four restaurant clusters are color coded blue, red, grey, and brown. Lastly, in both table 11 and 12, Rd stands for Restaurant distribution and the last column identifies the number of restaurants that will be serviced per each cluster.

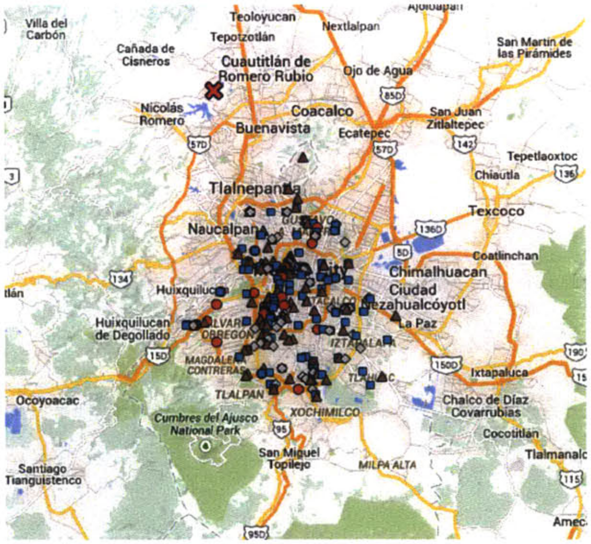


Figure 13: Four Cluster Graphical Representation

Total Transportation Cost

Transportation costs are a major component of logistic operations. Many variables such as new technology, increased fuel prices, and costly vehicle parts all generate critical decisions about the financial performance of a business. Truck costs are categorized into fixed and variable costs, which make up each scenario's total transportation cost. The fixed costs include capital recovery (interest and depreciation), insurance, and licenses, which do not vary regardless of the truck usage. The variable costs include repair and maintenance, tires, fuel, and labor, which vary directly with truck usage. The final transportation cost assessment was based on William Edwards Cost model developed at Iowa State University (Edwards, 2009). Please see thesis appendix title "Total Transportation Cost Scenario Assessment" for further details.

Chapter 6 Discussion

The data presented so far has been modeled in TransCAD to deliver three primary scenarios. Each scenario has been separated into the following categories: *No Clustering/Random, Three Clusters,* and *Four Clusters.* The *No Clustering/Random* scenario looks at vehicles stopping at all restaurants with no directed approach to their route. This scenario was the baseline look at collecting WVO from restaurants. On the other hand, the *Three* and *Four Cluster* scenarios used distance as a shared characteristic among the restaurants to identify homogenous groups. Each scenario provides insight on optimal performance and trade offs culminating in a financial logistics assessment.

After modeling the data, the results provided will be expressed in a few critical performance categories for each scenario. These categories, listed below will provide the necessary insight in analyzing the VRP in order to make the best strategic business decision for a biodiesel supply chain system.

Performance Metrics

- Time
- Distance
- Number of Vehicles
- Vehicle operating time
- Total transportation cost

Constant variables were used throughout each scenario. Table 13 shows each variable as it was defined in the model: one production facility to process WVO, 236 restaurants that produce in total 1214 L of WVO, and the Ford Transit Connect that has a capacity of 1134 L.

Table 13 Scenario Constant Variables

Description	Quantity
Number of Depots	1
Number of Restaurant Stops	263
Total WVO demand serviced	1214 L
Vehicle Capacity	1134 L

Each model was run under the assumption that vehicle capacity is sufficiently maximized to handle pick up of WVO demand. The performance results from the three scenarios are shown below in Table 14.

Table 14 Scenario Results

Scenarios	Random	3 Clusters	4 Clusters
Vehicle Capacity (L)	1134	1134	1134
Total Demand (L)	1214	1214	1214
Total Time (min)	4646	4731	4585
Total Travel Time	561	647	514
Total Distance (miles)	1121	1214	1026
Vehicle Utility	13%	11%	11%
Number of Vehicles	8	9	9

The model showed that given certain time constraints the cumulative demand per route might exceed the vehicle's capacity, and if this occurs, the route is deemed infeasible because the vehicle cannot collect the WVO at the next restaurant on the traveling path. Consequently, route iterations that were deemed infeasible resulted in an increase in vehicle fleet size and the fleet size increased until all demand was picked up and returned to the production facility.

