

1-1-2013

A Decision Support System to Design the In-Bound Supply Chain for Biomass Co-Fire in Power Plants

William David Bowen

Follow this and additional works at: <https://scholarsjunction.msstate.edu/td>

Recommended Citation

Bowen, William David, "A Decision Support System to Design the In-Bound Supply Chain for Biomass Co-Fire in Power Plants" (2013). *Theses and Dissertations*. 100.

<https://scholarsjunction.msstate.edu/td/100>

This Graduate Thesis - Open Access is brought to you for free and open access by the Theses and Dissertations at Scholars Junction. It has been accepted for inclusion in Theses and Dissertations by an authorized administrator of Scholars Junction. For more information, please contact scholcomm@msstate.libanswers.com.

A decision support system to design the in-bound supply chain for biomass co-fire in
power plants

By

William David Bowen

A Thesis
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Master of Science
in Industrial Engineering
in the Department of Industrial and Systems Engineering

Mississippi State, Mississippi

December 2013

Copyright by
William David Bowen
2013

A decision support system to design the in-bound supply chain for biomass co-fire in
power plants

By

William David Bowen

Approved:

Sandra D. Eksioglu
(Major Professor)

Stanley F. Bullington
(Committee Member)

Burak Eksioglu
(Committee Member)

Kari Babski-Reeves
(Graduate Coordinator)

Achille Messac
Dean
Bagley College of Engineering

Name: William David Bowen

Date of Degree: December 14, 2013

Institution: Mississippi State University

Major Field: Industrial Engineering

Major Professor: Dr. Sandra Eksioglu

Title of Study: A decision support system to design the in-bound supply chain for biomass co-fire in power plants

Pages in Study: 54

Candidate for Degree of Master of Science

This work is focused on designing a hub-and-spoke in-bound supply chain networks for coal plants. Biomass and coal are co-fired to produce electricity. One of the main reasons for focusing this study on biomass supply to coal plants is that biomass, in the form of forest and agricultural waste, is cleaner to burn as compared to coal. The user, most likely a supply chain manager or production control engineer, would input their supplier locations, costs and biomass availability. The mathematical model which supports this DSS is a mixed-integer program. The model uses this input to identify optimal order quantities which optimize costs. This DSS helps address the logistical issues of determining the in-bound supply chain network to transport biomass to coal plants.

DEDICATION

To my parents: Rick and Renee, and my siblings: Ricky, Kellye, Clara, Hank, and Collin, thank you for your prayers and support. I succeeded because of you.

TABLE OF CONTENTS

DEDICATION	ii
LIST OF TABLES	v
LIST OF FIGURES	vi
CHAPTER	
I. INTRODUCTION	1
Motivation.....	1
Thesis Objective.....	3
II. LITERATURE REVIEW	8
Decision Support Systems	8
Characteristics of DSS's	9
History of DSS's	10
Coal and Biomass	14
Coal and Biomass in Business	14
Coal and Biomass in Literature.....	16
Hub-and-Spoke Supply Chains.....	17
III. DEVELOPING THE DSS	21
Identify DSS Components	21
Model Base	23
Hub-and-Spoke Model.....	23
Math Model with Point-to-Point Truck Transportation for Short Distances	25
User Interface.....	27
Worksheets.....	28
Welcome	28
About.....	29
Coal Plant.....	29
Parameters.....	30
Network Shipping Plan (NSP)	31
CP Nodes	32
Sup Nodes	32

	Hub Nodes	33
	Range Nodes	33
	Full Network Arcs.....	33
	Potential New Arcs	33
	Definite New Arcs	33
	Regions	34
	CPLEX.....	34
	Summary Charts.....	34
	Previous Networks	34
	Multiple Saved Networks	35
	Functionalities of the User Interface.....	35
	Navigation.....	35
	Update Parameters	35
	Recall Networks.....	35
	Compare Networks	35
	Solve the Network.....	36
	Analysis Base.....	36
	Database.....	38
IV.	DATA COLLECTION	40
	Raw Data.....	40
	Preprocessing the Data.....	42
V.	REGIONAL ANALYSIS	45
	Regional Profiles.....	45
	Regional Analysis	46
	Sensitivity Analysis	47
	Effect of Supply	48
	Effect of Truck Cost.....	48
	Effect of Rail Cost	49
	Conclusions and Future Work	50
	REFERENCES	52

LIST OF TABLES

1	History of DSS's	11
2	Regional Profiles	46
3	Resulting Supply Chain Profiles	46
4	Resulting Supply Chain Costs.....	47
5	Effect of Supply	48
6	Effect of Truck Cost.....	49
7	Effect of Rail Costs	50

LIST OF FIGURES

1	Hub and Spoke Supply Chain Network	6
2	DSS Components	22
3	Hub-and-Spoke Model	23
4	DSS Structure	28
5	Welcome Worksheet	29
6	Coal Plant Worksheet.....	30
7	Parameters Worksheet.....	31
8	Network Shipping Plan Worksheet	32
9	Network Shipping Plan	36
10	Supplier Insight	37
11	Hub to Coal Plant Insight	37
12	County to Hub Insight	38
13	Direct Truck Shipment	38
14	US Rail Network	41
15	Coal Plant Locations	42
16	US Regions.....	45

CHAPTER I

INTRODUCTION

Motivation

Alternative fuel sources and biofuel research is a very popular topic now in the United States. The rise in gas prices, concern for the environment, and the fact that one day we will eventually run out of oil has sparked interest in identifying alternative sources of energy. Biomass is one of the most talked about and feasible options for an alternative fuel source. It also has become a major focus of energy policies proposed by the US Congress. The first major piece of legislation to address this issue was the Energy Policy Act of 1992. This bill encompasses everything from funding research to finding an alternative fuel source for gasoline to possibly using uranium as an energy source for power plants. In the middle of this bill, we see the topic of coal addressed. Here the Clean Coal Technology Subgroup is formed and the Secretary of Energy is directed to:

“... seek certain additional clean coal technology solicitations designed to ensure: (1) the timely development of technologies that achieve greater efficiency in converting coal to energy than is currently commercially available; and (2) the commercial availability of such technologies by the year 2010.” (Congress, Energy Policy Act of 1992).

Although this was a very general statement, this was a major milestone for clean coal technology and showed the US government's recognition of both the value of coal as an energy source and its need to produce energy using coal in a cleaner way.

Further steps were taken in February of 2000 when the Senate passed the Biomass Research and Development Act of 2000. In this bill was the appropriation of \$14 million and authorization of the construction of a corn-based ethanol research pilot plant (Congress, Biomass Research and Development Act of 2000, 1999). In follow up to this act, the Energy Policy Act of 2005 took much stronger steps towards renewable energy. The Secretary of Energy is to appropriate 60% of funds to facilities that use solar, wind, and biomass to generate electricity and created a grants program to improve the value of forest biomass for electric energy (Congress, Energy Policy Act of 2005). Also in 2005 a bill was introduced to the Senate that created a Clean Coal Research Development and Demonstration Program. This program was to fund projects that increase efficiency, environmental performance, and reduce costs of coal in the United States (Congress, Clean Coal Research, Development, Demonstration, and Deployment Act of 2005, 2005).

In response to the environmental concerns, cost reductions, and federal funding, some coal-fired power plants are beginning to adopt a technique known as co-firing. Co-firing is the process of burning more than one type of fuel at the same time (Laboratory N. E., Coal-Fired Power Plants (CFPPs)). This process is beneficial for a number of reasons. First, it has been seen that when low amounts of biomass are co-fired with coal it burns cleanly and effectively (Ciolkosz, 2010). According to the Department of Energy, co-firing is an attractive option because biomass can substitute for up to 20% of coal used in the boilers (Energy, 2004). If the power plants can generate power using biomass at the

same or less cost as it can using coal then co-firing with biomass is a feasible and attractive option. This would satisfy the power plant because they can now do more with less coal, the farmers because they now have someone to sell their biomass to, and the environmentalists who are concerned about coal's effect on the environment. Although clean coal technology such as co-firing is on the rise, one of the major factors is transporting existing biomass to the power plants in a cost effective manner.

Thesis Objective

Accompanying this new-found energy solution is also a set of problems that an IE can address. First and most obvious is how to efficiently transport biomass from its raw form such as corn to a refinery and then to its final destination at a co-fire power plant. In order to transport the biomass efficiently we will need to determine how much biomass to transport from each supplier and to each co-fire power plant. The amount shipped to each co-fire power plant will obviously be the demand for that power plant. Once we know how much needs to be shipped we need to determine how to ship it, by rail or truck, and consequently how many trucks or rail cars we will need. The decisions continue with questions like, "Which rail arc will we use? Do I think that particular arc is being over used? If so, how will I re-route some of the shipments?"

All of these problems, and others, form a proverbial logistical nightmare, but a Decision Support System (DSS) can be created to help address these logistical issues. This DSS would be designed to help the user find the most efficient shipping solution of biomass in their supply chain network. It would tell them specifically how much biomass would be transported from each supplier, how it is being transported and of course the bottom line of how much will it cost. The user, most likely a supply chain manager or

production control engineer, would input their supplier locations, costs and biomass availability. The DSS would use this input to identify optimal order quantities which optimize costs. To make implementation easy, the DSS will be built in Microsoft Excel. In regards to how to implement the DSS, the user would use it as a forecasting tool. As demands come in, they can forecast how they will meet those demands with their suppliers. If a supplier has more or less biomass, this can affect the supply chain and thus the user may need to adjust their forecast.

The objective of this work is to create a DSS that will help the user address the logistical issues and find an optimal solution for an in-bound supply chain network that delivers biomass to a coal plant which relies on rail transportation. This work is focused on designing a hub-and-spoke in-bound supply chain network. A hub-and-spoke network is a network design intended to make transportation more efficient by simplifying a network of routes (Smith, 2013). The best example of this is the airline industry. Up until 1978 airlines were required to fly from one small city to another small city. This is called a point to point system or as we would call it, a direct flight. Although this is convenient for the customer in terms of time, this can be very costly for the airline because demand for flights to and from small cities is very small. However, after the government deregulated the airline industry in 1978, many airlines switched to a hub-and-spoke network. Instead of flying from a small city to a small city, airlines would fly from a small city to a larger city and then to a small city (Bonsor, 2001).

For example, let's say you wanted to fly from Birmingham, AL to Orlando, FL. There are probably not a lot of people who fly to Orlando every single day from Birmingham, but there are still people who need to fly out of Birmingham. So instead of

having several half full planes leaving Birmingham every day, an airline would use a few planes to transport these passengers to a larger airport that acts as a kind of center that the other airports in the area are connected to. In this case, Atlanta, GA is a good example. From Atlanta you would board a plane with other people who also need to end up in Orlando. In this example, Birmingham and Orlando are spokes and Atlanta is the hub. The result of this is high occupancy on flights and a minimization of the number of flights, which minimizes costs for the airline and consequently the customers. This is exactly what we are trying to do, but instead of airplanes we have trains and instead of people we have biomass. I chose rail instead of plane, truck, or water transportation because of the high capacity, consistency in distance and time, and the already existing rail network. Figure 1 shows a basic hub-and-spoke design.

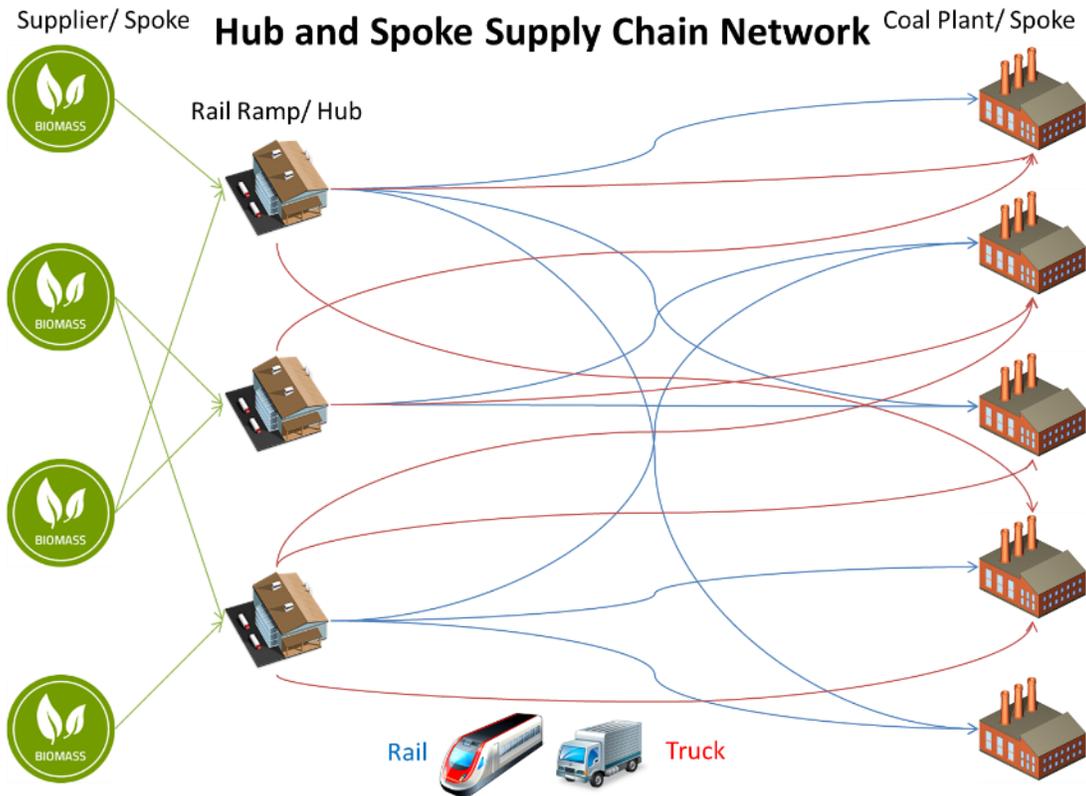


Figure 1 Hub and Spoke Supply Chain Network

The goal of this thesis is to find the hub-and-spoke in-bound network design and shipping plan for a particular coal plant. By this I mean that I want to find where to locate consolidation hubs, which supplier will ship to which consolidation hub, which consolidation hub will ship to the coal plant, and the amount shipped between facilities. In doing so the model will be able to provide the supply chain manager or production control engineer with a minimum cost of receiving shipments, at that particular coal plant, of biomass across the country using the rail network. This will be very beneficial in managing the supply chain. In addition to simply finding the optimal solution to this problem, I also wanted to create a decision support system (DSS) which will help

managers with logistics-related decisions. The DSS will have the following functionalities, which will provide insight into the data and make the model flexible for the user:

- Allow the user to edit the supply chain
- Save, Reload, and Solve the current network for an optimal solution
- Provide a detailed shipping plan showing the number of units shipped to and from each location and charts that are easy to understand and provide insight into this shipping plan
- Provide an interface in which the user can make changes to the resulting shipping plan and re-solve the network using an algorithm to see if the changes that the user wants are feasible

CHAPTER II

LITERATURE REVIEW

Decision Support Systems

“A Decision Support System (DSS) is an interactive computer-based system or subsystem intended to help decision makers use communications technologies, data, documents, knowledge and/or models to identify and solve problems, complete decision process tasks, and make decisions. Decision Support System is a general term for any computer application that enhances a person or group’s ability to make decisions. (Power D. , A Brief History of Decision Support Systems, 2003)”

As you can see from this quote from DJ Power, DSS’s can be used in a variety of fields and can make use of simulation models, Excel spreadsheets, interactive websites, and much more. The interface and format of the DSS’s has changed as technology has changed. At one point in time a DSS was nothing more than a hands on auto-calculating spreadsheet which resembled a primitive version of Excel (Power D. , A Brief History of Decision Support Systems, 2003). Now, we use similar spreadsheets as the basis for our DSS’s. Along with the increasing of computing power, graphics have also improved, thus improving simulation models and consequently DSS’s because the user can now see their item traveling down their conveyor in their simulated warehouse. These changes did not happen overnight. DSS’s started off as simply methods and tools that aided in the

decision making process. Now, we use that same principle, but with much more powerful analytical tools and better ways of reporting out these results.

Characteristics of DSS's

Before we get too far into looking at the history of DSS's it is first good to recognize that there are some principles that all DSS's should have regardless of the technological advancements or lack thereof. Eom lists four characteristics of DSS's (Eom, 2001):

1. Supports decision makers rather than replaces them
2. Utilizes data and models
3. Solves problems with varying degree of structure
4. Focuses on effectiveness rather than efficiency in decision processes

Eom goes on to say that DSS needs to support all phases of the human decision making process: intelligence, design, and choice (Eom, 2001). The DSS needs to be intelligent and sophisticated in its problem solving, the design needs to be smooth and user friendly, and the DSS needs to present the user with options to choose from. It is key to remember that the DSS aids in making decisions—it does not make the decision.

Alter has an even more general set of characteristics. This is probably because Alter listed these in 1980, the beginning of the personal computer era, as opposed to Eom who wrote his in 2001. Alter said that a DSS should (Alter, 1980):

1. Be designed specifically to facilitate decision processes
2. Support rather than automate decision making
3. Be able to respond quickly to the changing needs of decision makers

Looking at these two lists from two opposite ends of the personal computer age, there are two characteristics that are common to both. First, DSS's are to assist decision makers in their decision making. DSS's are not to replace the decision makers. Second, they need to be nimble enough to solve a variety of problems but powerful enough to solve them quickly. We will look for these two characteristics in both the history of DSS's and in the development of our own DSS.

History of DSS's

Although today we think of DSS's as being computer based in nature, there was a time when that was not so. Up until the seventies DSS's existed more in theory than in practice. Even when DSS's became computer based, computers were so large and expensive that very few people had access to them to be able to further develop DSS's. It wasn't until the invention of the microprocessor and consequently the personal computer that DSS's really began to make technological strides. However, it is in the years prior to the personal computer that DSS theory was developed and ideas were formed.

One of the earliest uses of a DSS was in 1951. A tea shop business used a LEO digital computer to help determine the goods that should be carried by produce vans (Power, Burstein, & Sharda, 2011). In the late 50's SAGE (Semi-Automatic Ground Environment) was an air defense DSS for the US military. It is said that this, "was the first computerized real time, data driven DSS" (Power, Burstein, & Sharda, 2011).

Table 1 shows some of the changes that have come to DSS's during the early years of computer development (O'Leary).

Table 1 History of DSS's

Year	Major Milestones
1945	V. Bush proposed Memex
1947	H. Simon's book Administrative Behavior
1952	Dantzig joined RAND and continued research on linear programming
1953	Johnniac computer became operational at RAND, one of the first online time-sharing systems.
1955	Semiautomatic Ground Environment (SAGE) system at M.I.T. Lincoln Lab uses first light pen
1956	Forrester started System Dynamics Group at the M.I.T. Sloan School
1958	SAGE system initial site goes online, completed in 1962 -- First data-driven Decision Support System
1960	Simon book The New Science of Management Decision; McCarthy developed Lisp AI language; Licklider article on "Man-Computer Symbiosis"
1961	Bachman at General Electric develops first database management system, IDS. SAGE system completed.
1962	Licklider architect of Project MAC program at M.I.T.; Iverson's book A Programming Language(APL); Engelbart's paper "Augmenting Human Intellect: A Conceptual Framework"
1963	Englebart established Augmentation Research Center at SRI
1964	IBM launched System/360 on April 7, 1964; IBM 7094 II Data Processing System for scientific computing; DEC shipped the PDP-8
1965	Stanford team led by Feigenbaum created DENDRAL expert system; Anthony's book on Planning and Control Systems; Problem Statement Language/Problem Statement Analyzer (PSL/PSA) developed at Case Institute of Technology;Licklider article "The Computer as a Communication Device"

It was in the 1960's that "researchers began systematically studying the use of computerized quantitative models to assist in decision making and planning" (Power D. , A Brief History of Decision Support Systems, 2003). This led to a management decision system developed by Scott Morton in 1966. Morton focused his work on building models that managers could use for "recurring key business planning decisions" (Power D. , A Brief History of Decision Support Systems, 2003). It was through Morton's future work that the term decision support system was first introduced. Morton and Gorry in 1971

argued that, “Management Information Systems primarily focused on structured decisions and suggested that information systems for supporting semi-structured and unstructured decisions should be termed “Decision Support Systems” (Power, Burstein, & Sharda, 2011).