Highlighting the above specific results in Table 14, the *Random Scenario* shows 8 vehicles in its fleet while the cluster scenarios utilized 9 vehicles for collecting WVO. Time and distance are significantly different depending on the scenarios. Scenario *Random* has the least amount of vehicles but scenario *4-Clusters* has the smallest operating time and distance traveled. Data was modeled within each scenario to uncover the individual, per vehicle, operating time. This shows, the significance, time has as a value added component.

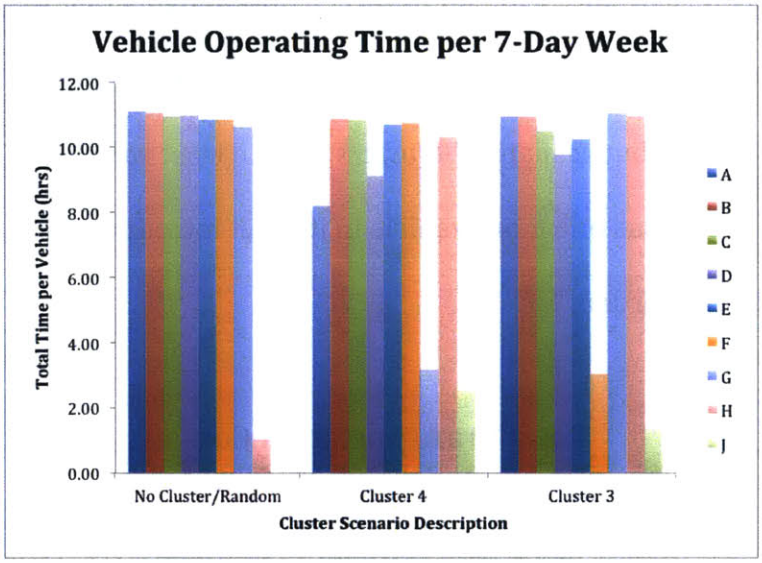


Figure 14: Vehicle Operating time per 7-day Week

Figure 17, titled, "Vehicle Operating Time per 7-Day Week" shows eight vehicles listed as letters A, B, C, D, E, F, G, H, J. Each vehicle has a respective operating time for collecting WVO per each scenario. Scenario *Random* has a higher statistical total mean time per vehicle at 9.7 hrs. +/- 3.5hrs. Scenario *4-Clusters* has a lower statistical total mean time per vehicle at 8.5 hrs. +/- 3.3hrs. The lower mean time per vehicle shows 4-cluster has the optimal vehicle fleet time usage.

Managing the optimization of vehicle fleet time usage can generate manpower and vehicle scheduling benefits. Manpower would be balanced between eight working hours and overtime working hours (any hour over eight working hours). Also, vehicle scheduling can be optimized due to vehicles that finish their routes early as seen in the *4-Cluster* scenario. These variables can generate new business decisions for optimization of variable cost.

Last, in Figure 16, "Total Transportation Cost" data shows each scenario's fix, variable, and total transportation cost. In this study, the financial assessment can provide the most insight for a new biodiesel startup company that typically has limited resources. The below figure shows scenario *Random* with the least fix cost due to one less vehicle but scenario *4-Clusters* has the least variable cost. However, the *4-Cluster* scenario has one more vehicle in its fleet introducing a larger upfront financial investment burden.