Through the 1970’s we saw several data driven computer based DSS’s being built. We had AAIMS (An Analytical Information Management System) developed in 1974 for American Airlines. SLIM (System Laboratory for Information Management) was developed in the late 1970’s by Courtney and Jensen. Among these we also had Rockart’s work in 1979 that fueled the development of EIS’s (Executive Information Systems) and ESS’s (Executive Support Systems) (Power, Burstein, & Sharda, 2011). It is no surprise that the 1970’s were a booming time for computer based DSS’s. The reason being is that computers were becoming much more sophisticated, accessible, and affordable. The climax of this was in 1974 when IBM released the first personal computer (Bellis, 2013).

In 1980 Steven Alter published his MIT doctoral dissertation which focused on using models for DSS’s. This publication became very influential in DSS circles. Alter concluded, “ that decision support systems could be categorized in terms of the generic operations that can be performed by such systems” (Power D. , A Brief History of Decision Support Systems, 2003). He conducted a study of 56 different DSS’s that he then grouped into seven distinct types of DSS’s (Power D. , A Brief History of Decision Support Systems, 2003):

- File drawer systems: provide access to data items.
- Data analysis systems: support the manipulation of data by computerized tools tailored to a specific task and setting or by more general tools and operators.
- Analysis information systems: provide access to a series of decision-oriented databases and small models.
- Accounting and financial models: calculate the consequences of possible actions.
- Representational models: estimate the consequences of actions on the basis of simulation models.
- Optimization models: provide guidelines for action by generating an optimal solution consistent with a series of constraints.
- Suggestion models: perform the logical processing leading to a specific suggested decision for a fairly structured or well-understood task.

One of the greatest advances for DSS's came in 1982 with Sprague and Carlson's book *Building Effective Decision Support Systems*. It was such an important milestone because it provided an easy to understand way for organizations to build DSS's and also explained Sprague's DSS's framework which consists of Database, Model Base, Dialog Generation, and Management Software (Power D. , A Brief History of Decision Support Systems, 2003). After Sprague and Carlson's book was published, this provided people with the tools to DSS's on their own. Furthermore, it showed that there was a market for this type of literature.

According to O'Leary, technology is one of the reasons for the evolution of DSS's. This evolution of technology will not only have an effect on the process time of the DSS to arrive at a conclusion, but also on things such as the application itself and the medium that it is used in (O'Leary). For example, the iPad is a piece of technology that allows the user to easily collect and process data on the go as opposed to having to sit at a desktop or carry around a laptop. Because of the iPad, applications have been developed and changed from being desktop/laptop based to being more mobile in the form of an iPad application. So the world in which the application and DSS exists has completely changed. DSS's will continue to be a part of decision making and will improve in their effectiveness as technology evolves.

Coal and Biomass

Coal and Biomass in Business

We saw earlier the need for alternative energy and the focus of the US Government to find sources and producers of this alternative energy. Although, clean energy and co-firing has been a relatively new idea and practice, there was actually an occurrence of this happening over twenty years ago. Minnesota Power began co-firing in Duluth when a paper mill opened up and needed something to do with the leftover bark. The power plant began co-firing at a 75-25 coal to wood ratio. Now it operates at a 10-90 coal to biomass ratio and generates 50 MW of power (Austin, 2011). The biggest issue that they have operating with such a high biomass ratio is securing and storing the biomass. In the event that they cannot acquire the necessary amount of biomass, they simply throw more coal into the burners.

It is estimated that over twenty power plants now use biomass to replace 5%-25% of coal. In New Hampshire three coal fired power plants were converted to co-fire with biomass for \$75 million. It was found that the newly converted plant has: “lower operational costs, higher earnings, and reduced emissions” (Silverstein, 2013). From the North East to the deep South, co-firing is a popular method of generating alternative energy. Southern Company is using co-firing in an Alabama power plant and says that “The high capital and operating costs involved with a new stand-alone power plant are avoided. It is a renewable technology most likely to directly displace coal” (Silverstein, 2013).

In July 2012, Dominion Resources opened up a co-fire power plant, firing wood and coal, in southwest Virginia. It cost \$1.8 billion to build and generates 585 megawatts of energy. David Christian, CEO of Dominion, estimates that the plant will save the southwest Virginia area \$250 million per year. Christian goes on to say that “The use of low-cost waste coal and biomass will result in the unit having favorable economics, bringing savings to customers” (Silverstein, 2013). Dominion plans to refit its three other power plants in Virginia so that they can co-fire with wood chips as well.

Most recently, April of 2013, Drax Group commissioned the largest converted power plant in the world. After four months, it puts out 585 MW of while still be flexible. According to Dorothy Thompson, CEO of Drax, “... we have not encountered significant slagging, fouling or corrosion inside the boiler. Emissions of nitrogen oxides have been significantly lower than for the coal units. The efficiency modifications we have made so far have been effective and the overall combustion process is stable,” (Voegele, 2013). What we see

here is that biomass is a legitimate alternative fuel resource and can successfully displace coal.

Coal and Biomass in Literature

In 2006 Sokhansanj, Kumar, and Turhollow created a simulation model for transporting large quantities of biomass and estimating its delivery costs. There were a few interesting things about their model setup. First, they considered events, queues, and others steps in the process as a part of the network rather than just factors and variables in the network (Sokhansanja, Kumarc, & Turhollowa, 2006). What was also interesting to see is that they not only looked at the typical fixed costs of transporting biomass but also considered factors like the effects of weather on moisture content and consequently the amount of biomass lost while moving through the supply chain. In the end, they were able to successfully determine the effects of weather on the biomass as well as the fixed and variable costs associated with the supply chain. This led to the ultimate conclusion of determining the delivery cost of biomass to the bio refinery.

Similar to Sokhansanj, De Mol et al. in 1997 looked at the logistics of collecting, treating, and transporting biomass to an energy plant. What was interesting about their work is that they created both a simulation and an optimization model to look at this problem. The simulation model was created in PROSIM and tracks biomass lots as it passes through the network and records costs, energy consumption, and losses for each lot. It leaves the network as it is and simply ships biomass through the network as capacity allows is. However, the optimization model is a MIP that uses a knapsack formulation to pack the trucks and ship the biomass optimally through the network.

According to De Mol et al.: “*The knapsack model determines the optimal combination of*

solutions from sub-models for the total capacity. (De Mol, Jogems, Van Beek, & Gigler, 1997)” It was found that both the simulation and optimization models provided similar insights into network in regards to energy consumption, losses during storage (De Mol, Jogems, Van Beek, & Gigler, 1997).

In an article by Pantaleo et al. we see them address the fact that there are several different types of biomass networks and processes due mainly to the fact that there are different types of biomass and thus different processes and procedures needed to collect, refine, and ultimately transform into energy. One thing that I found interesting in the section on transporting solid biomass, was that the transportation cost accounted for about 20%-40% of the total delivery cost depending on the transportation method (Pantaleo & Shah, 2013). Similar to what we’ll see in the next section, they Pantaleo et al.’s research shows that optimum size of transporting biomass is large relative to the size of the biomass available. Another interesting point that they brought out is that although truck shipping a legitimate shipping method, it may not be feasible in urban areas. All in all, this article was a great overview on different types of biomass and the transportation methods needed to get the biomass to the refineries and plants.

Hub-and-Spoke Supply Chains

Now that we have a good understanding of both the history of DSS’s and of the benefits of co-firing coal and biomass, we need to turn our attention to supply chains. Keep in mind that our end goal is to design a supply chain network that will efficiently transport the necessary amounts of biomass from each of suppliers to each of the coal plants. We will focus our attention specifically on the hub-and-spoke type of network.

In Bryan and O’Kelly’s analysis of a hub-and-spoke network, we are introduced to a specific type of hub-and-spoke network called a “pure” hub-and-spoke. In a pure hub-and-spoke, all connections in the network either begin or end with a hub. We also see that a hub-and-spoke network can either be connected to a single hub (single assignment) or to multiple hubs (multiple assignment). Regardless of which assignment type is used, Bryan and O’Kelly found that travel costs from origins to destinations were reduced in the hub-and-spoke networks as compared to the completely interconnected network (Bryan & O’Kelly, 1999). What we see here is that an efficient network doesn’t necessarily have to be totally interconnected. This is especially good news for our network because we have over 40,000 points. That would be a huge spider web to try and untangle. It would be too much for the model to solve in an efficient time frame.

Although Bryan and O’Kelly’s work provided us with a keen insight into hub-and-spoke networks in general, Zapfel and Wasner’s work was even more applicable. They looked at the planning and optimization of cooperative third party logistics providers that formed hub-and-spoke networks in the European Union (EU). Small and medium sized freight carriers were forming alliances and build a transportation network acting under a single name in order to be competitive against larger freight transportation companies and counteract the increase in transport tariffs. The resulting network of these alliances is a pure hub-and-spoke network. The coordination of logistic flow is achieved by bunching all shipments from one depot (spoke) to another using a transshipment center (hub) (Zapfel & Wasner, 2002).

An interesting article by Nero focused on the competitive advantage of having a large hub-and-spoke network. Specifically, he looked at the cost benefits of having a

larger network. The results show that there is indeed a competitive advantage to increasing the size of your network. Nero goes on to say that the force that drives this is the “spillover effect” on traffic, fares, and costs throughout the hub-and-spoke network. In one of his test models, under mild economic assumptions, the results showed that when an end point is added to the network the effect on revenue dominates the effect on cost. Nero does go on to say that this could be negated by factors such as congestion if the network gets too big (Nero, 1999). The obvious question that comes out of this now is what is the optimal size for our network? A key take away here is that just because we have a lot of connections i.e. a large network does not necessarily mean that we will have an efficient network. This is supported by Bryan and O’Kelly’s work that we mentioned earlier. When creating our network we will need to keep an eye out for congestion in our large network.

Similar to Zapfel and Wasner, Jeong et al. performed work similar to what I am aiming to accomplish. They looked at the European freight railway system as a hub-and-spoke network. Their model allowed goods to be shipped through however many hubs as long as the overall cost was reduced. The cost is based off of total time, delays, and other cost functions (Jeong, Lee, & Bookbinder, 2007). Again, as we have seen previously, an effective hub-and-spoke network will reduce cost, provided it is not too large as we have been warned by Nero’s work.

In Abduljabbar’s and Tahar’s (2012) paper on petroleum logistics we not only see a supply chain but also an Excel based DSS. They developed a DSS that was supported by a simulation model in ARENA while the user interface was created using VBA. Their aim was to create a DSS that would address inventory routing problem for petroleum

companies of transporting petroleum through their supply chain. They state that their goals are similar to other supply chain goals: “To offer good service to the final customer, while keeping: profits high, costs and lead times low.” They identified the main cost drivers to be the number of stock outs, stock level at the oil depot and process execution costs (Abduljabbar & Tahar, 2012).

In a similar vein, Acharya et al. (2012) created an Excel based DSS that aided in supply chain design and management of biofuels. Similarly, they also used a supply chain rail network to transport these biofuels to refineries. However, where they built a model around biomass for biofuel, I am building a model around biomass for electricity. One thing that they did that I will look in to incorporating was a sensitivity analysis on the parameters (Acharya, 2012).

In all of these articles I believe that there are a few key take away’s. First we saw that a network doesn’t have to be totally interconnected for it to be efficient. In fact, a large interconnected network could cause congestion as well as take a large amount of time for the model to solve. Probably the most applicable article was Zapfel and Wasner’s. Here we saw them create an actual hub-and-spoke style network that shipped goods and reduced the cost of shipping across the EU. Moving forward we need to try and create a hub-and-spoke network with these 40,000 points that reduces cost, while keeping in mind that congestion could be a sign of a large and inefficient network.

CHAPTER III

DEVELOPING THE DSS

Identify DSS Components

Earlier we looked at the different characteristics of DSS's. Now as we begin to develop the DSS we need to change our focus to the components that make up a DSS. For example, Kuo (2002) created a DSS that was used to select the location for convenience stores. His system had four components to it: 1.) Fuzzy analytic hierarchy process (fuzzy AHP) 2.) Weights determination 3.) Data collection 4.) Decision making (Kuo, 2002). Similarly Eksioglu in 2011 lists five components: 1.) Database 2.) Model Base 3.) Knowledge Base 4.) GUI (Graphic User Interface) and 5.) The User (Sandra D. Eksioglu, 2011). Figure 2 shows how these five components interact with each other.

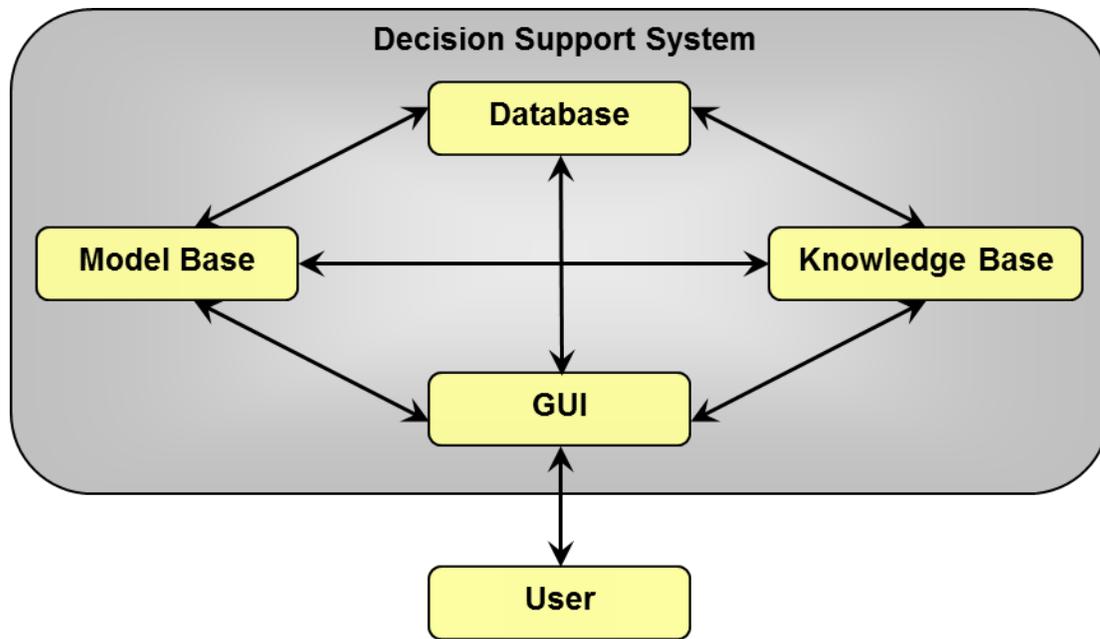


Figure 2 DSS Components

(Sandra D. Eksioglu, 2011)

For our DSS, we will use a DSS with five components. These components are: The Model Base which consists of the mathematical models of the problem. The User Interface that serves as a way for the user to interact with the mathematical model, the Database and Analysis Base. The Analysis Base that takes the output from the Model Base and the Database and provides insight in to what the results mean. The Database that stores the information that feeds the Model Base and Analysis Base. Finally, the centerpiece of this system is the user. When we build a DSS we always need to keep in mind who will use this system and what questions the user need answered.

Model Base

Hub-and-Spoke Model

The following figure shows the supply chain network for a single coal plant with direct truck shipment:

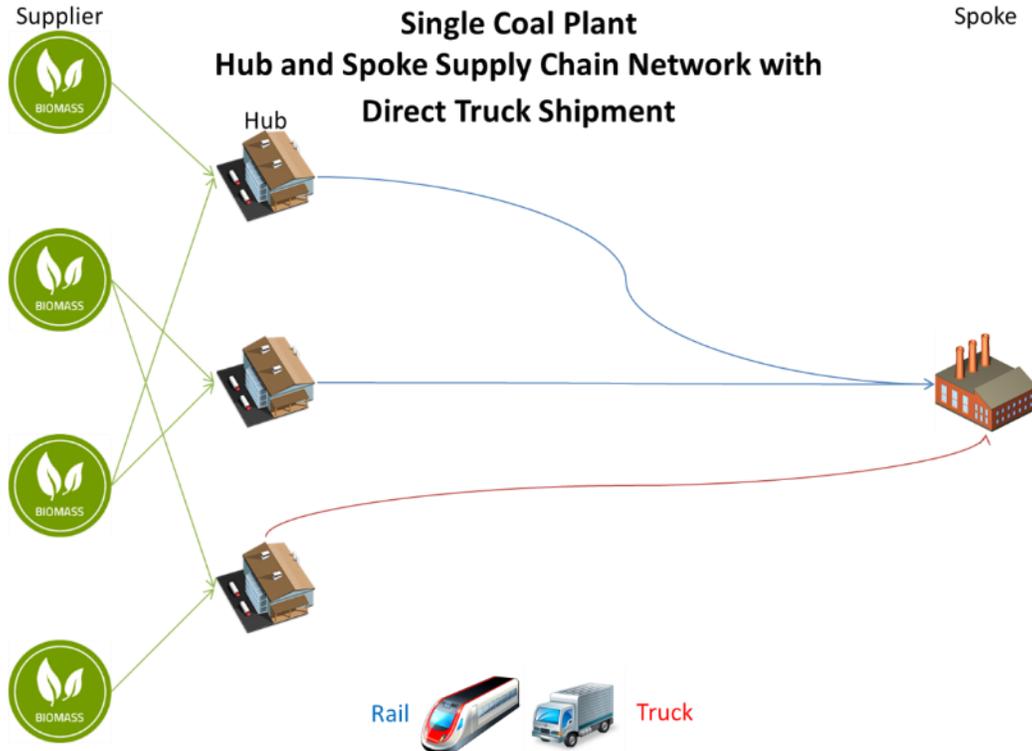


Figure 3 Hub-and-Spoke Model

We know that our objective is to minimize the transportation cost of the biomass throughout the supply chain network. In this model we have a few parameters and indices. First, we have I which denotes the set of all biomass suppliers; J is the set of hubs; C is the coal plant. A denotes the set of arcs in the network. S_i is the amount of biomass available at county supplier $i \in I$. D is the amount of biomass required at coal

plant C . m is the maximum amount of biomass allowed on each train.

u_j is the max capacity of each hub. c_{ij} represents the cost of transporting one unit of biomass across an arc $(i, j) \in A$. Ψ_j represents the fixed cost of operating hub $j \in J$.

Finally there is the fixed cost per train leaving hub $j \in J$, γ_j .

The decision variables are: X_{ij} which represents for each arc in the network the amount shipped across an arc $(i, j) \in A$. Y_j , the total number of trains initiated from hub $j \in J$, and W_j which is a binary variable indicating whether a hub is used or not.

The model can be seen here in detail and is a special case of the model presented by Roni (Roni, 2013):

$$\text{Min } Z = \sum_{(i,j) \in A} c_{ij} X_{ij} + \sum_{j \in J} \gamma_j Y_j + \sum_{j \in J} \Psi_j W_j \quad (1)$$

$$\text{s. t } \sum_{j=1}^J x_{ij} \leq S_i \quad \forall i = 1, \dots, I; \quad (2)$$

$$\sum_{i=1}^I x_{ij} - x_{jc} = 0 \quad \forall j = 1, \dots, J; \quad (3)$$

$$\sum_{j=1}^J x_{jc} = D \quad (4)$$

$$x_{jc} \leq mW_j \quad \forall j = 1, \dots, J; \quad (5)$$

$$\sum_{i=1}^I x_{ij} \leq u_j Y_j \quad \forall j = 1, \dots, J; \quad (6)$$

$$X_{ij} \in R^n \quad \forall (i, j) \in A \quad (7)$$

$$W_j \in \{0,1\} \forall j = 1, \dots, J; \quad (8)$$

$$Y_j \in Z^+ \forall j = 1, \dots, J; \quad (9)$$

Equation (1) is the objective function which minimizes total supply chain cost. Constraints (2) indicate that the amount of biomass available at a supply node i is limited. This constraint also indicates that a supplier initiates a shipment when an order is received. Constraints (3) indicate that the amount of biomass arrived at a hub j is equal to the amount of biomass that leaves hub j . Constraints (4) guarantee that demand for the coal plant is satisfied. Constraints (5) show that the amount of biomass (in tons) sent from a hub to the coal plant cannot be greater than the capacity (in tons) of the trains. Constraints (6) show that a hub cannot receive more biomass than it has capacity for. Constraints (7) are the non-negativity constraints. Constraints (8) are the binary constraints. Constraints (9) are the integer constraints (Roni, 2013).