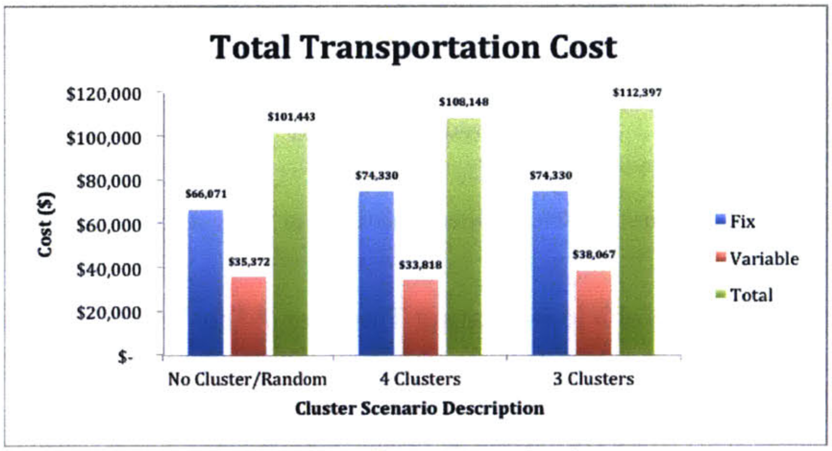


Figure 15 Total Transportation Cost

Nevertheless, for long-term operation, the smaller variable cost in *4-Clusters* will provide an advantage over the other scenarios because of the cost dependence on WVO demand. WVO collection is uncertain and initial growth for a start up company will be slow. Thus, demand fluctuations will result in a company benefiting from low variable costs by optimizing risk and saving cost.

Scenario *Random* will always have the best total transportation cost due to the lower fixed cost of one less vehicle versus the cluster scenarios. The introduction of clusters, however, for a business perspective has a few benefits:

- More vehicles but less hours of operating time
- Specialization - help create better relationships with the customers
- More reasonable operation schedule during the day
- Geographically better to manage urban city traffic

These benefits translate into added value for a strategic approach to collecting WVO. Consequently, a business will need to understand their financial health, before implementing a *Random* versus *Clustering* scenario supply chain, design strategy. For a start up enterprise, the *4-Cluster* scenario is most advantageous because if provides more benefits for long-term value appropriation than the other two scenarios.

Chapter 7 Conclusions

Operational excellence was a key goal for designing a biodiesel supply chain. Objectives of collecting Depot (biodiesel production facility) and Restaurant Stop data, creating a vehicle routing matrix, creating a vehicle table, and solving the vehicle routing problem, all established the foundation for modeling the necessary three scenarios for analysis.

This thesis explored the vehicle routing problem positioned in Mexico City. In conclusion, the three scenarios of random/no clusters, three clusters, and four clusters collection strategies were observed. The optimal scenario chosen was the *4-Cluster* scenario. Financially, It provided a marginal increase in fix cost but lower variable cost and due to clustering has the potential for leveraging qualitative benefits such as improved customer service and urban traffic navigation.

Assumptions and Limitations

Assumptions were used in calculating the total transportation cost: licenses, insurance, truck repair, tires, and salvage value. These costs were based within a USA context and not specifically Mexico City, Mx. Also, less than 5 data points were taken to collect time study data for service time calculations.

A limitation was the design of central pick up locations designed within each established cluster. The TransCAD software was limited to designing specific depots within each established cluster. Thus, this limitation could not create a central pick up location to generate fewer actual stops optimizing time, distance and total transportation cost.

Chapter 8 Further Research

Research that can further the analysis would be to create a vehicle routing origin-destination (OD) matrix based on a network method. This method is generated from the actual cities road network and stop nodes from a GIS file. It captures the most accurate distance and time values traveled on a street network between any two points, taking into account such constraints as speed limits, directional attributes of streets, and accurate road segment distances. Also, design a collection ecosystem with one major depot that provides a line haul to the individual central pickup locations within a cluster of stops. This will allow the opportunity for greater logistic performance. Lastly, collect customer feedback in Mexico City to validate the TransCAD model in areas of service time and WVO demand.