Math Model with Point-to-Point Truck Transportation for Short Distances

In this model we have a few parameters and indices. Let $G(N,A)$ represent the in-bound distribution network of the coal plant that is within the truck shipping radius determined by the user. Let N denote the set of nodes, and A denote the set of arcs. Set N consists of subsets: I which represents the set of all biomass suppliers, and node C which represents the coal plant. A denotes the set of arcs in the network. Set A consists of arcs (i,C) which traverse suppliers and coal plants. S_i is the amount of biomass available at county supplier $i \in I$. D is the amount of biomass required at coal plant C . m is the capacity of each truck. u is the capacity of the coal plant. c_{iC} represents the cost of transporting one unit of biomass across an arc $(i,C) \in A$. Ψ_i represents the fixed order

cost per shipment from location i . γ is the fixed cost for loading and unloading a truck, and it is the same for all arcs in the network. The decision variables are: X_i which represents for each arc in the network the amount shipped across an arc $(i, C) \in A$. Y_i is the total number of trucks shipped from supplier j to the coal plant. W_{iC} is a binary variable indicating whether or not a shipment is received from that supplier $j \in J$. The model can be seen here in detail:

$$\text{Min } Z = \sum_{(i,c) \in A} c_{iC} X_{iC} + \sum_{i \in I} \gamma Y_i + \sum_{i \in I} \psi_i W_i \quad (10)$$

$$s. t \ X_{iC} \leq S_i W_i \quad \forall i = 1, \dots, I; \quad (11)$$

$$X_{iC} \leq m Y_i \quad \forall i = 1, \dots, I; \quad (12)$$

$$\sum_{i=1}^I X_{iC} \leq u; \quad (13)$$

$$X_{iC} \in R^+ \quad \forall (i, C) \in A \quad (14)$$

$$W_i \in \{0,1\} \quad \forall i = 1, \dots, I; \quad (15)$$

$$Y_i \in Z^+ \quad \forall i = 1, \dots, I; \quad (16)$$

Equation (10) is the objective function which minimizes the total supply chain cost. Constraints (11) indicate that the amount of biomass available at a supply node i is limited. Constraints (12) show that the amount of biomass (in tons) sent from a supplier to a coal plant cannot be greater than the capacity (in tons) of the truck. Constraints (13) show that a coal plant cannot receive more biomass than it has capacity for. Constraints (14) are the non-negativity constraints. Constraints (15) are the binary constraints. Constraints (16) are the integer constraints.

These models will be implemented using VBA code to populate the CPLEX solver with the variables and constraints.

User Interface

In Druzdzel and Flynn's report on DSS's, they state, "Decision support systems aid human cognitive decisions by integrating various sources of information, providing intelligent access to relevant knowledge, aiding the process of structuring, and optimizing decisions." They go on to say that the most critical part of the DSS is the user interface and that, "cumbersome and unclear interfaces that require unusual skills are rarely useful and accepted in practice." Another key principle that I believe can be taken from Druzdzel and Flynn's article on DSS's is that modeling is rarely a one-shot process, and models are usually refined and enhanced as their users gather practical experiences with the system recommendations (Druzdzel & Flynn, 2002).

Based on this it is clear that it is just as important to have a friendly user interface as it is to have a robust model. Because of this truth, the GUI went through several different revamps. To understand how the user interface works it is best to look at the Excel file sheet by sheet. The following figure shows the structure of the DSS.

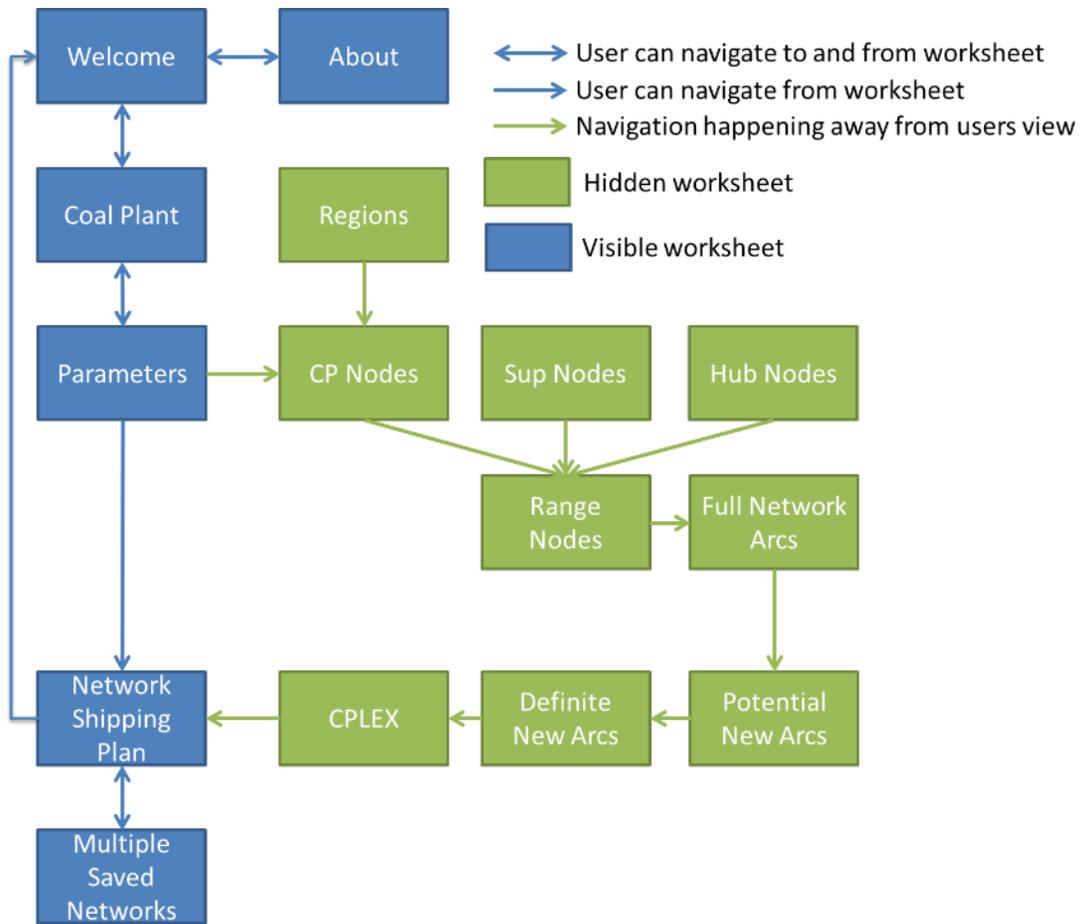


Figure 4 DSS Structure

Worksheets

Welcome

The worksheet that is visible upon opening the DSS. It contains four buttons that link to other worksheets in the DSS. Underneath these four buttons is a graphic that depicts the basic layout and flow of the type of supply chain that the DSS can find a Network Shipping Plan for. Figure 4 shows the Welcome worksheet.

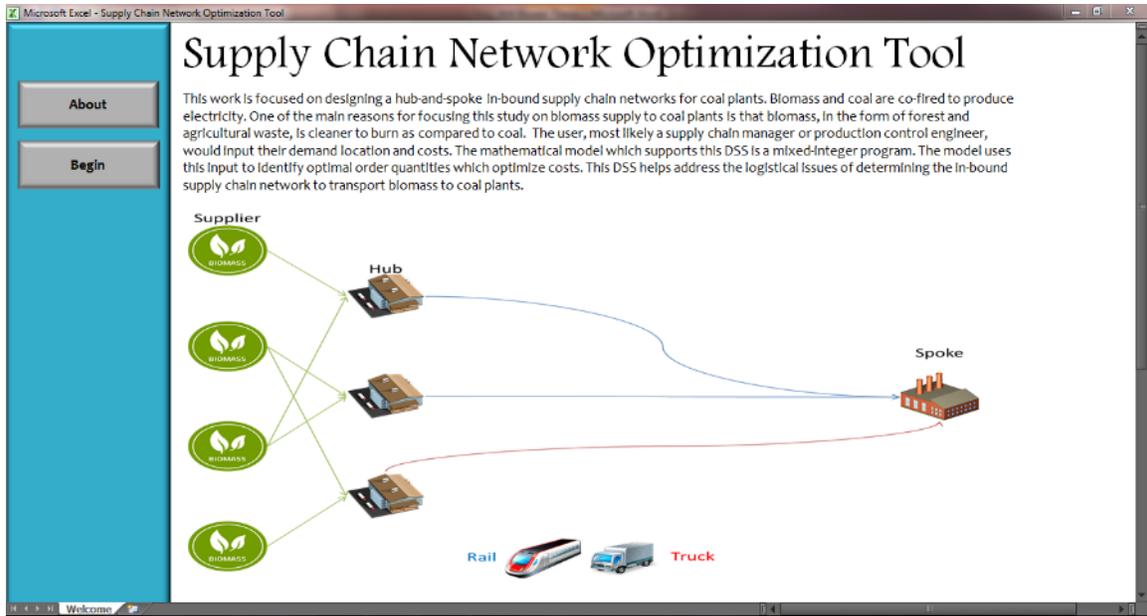


Figure 5 Welcome Worksheet

About

This worksheet can be accessed by selecting the About button on the Welcome sheet. This worksheet describes in detail the layout, functions, design, development and implementation of the model that became the DSS.

Coal Plant

This is a visible worksheet that contains the listbox with all of the coal plants in it. The user selects a single coal plant and the linked cell in the CP Nodes worksheet changes to reflect the selected coal plant. This in turn changes a series of cells that affects the definite network used in the CPLEX model. The flow of the DSS takes the user from this worksheet to the Parameters worksheet. Figure 5 shows the Coal Plant worksheet.