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Appendix

Total Transportation Cost Scenario Assessment

No Cluster Scenario

					Vehicles			
NO Clusters	A	B	C	D	E	F	G	H
hrs	11	11	10	10	10	10	10	1
mins	6	2	57	59	51	52	38	1
Total Time (mins)	666	662	657	659	651	652	638	61
Total Distance (miles)	187	191.5	160.4	156.8	126.9	131.2	108.8	58.6
Demand	177.4	142	154.7	178.9	183.4	197.5	179.9	0.1
Total Time per Vehicle	**11.10**	**11.03**	**10.95**	**10.98**	**10.85**	**10.87**	**10.63**	**1.02**
Operating Hours per Fleet	**77.43**							
Fleet Size (Vehicles)	**8**							
Total Distance per Fleet	**1121.2**							

Truck					**No Clusters**			
Purchase price	$22,075	$22,075	$22,075	$22,075	$22,075	$22,075	$22,075	$22,075
Years truck will be owned (years)	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1
Expected salvage value at end of ownership	$5,114	$5,114	$5,114	$5,114	$5,114	$5,114	$5,114	$5,114
Annual cost of repairs	$875	$896	$751	$734	$594	$614	$509	$274
Number of tires	4	4	4	4	4	4	4	4
Replacement cost per tire	$178	$178	$178	$178	$178	$178	$178	$178
Lifetime per tire (miles)	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Miles driven per year (miles)	9,724	9,958	8,341	8,154	6,599	6,822	5,658	3,047
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Interest rate	7%	7%	7%	7%	7%	7%	7%	7%
Price of fuel ($/ gallon)	$3.00	$3.00	$3.00	$3.00	$3.00	$3.00	$3.00	$3.00
Fuel efficiency (miles per gallon)	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0
Average hauling speed (miles per hour)	30	30	30	30	30	30	30	30
Annual cost of license	$1,750	$1,750	$1,750	$1,750	$1,750	$1,750	$1,750	$1,750
Annual cost of insurance	$1,250	$1,250	$1,250	$1,250	$1,250	$1,250	$1,250	$1,250
Drivers (people)	1	1	1	1	1	1	1	1
Operating Time (hrs)	577.2	573.7	569.4	571.1	564.2	565.1	552.9	52.9
Driver labor rate ($ per hour)	$5.00	$5.00	$5.00	$5.00	$5.00	$5.00	$5.00	$5.00

Transportation Financial Cost	**Truck**	**Truck**	**Truck**	**Truck**	**Truck**	**Truck**	**Truck**	**Truck**
Ownership Fixed Costs	**$/year**	**$/year**	**$/year**	**$/year**	**$/year**	**$/year**	**$/year**	**$/year**
Capital recovery (interest and depreciation)	$5,259	$5,259	$5,259	$5,259	$5,259	$5,259	$5,259	$5,259
Taxes, insurance, license	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000
Total ownership cost	$8,259	$8,259	$8,259	$8,259	$8,259	$8,259	$8,259	$8,259
Operating Variable Costs								
Repair cost	$875	$896	$751	$734	$594	$614	$509	$274
Tires cost	138	142	119	116	94	97	81	43
Fuel and lubrication cost	1,528	1,565	1,311	1,281	1,037	1,072	889	479
Labor cost	2,886	2,869	2,847	2,856	2,821	2,825	2,765	264
Total operating cost	$5,428	$5,472	$5,027	$4,987	$4,546	$4,609	$4,243	$1,061
Total Ownership plus Operating Costs	**$13,687**	**$13,730**	**$13,286**	**$13,246**	**$12,805**	**$12,867**	**$12,502**	**$9,320**

Net Total Fix Cost ($ per year)	**$66,071**
Net Total Variable Cost ($ per year)	**$35,372**

Three Cluster Scenario

Vehicles

Clusters			**1**			**2**		**3**	
No of Stops			143			43		77	
Vehicles	A	B	C	D	E	F	G	H	J
hrs	10	10	10	9	10	3	11	10	1
mins	57	57	31	47	15	2	2	59	21
Total Time (mins)	657	657	631	587	615	182	662	659	81
Total Distance (miles)	167.4	176.5	141.4	128.7	161.1	108.2	164.7	146.7	97.7
Demand	160.6	157	172.5	188.6	108.2	21.3	211.7	191.8	1.7
Total Time per Vehicle	**10.95**	**10.95**	**10.52**	**9.78**	**10.25**	**3.03**	**11.03**	**10.98**	**1.35**
Operating Hours per Fleet	**78.85**								
Fleet Size (Vehicles)	**9**								
Total Distance per Fleet	**1292.4**								

3 Clusters

Truck									
Purchase price	$22,075	$22,075	$22,075	$22,075	$22,075	$22,075	$22,075	$22,075	$22,075
Years truck will be owned (years)	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1
Expected salvage value at end of ownership	$5,114	$5,114	$5,114	$5,114	$5,114	$5,114	$5,114	$5,114	$5,114
Annual cost of repairs	$783	$826	$662	$602	$754	$506	$771	$687	$457
Number of tires	4	4	4	4	4	4	4	4	4
Replacement cost per tire	$178	$178	$178	$178	$178	$178	$178	$178	$178
Lifetime per tire (miles)	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Miles driven per year (miles)	8,705	9,178	7,353	6,692	8,377	5,626	8,564	7,628	5,080
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Interest rate	7%	7%	7%	7%	7%	7%	7%	7%	7%
Price of fuel ($/ gallon)	$3.00	$3.00	$3.00	$3.00	$3.00	$3.00	$3.00	$3.00	$3.00
Fuel efficiency (miles per gallon)	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0
Average hauling speed (miles per hour)	30	30	30	30	30	30	30	30	30
Annual cost of license	$1,750	$1,750	$1,750	$1,750	$1,750	$1,750	$1,750	$1,750	$1,750
Annual cost of insurance	$1,250	$1,250	$1,250	$1,250	$1,250	$1,250	$1,250	$1,250	$1,250
Drivers (people)	1	1	1	1	1	1	1	1	1
Operating Time (hrs)	569.4	569.4	546.9	508.7	533.0	157.7	573.7	571.1	70.2
Driver labor rate ($ per hour)	$5.00	$5.00	$5.00	$5.00	$5.00	$5.00	$5.00	$5.00	$5.00

ıicle

Transportation Financial Cost	**Truck**	**Truck**	**Truck**	**Truck**	**Truck**	**Truck**	**Truck**	**Truck**	**Truck**
Ownership Fixed Costs	**$/year**	**$/year**	**$/year**	**$/year**	**$/year**	**$/year**	**$/year**	**$/year**	**$/year**
Capital recovery (interest and depreciation)	$5,259	$5,259	$5,259	$5,259	$5,259	$5,259	$5,259	$5,259	$5,259
Taxes, insurance, license	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000
Total ownership cost	$8,259	$8,259	$8,259	$8,259	$8,259	$8,259	$8,259	$8,259	$8,259
Operating Variable Costs									
Repair cost	$783	$826	$662	$602	$754	$506	$771	$687	$457
Tires cost	124	131	105	95	119	80	122	109	72
Fuel and lubrication cost	1,368	1,442	1,155	1,052	1,316	884	1,346	1,199	798
Labor cost	2,847	2,847	2,734	2,544	2,665	789	2,869	2,856	351
Total operating cost	$5,122	$5,246	$4,656	$4,293	$4,855	$2,259	$5,107	$4,850	$1,679
Total Ownership plus Operating Costs	**$13,381**	**$13,505**	**$12,915**	**$12,552**	**$13,114**	**$10,518**	**$13,366**	**$13,109**	**$9,938**

Net Total Fix Cost ($ per year)	**$74,330**
Net Total Variable Cost ($ per year)	**$38,067**