Microsoft Excel - Supply Chain Network Optimization Tool

Please select a Coal Plant:

Node ID	NAME	STATE	X	Y	SPLC	Rail Station?	Biomass Der
12095	MOORMAN	KY	-87.1444206104	37.3824454501	297114	1	-394
12162	PARADISE	KY	-86.9873362376	37.2383949416	297136	1	-4919
12272	BURNSIDE	KY	-84.3968604975	36.9967694198	292163	1	-653
12421	NEW RICHMON	KY	-84.2897522871	38.9461499151	282485	1	-2761
12501	BASTROP	LA	-91.91190244605	32.7872728448	651560	1	-115
12632	BAYOU PIERRE	LA	-93.5323232595	32.14859349471	656140	1	-1649
12693	COLFAX	LA	-92.7022780291	31.51486999231	655794	1	-1934
12801	PATINS GIN SP	LA	-91.49966812091	30.69324731821	6444219	1	-3605
12937	MOSSVILLE	LA	-93.2984568869	30.24120424291	688672	1	-3077
13418	RUMFORD	ME	-70.5413878427	44.55037185651	116721	1	-117
13495	WESTBROOK C	ME	-70.3488140261	43.67912371801	119320	1	-2
13583	WILLIAMSPOR	MD	-77.8205714651	39.6076142489	233499	1	-212
13587	NORTH BRANC	MD	-78.7384713981	39.5907792608	233672	1	-442
13627	LUKE	MD	-79.0563772661	39.47350606082	233784	1	-126
13671	CHASE	MD	-76.3689822331	39.3625083860	232314	1	-802
13690	HARVEY 1	MD	-79.33455221181	39.2995947072	232860	1	-154
13793	DICKERSON	MD	-77.444662692	39.22681447511	232301	1	-1792
13813		MD	-76.548284596	39.20281019181	232350	1	-4679
13862	INDIAN HEAD J	MD	-76.944077409	38.58710602621	239420	1	-2983
13865	HERBERT	MD	-76.7975409111	38.55958223281	237898	1	-4071
13968	SALCAM	MA	-76.0960916881	42.3214492119	140420	1	-1532

Figure 6 Coal Plant Worksheet

Parameters

Here the user can update the Parameter values of the model. This is convenient for the user if cost or capacity values change. These values are copied and pasted into the CPLEX worksheet in preparation for the model being solved. This worksheet's next button launches a series of sub procedures that create the sub-network, set up the CPLEX worksheet, and launch the CPLEX solver. Figure 6 shows the Parameters worksheet.

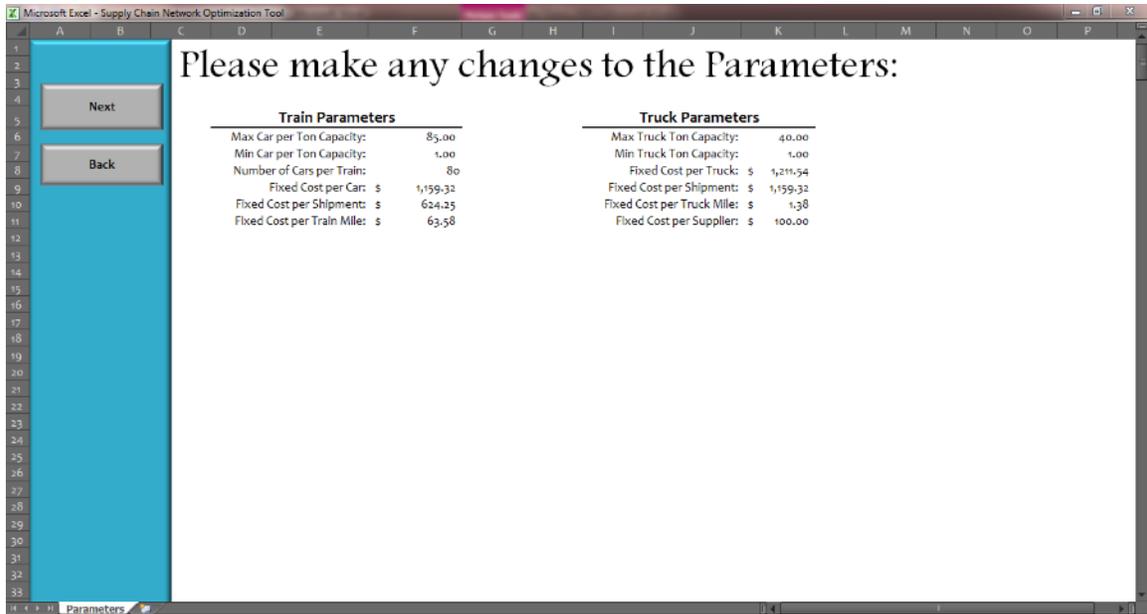


Figure 7 Parameters Worksheet

Network Shipping Plan (NSP)

This worksheet is the final output and optimal solution given the network structure. This has the NSP which tells how much you order from which supplier, how much it is going to cost you, and which hub(s) it is being routed through. The user will also have the ability to make potential changes to the NSP and have the model re-solve for an optimal solution based on the changes that is made. The user can also view graphs that provide more insight into the resulting NSP. Figure 7 shows the Network Shipping Plan worksheet.

Coal Plant	Region	Total Arcs	Train Arcs	Rail Arcs	Total Cost: \$ 7,007,78													
13968	NE	1	0	1														
Arc	From	To	Connection Type	Distance	Max Arc Capacity	Residual Arc Capacity	Arc Utilization	Flow Cost	Active	No. of Trains	Quantity (Tons)	Cost						
Truck Route	157	327	13	43.54795	40	38.00	0.0500	\$ 55.20	1.00	3.00	63.00	\$ 7,007,78						

Figure 8 Network Shipping Plan Worksheet

CP Nodes

This is the list of all coal plants in the network. This worksheet feeds the listbox in the Coal Plant worksheet.

Sup Nodes

This is a hidden worksheet that contains all of the information for all of the suppliers in the network. These are filtered out based on their distances from the coal plant. Only suppliers within the radius are included in the Potential New Arcs worksheet. It is important to note that if the supplier amount of biomass within the radius is not adequate, this will trigger the macro to increase the radius until there is enough supply to meet demand.

Hub Nodes

This is a hidden worksheet that contains all of the information for all of the hubs in the network. As in Sup Nodes, these are filtered out based on their distance from the coal plant and only those within the radius are included in the Potential New Arcs worksheet.

Range Nodes

This is the list of all the nodes that are in the radius. They are grouped according to supplier, hub, or coal plant and their respective capacities are listed with them.

Full Network Arcs

This is a list of all of the arcs in the entire network. These are filtered based on whether or not both of the nodes in the arc are within the coal plants radius. If so, they are added to the Potential New Arcs worksheet.

Potential New Arcs

This is a hidden worksheet and is list of all of the arcs that came from the Full Network Arcs worksheet that had both nodes within the coal plant radius. A depth first approach, described later, is applied to these arcs to determine which arcs are actually connected to the coal plant. These arcs are pasted into the Definite New Arcs worksheet.

Definite New Arcs

This is a hidden worksheet that that contains the list of arcs and grouped nodes that will be used in the CPLEX model formulation. These are copied and pasted into the CPLEX worksheet.

Regions

This is a hidden worksheet that has a list of all the states and the regions that they are associated with. A vlookup formula is used in the CP Nodes worksheet to link the Region to the Nodes.

CPLEX

This is a hidden worksheet that cannot be accessed by the user. This worksheet is populated from the Current Network worksheet when the Solve the Current Network button is pressed. The data in the CPLEX worksheet is what the CPLEX engine references when it is looking for an optimal solution to the current network.

Summary Charts

This is also a hidden worksheet. This is where the charts are generated that are later displayed in the Network Shipping Plan worksheet. The final NSP is copied from the CPLEX output and is pasted into this worksheet. From there, a series of pivot tables and pivot charts that reference the range where the NSP is located are refreshed, thus reflecting the new data. Now the refreshed charts and graphs are saved as .gif files and are later pasted as images into a form that can be referenced from the Network Shipping Plan worksheet.

Previous Networks

This worksheet is designed to serve as a place where users can recall previous NSP's to view or can compare multiple NSP profiles side by side.

Multiple Saved Networks

These worksheets are NSP's for a particular coal plant. Ideally, the worksheet's name will have some sort of a descriptive name that will make it easy to determine which coal plant that particular NSP is associated with.

Functionalities of the User Interface

Navigation

As we saw in the previous section, the user interface is setup in a way that forces the user in one of two directions: backward and forwards. Each visible worksheet in the DSS serves to gather information from the user and uses that to setup the CPLEX solver. Even though there are 14 worksheets in the model, the user only sees 6 of them and one is the Welcome screen.

Update Parameters

This functionality is encompassed in a single worksheet and is actually a very simple yet powerful concept. This allows the user to adjust the cost and capacity values as they might change over time.

Recall Networks

This allows the user to pull up previous NSP's to simply view them. The functionality is found on the Previous Networks worksheet.

Compare Networks

This functionality allows the user to pull up the supply chain of a particular coal plant and compare it with another coal plant. This adds another level of data analysis for

the user as well as an easy way to recall previous supply chains without having to resolve them.

Solve the Network

This functionality is a behind the scenes process that makes use of the overall network and the information gathered from the user throughout the DSS that they have to walk through. The network is solved using CPLEX. Once the supply chain has been found, the DSS outputs a NSP as well as graphs that provide insight into the supply chain.

Analysis Base

The analysis of the NSP is done on the Summary Charts worksheet. On this worksheet we attempt to summarize and provide insight into the NSP by providing the user with graphs and tables that are easy to understand. The first table that we have is the actual NSP. This is the detailed shipping plan of each unit through the entire supply chain network.