Four Cluster Scenario

					Vehicles				
Clusters	**1**		**2**			**3**		**4**	
No of Stops	27		107			85		44	
Vehicles	A	B	C	D	E	F	G	H	J
hrs	8	10	10	9	10	10	3	10	2
mins	11	53	51	6	42	45	9	18	31
Total Time (mins)	491	653	651	546	642	645	189	618	151
Total Distance (miles)	155.4	168.4	115	108	118	119.7	71.8	103.3	66.4
Demand	108.1	130.6	174.8	155.5	182	175.6	41	217.9	28.2
Total Time per Vehicle	**8.18**	**10.88**	**10.85**	**9.10**	**10.70**	**10.75**	**3.15**	**10.30**	**2.52**
Operating Hours per Fleet	**76.43**								
Fleet Size (Vehicles)	**9**								
Total Distance per Fleet	**1026**								

Truck					**4 Clusters**				
Purchase price	$22,075	$22,075	$22,075	$22,075	$22,075	$22,075	$22,075	$22,075	$22,075
Years truck will be owned (years)	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1
Expected salvage value at end of ownership	$5,114	$5,114	$5,114	$5,114	$5,114	$5,114	$5,114	$5,114	$5,114
Annual cost of repairs	$727	$788	$538	$505	$552	$560	$336	$483	$311
Number of tires	4	4	4	4	4	4	4	4	4
Replacement cost per tire	$178	$178	$178	$178	$178	$178	$178	$178	$178
Lifetime per tire (miles)	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Miles driven per year (miles)	8,081	8,757	5,980	5,616	6,136	6,224	3,734	5,372	3,453
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Price of fuel ($/ gallon)	$3.00	$3.00	$3.00	$3.00	$3.00	$3.00	$3.00	$3.00	$3.00
Fuel efficiency (miles per gallon)	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0
Average hauling speed (miles per hour)	30	30	30	30	30	30	30	30	30
Annual cost of license	$1,750	$1,750	$1,750	$1,750	$1,750	$1,750	$1,750	$1,750	$1,750
Annual cost of insurance	$1,250	$1,250	$1,250	$1,250	$1,250	$1,250	$1,250	$1,250	$1,250
Drivers (people)	1	1	1	1	1	1	1	1	1
Operating Time (hrs)	425.5	565.9	564.2	473.2	556.4	559.0	163.8	535.6	130.9
Driver labor rate ($ per hour)	$5.00	$5.00	$5.00	$5.00	$5.00	$5.00	$5.00	$5.00	$5.00

Transportation Financial Cost	**Truck**	**Truck**	**Truck**	**Truck**	**Truck**	**Truck**	**Truck**	**Truck**	**Truck**
Ownership Fixed Costs	**$/year**	**$/year**	**$/year**	**$/year**	**$/year**	**$/year**	**$/year**	**$/year**	**$/year**
Capital recovery (interest and depreciation)	$5,259	$5,259	$5,259	$5,259	$5,259	$5,259	$5,259	$5,259	$5,259
Taxes, insurance, license	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000
Total ownership cost	$8,259	$8,259	$8,259	$8,259	$8,259	$8,259	$8,259	$8,259	$8,259
Operating Variable Costs									
Repair cost	$727	$788	$538	$505	$552	$560	$336	$483	$311
Tires cost	115	125	85	80	87	89	53	76	49
Fuel and lubrication cost	1,270	1,376	940	883	964	978	587	844	543
Labor cost	2,128	2,830	2,821	2,366	2,782	2,795	819	2,678	654
Total operating cost	$4,240	$5,119	$4,384	$3,834	$4,386	$4,422	$1,795	$4,082	$1,557
Total Ownership plus Operating Costs	**$12,499**	**$13,377**	**$12,643**	**$12,093**	**$12,645**	**$12,681**	**$10,054**	**$12,341**	**$9,816**

Net Total Fix Cost ($ per year)	**$74,330**
Net Total Variable Cost ($ per year)	**$33,818**

Total Cost Reference Sheet

Each value shown above used the following reference respectively:

Vehicle purchase price – (Ford Motor Company, 2015)
Truck Economic Life and Useful Life - (Department of the Treasury, 1991)

Salvage Value is calculated by the following formula - Salvage Value Source: (Jasso, 2015):

Salvage Value = P*(1-i)^Y

where:

S = salvage value
P = original price
i = nominal depreciation rate
Y = age of product in years

Tire Cost: (Goodyear Corporation, 2015)
Fuel Prices - (U.S. Energy Information Administration, 2015)

Annual license and insurance values are based on US fees from the trucking farming industry - (William Edwards, 2009)

Vehicle fuel economy – (Ford Motor Company, 2015)

Labor Cost - "The Mexican minimum-wage commission on Friday determined to raise the country's daily minimum wage by 4.2%—in line with current inflation—to about 70 pesos a day, less than $5 at current exchange rates." (HARRUP, 2014)

Diesel Fuel Pros and Cons

Diesel Fuel	
Pros	Cons
*Mileage is 25 percent to 40 percent higher than gasoline.	* Engines and emissions systems can be costly.
* Carbon dioxide emissions are lower.	* Diesel fuel currently costs far more than gasoline.
* Highway mileage and performance are better than hybrids'.	* Like gasoline, diesel is a petroleum product from foreign suppliers.
* High torque is well suited to large pickups and S.U.V.'s.	* Though outdated, image as a dirty technology lingers.
* Extended driving range means less frequent fill-ups.	Limited diesel filling stations.
* Engines are robust, often lasting 300,000 miles or more.	

Source: (New York Times, 2008)

Comparison list between Gasoline Engines versus Diesel Engines

<table>
<tr><th colspan="3">Gasoline Engines versus Diesel Engines</th></tr>
<tr><td>Category</td><td>Gasoline Engines</td><td>Diesel Engines</td></tr>
<tr><td>Purchase Cost</td><td>Initial purchase cost is lower</td><td></td></tr>
<tr><td>Fuel Consumption</td><td>Fuel is widely available and winter treatment is invisible</td><td>100% better fuel economy
Requires clean fuel free of dirt & water. Use of low sulfur. Blending w/ additives to prevent clouding or jelling in cooler climates</td></tr>
<tr><td>Maintenance Parts</td><td>Lighter weight engine
Require more service attention – frequent service interval between overhauls
Replacement parts cost less & readily available</td><td>Heavier weight engine and support components (tires, transmission, suspension, driveline)
Scheduled maintenance is 50% less frequent than gasoline engines
Expensive engine parts
Part availability can be a problem</td></tr>
<tr><td>Operations</td><td>Higher governed speeds.
With less engine torque, lighter vehicle weight components can be used to transmit power more efficiently to the rear wheels. The low starting torque requires less battery capacity. Gas engines have inefficient idling characteristics, but start well in cold weather.</td><td>Lower governed speeds.
Overall heavier vehicle components reducing fuel economy. Better idling characteristics.
Hard to start in cold requiring fuel additives and block heaters.</td></tr>
<tr><td>Technology</td><td>Fuel Injection
Electronic ignition
Trouble code diagnostic systems</td><td>Emission control
Turbo charging low-sulfur fuels
Particulate traps
Exhaust gas recirculating systems</td></tr>
<tr><td colspan="3">Modified from the 2006 Source: (Exploring the Pros and Cons of Gas vs. Diesel Engines, Feb. 2006)
(Automotive Fleet, 2006)</td></tr>
</table>