Arc	From	To	Connection Type	Distance	Max Arc Capacity	Residual Arc Capacity	Arc Utilization	Unit Flow Cost	Active	No. of Trains	Quantity (Tons)	Total Cost
4	4	20	1-2	15.00	1,000.00	999.00	0.001	75.00	1.00	1.00	100.00	120,125.00
8	8	24	1-2	45.00	1,000.00	997.00	0.003	225.00	1.00	3.00	1,000.00	558,625.00
9	9	25	1-2	37.00	1,000.00	999.00	0.001	185.00	1.00	1.00	400.00	186,625.00
11	11	27	1-2	11.00	1,000.00	999.00	0.001	55.00	1.00	1.00	200.00	123,625.00
12	12	28	1-2	23.00	1,000.00	997.00	0.003	115.00	1.00	3.00	1,000.00	448,625.00
15	15	31	1-2	62.00	1,000.00	999.00	0.001	310.00	1.00	1.00	250.00	190,125.00
16	0	31	1-2	58.00	1,000.00	999.00	0.001	290.00	1.00	1.00	100.00	141,625.00
18	2	17	1-2	15.00	1,000.00	999.00	0.001	75.00	1.00	1.00	50.00	116,375.00
26	10	25	1-2	26.00	1,000.00	999.00	0.001	130.00	1.00	1.00	200.00	138,625.00

Figure 9 Network Shipping Plan

Now that we have the NSP, as we said earlier, we want to provide insight into the NSP to the user by way of graphs. We will generate graphs

that provide insight into the county suppliers (spokes), hub locations (hubs), and coal plants (spokes). Particularly we want to show the amount shipped and cost of shipping from each supplier, amount received and shipped and the cost of receiving and shipping for each hub, and the amount received and cost of receiving for each coal plant. The following graphs do just that:

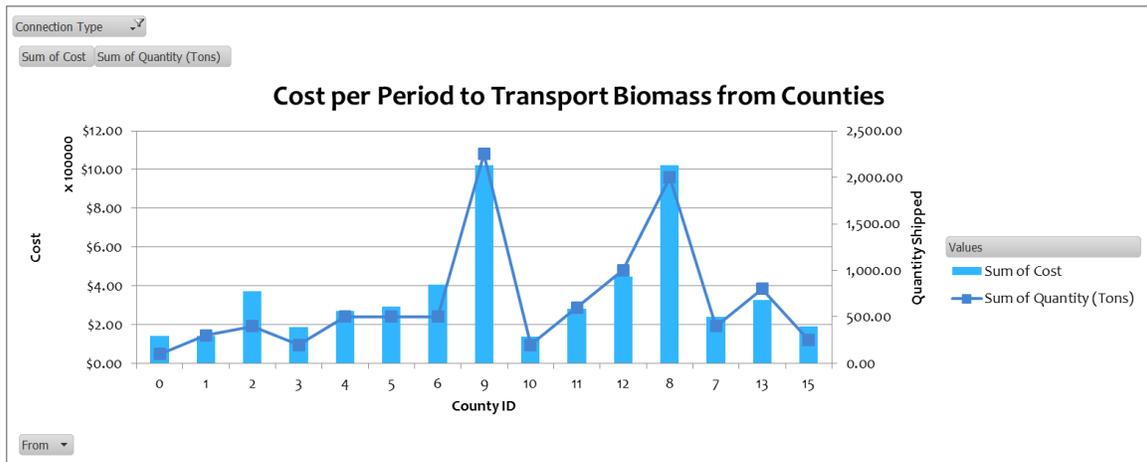


Figure 10 Supplier Insight

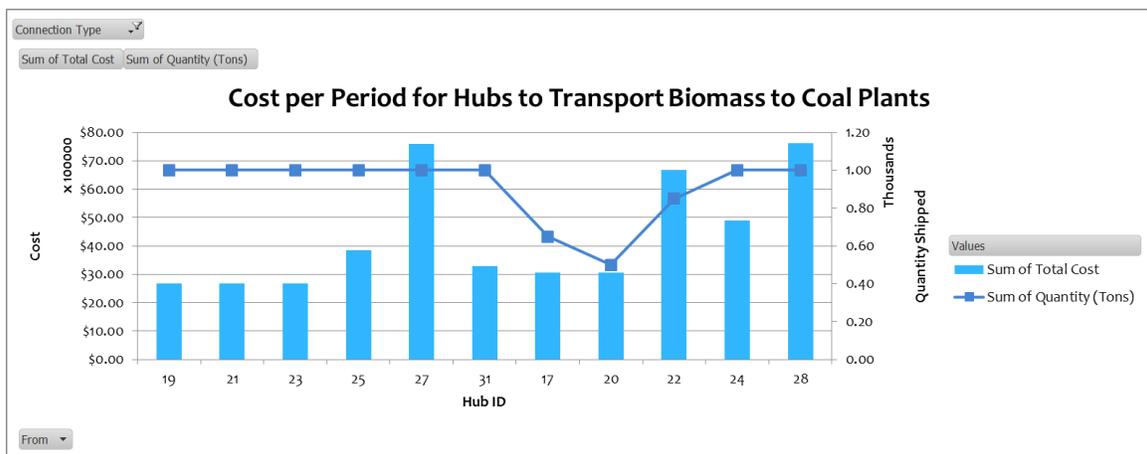


Figure 11 Hub to Coal Plant Insight

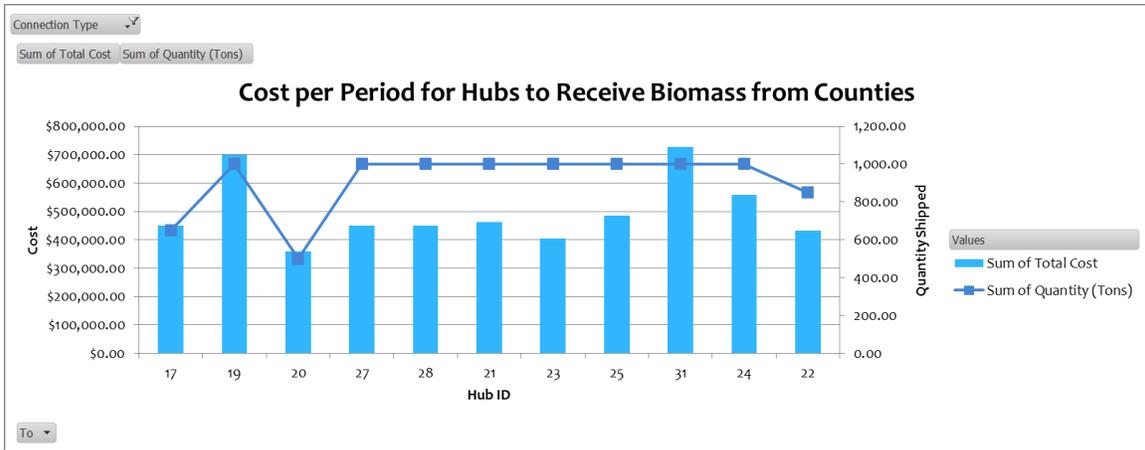


Figure 12 County to Hub Insight

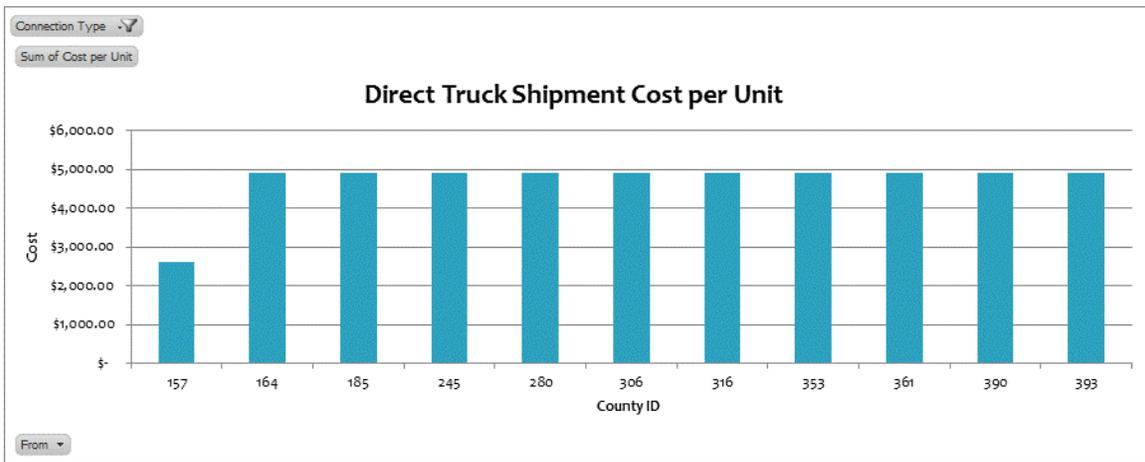


Figure 13 Direct Truck Shipment

Database

The data in our Database is composed of two parts. The first is the list of routes in the network and their associated unit flow costs, utilizations, distances, max and min capacities, etc. Second, are the parameter costs: max and min rail car capacity, fixed costs per car, train, mile, and hub. The first part is a static list of over 40,000 rail arcs and is not

editable by the user. The second part is visible and editable by the user in case capacities or costs change. The rail arc data was provided by Idaho National Labs and for the purposes of our model formulation went through a few steps to reduce the arcs to try and solve the supply chain. The steps taken to reduce this network size are discussed in the next chapter.

CHAPTER IV

DATA COLLECTION

Raw Data

The data about the rail network comes from the Center for Transportation Analysis (CTA) Railroad Network which is an extension of the Federal Railroad Administration's strategic network and is a representation of the North American railroad system. This Database contains every railroad route in the US, Canada, and Mexico that has been active since 1993 (Laboratory O. R., 2012). We are only interested in the US railroads. The raw data contains the location of each rail link. The location is presented in terms of latitude and longitude. Biomass will be transported from each county to a centralized county via truck. These centralized counties will serve as our supplies points and are spokes in our hub-and-spoke network. The biomass will then be transported by rail through the various hubs and eventually to the demand points, also spokes, which are power plants. Figure 13 shows existing rail networks across the US.



Figure 14 US Rail Network
(World, 2013)

The power plant location data comes from the National Energy Technology Laboratory (NETL). This dataset contains the location and biomass demand of every coal-fired power plant in the US. Since we have the locations for these coal plants as well as the various rail stations on the rail network, we identified the rail stops closest to each coal plant. Similar to the supply locations, the actual demand point is the rail location. Figure 14 shows the location of coal plants across the US. Now that we have all of the supply and demand data in one location we can begin to analyze and clean the data if necessary.