Biodiesel Transportation Performance Indicators

Distribution/Transport	**Quality Indicator**
	On-Time Arrivals
	% of Shipments Where Quantity Dispatched Equals Quantity Received
	% of Shipments Arriving in Good Condition
	Kilometers Between Accidents
	Time Between Accidents
	Response Time Indicator
	Average Delivery Time
	Average Vehicle Loading/Unloading Time
	Vehicle Turnaround Time
	Cost/Financial Indicator
	Total Transportation Cost
	Average Transportation Cost Per Kilometer/Volume/Weight
	Ratio of Transportation Cost to Value of Product
	Productivity Indicator
	Vehicle Use Availability
	Container Capacity Utilization
	Fleet Yield
	Average Number of Stops Per Route

Source reference from the following article: (USAID | DELIVER PROJECT, Task Order 1, 2010)

Biodiesel Publications: Mexico vs. USA

A scientific paper search with Engineering Village, a web engineering search platform was performed and found the publications starting in 2007 with only a minor increase in 2011.

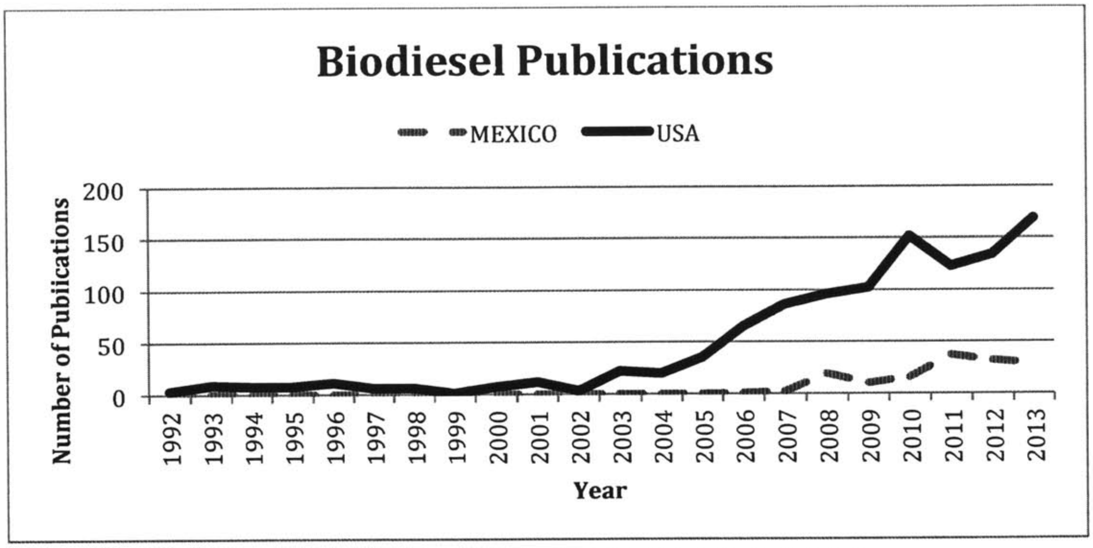

Figure 16: Biodiesel Publications 1992-2013 (Elsevier, 2014)

The scientific paper search identified the level of research efforts for specified topics (technology, policy, innovation, etc.) examining the feasibility of biodiesel and to understand the research progression for underlying topics related to biodiesel. This disconnect from the early research growth in the U.S.A. could be due to the increase in industry and governmental action in the U.S. around alternative fuels starting in 2008 with the introduction of the Law of Promotion and Development of Bioenergetics.

Engine Fuel: Straight Vegetable Oil – Barriers to Usage

Further barriers to SVO were explained by Dr. John J. Milledge, a research fellow at University of Greenwich, in a presentation titled, "Biodiesel-Harvey:"

- Incomplete combustion of vegetable oil
- Coking of the injectors leads to incomplete atomization, which contributes to poor combustion
- Carbon deposits can cause piston ring sticking
- Straight vegetable oil can deteriorate during storage
- Oxidation results in 'gum' production: Gum combusts poorly, leading to carbon build up in the engine.
- Gum can also transfer into the lubrication oil leading to an increase in oil viscosity resulting in engine wear