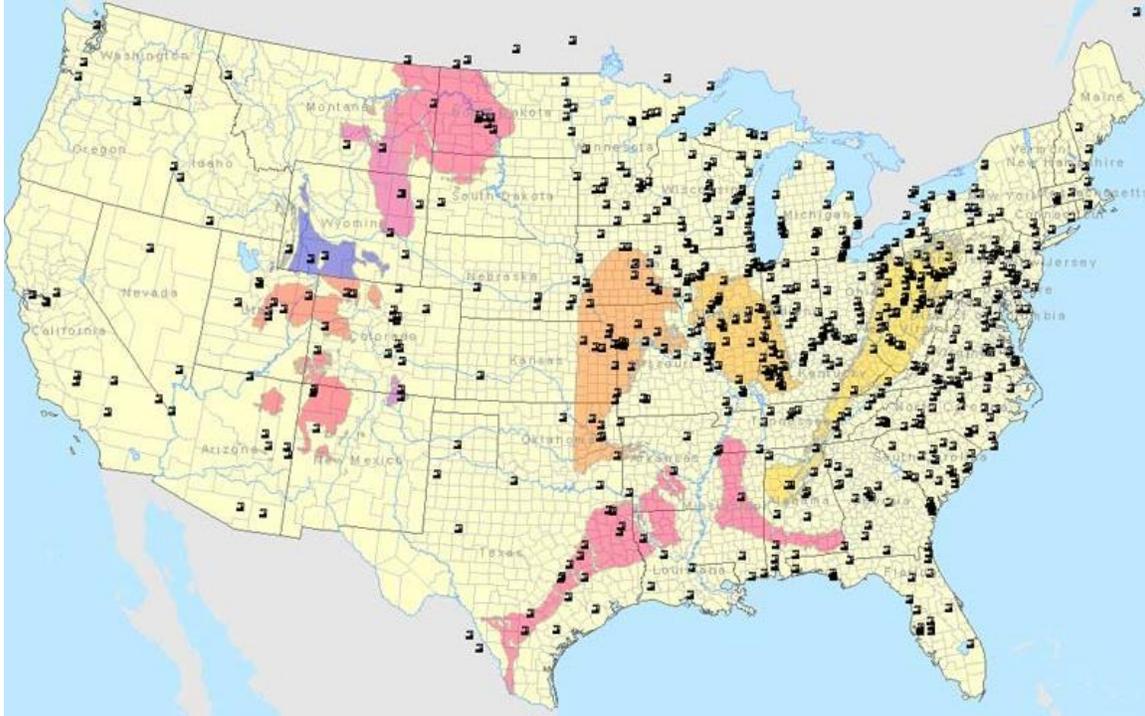


Figure 15 Coal Plant Locations
 (Laboratory N. E., Coal-Fired Power Plants (CFPPs), 2013)

Preprocessing the Data

Preprocessing the data consists of two parts: calculating demand and creating the sub-network. The demand for each coal plant is given to us in terms of demand per year. We first convert this to weekly data by dividing by 52. Now we will multiply the remaining value by 0.2 because we want to displace up to 20% of the coal. This gives us our weekly biomass demand for the respective coal plant.

The main part of preprocessing the data was creating a sub-network for each coal plant. We have to create these sub-networks for a couple of reasons. First, we want to reduce the number of arcs to make it easier for CPLEX to solve. Second, because we are focusing on satisfying demand for individual coal plants and not all of the coal plants at the same time. Although, this takes some extra work on the front end, it can save time

when trying to find an optimal solution. There are a few steps that went in to creating these sub-networks.

First, it is important to know that provided in the raw data for every location are the latitudinal and longitudinal coordinates. From these coordinates we can calculate the distance between a node and any other node in the network. Specifically, we want to know the distance from each supplier and hub to coal plant chosen by the user. In order to do this I had to create a few extra fields. First I needed a cell that was linked to the list box containing the coal plants. When a user selects a coal plant the coal plant's unique ID would be placed in the linked cell. Then with the help of a couple of vlookup formulas I was able to pull the latitude and longitude of the coal plant. Next I created an extra field next to the list of suppliers and hubs coordinates that calculated the distance from the suppliers and hubs to the values placed in the coal plant coordinate cells,

With these known distances from the suppliers and hubs to the coal plant I can filter for only those that are within a certain radius of the coal plant. For the purposes of this model, I chose to start the radius at 50 miles and increase it by 50 miles until there is enough biomass to satisfy the demand of the coal plant. Now that I have my list of hubs and suppliers that are within the radius I went through the arcs and pulled out only the ones that have both the from and to locations inside the radius of the coal plant. The resulting list of arcs is what I call "potential arcs". They are potential because they are inside the radius but they may be removed if the arc does not connect to the coal plant via itself or another arc inside the radius.

In order to determine which arcs will be in the network used to determine the supply chain we need to apply a depth-first search approach to determining the coal

plant's supply chain network. Simply, we look at each hub via an arc that directly feeds into the coal plant. We then worked back from these hubs until we arrived at a supplier. Each of the arcs that lead from the coal plant back to a supplier was added to the definite arcs list. To put into perspective how effective this is, this reduced a list of potential arcs containing about 1500 arcs to a list of definite arcs containing about 15 arcs. This obviously decreased process time which made the model much more efficient.

CHAPTER V
REGIONAL ANALYSIS

Regional Profiles

The network was divided into five different regions in order to compare their NSP's. The five regions are shown in the following map (United States Regions, 2006) and the regional profile is shows in Table 3:

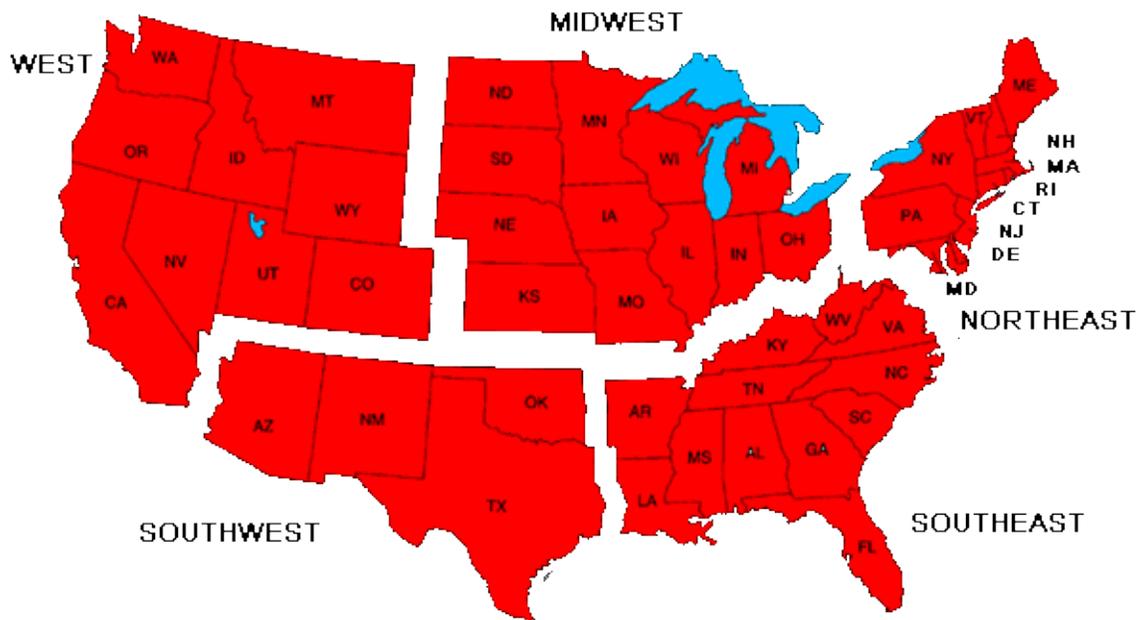


Figure 16 US Regions

Table 2 Regional Profiles

Region Profiles	Total Nodes	Suppliers	Hubs	Coal Plants	Biomass Ratio
SE	8689	719	7820	150	21%
SW	4147	114	3999	34	30%
W	5471	134	5291	46	34%
MW	12142	832	11099	211	25%
NE	5310	111	5103	96	86%

Based on the regional profiles we can draw a few hypotheses and test to see if they are true. One thing to point out is the column Biomass Ratio This is simply the number of coal plants divided by the number of suppliers. Based on this table there are two hypotheses that we can come up with. First, the closer the Biomass Ratio is to 1 the more likely the coal plant will need a larger radius to meet its demand because of the limited supply. Second, the larger the radius the higher the cost will be to meet demand. We will determine the NSP's and profiles for five randomly selected coal plants, one from each region, and compare the results.

Regional Analysis

Here are the five selected coal plants and their respective regional profiles and costs:

Table 3 Resulting Supply Chain Profiles

Coal Plant	Location	Region	Radius	Total Arcs	Truck Arcs	Rail Arcs
327	Childersburg, AL	SE	50	1	1	0
30397	Singleton, TX	SW	50	1	1	0
2234	Ortega, CA	W	50	1	1	0
7896	Sicily, IL	MW	50	1	1	0
4151	Dagsboro, DE	NE	50	2	2	0

Table 4 Resulting Supply Chain Costs

Coal Plant	Location	Region	Demand	Total Cost	Cost per Unit
327	Childersburg, AL	SE	63	\$ 7,060.00	\$ 112.06
30397	Singleton, TX	SW	795	\$ 68,722.12	\$ 86.44
2234	Ortega, CA	W	116	\$ 11,197.14	\$ 96.53
7896	Sicily, IL	MW	2542	\$219,016.28	\$ 86.16
4151	Dagsboro, DE	NE	1540	\$134,576.70	\$ 87.39

A few observations: First, we notice that every single NSP chose to use trucks instead of trains. The reason for this is that obviously the cost per unit is cheaper with a truck than it would be with rail. Similarly, every NSP could meet demand via rail with only a 50 mile radius. We see that the SW, MW, and NE regions were all fairly close in terms of cost per unit, whereas, the W and SE regions were both noticeably larger. To answer the question as to why the SE region’s cost per unit is so much higher we need to go back and look at the parameters. When we look, we see that the capacity of an 18-wheeler truck is only 40 tons which means that for every 40 tons you will have to bring on another truck, even though only partially full, to meet demand. That is why the SE region has such a higher cost per unit than the others—it’s only half full! So the key here isn’t necessarily being closer to the coal plant as much as it is fully utilizing whatever resources you need to meet demand.

Sensitivity Analysis

A few sensitivity analyses were performed to see what the effects of supply, truck costs, and rail costs were on the total cost.

Effect of Supply

The following table shows the effect of supply on the total cost. The percent of biomass available to the coal plant is limited to attempt simulate what it would be like if the model could accommodate multiple coal plants in the same area. It is clear to see that given these parameters it has no affect. This is because of the low quantity needed by the coal plant and the fact that the quantity can be shipped via truck. So even though the radius does increase to 100, suppliers within 50 miles are used to meet demand using truck shipments. What this does show us is that if a rail shipment was needed it would need a larger radius of supply in order to meet demand.

Table 5 Effect of Supply

Coal Plant 2234 Ortega, CA							
Supply	Results						
% of Total	Radius	Total Arcs	Truck Arcs	Rail Arcs	Demand	Total Cost	Cost per Unit
20%	100	1	1	0	116	\$11,197.14	\$ 96.53
40%	100	1	1	0	116	\$11,197.14	\$ 96.53
60%	50	1	1	0	116	\$11,197.14	\$ 96.53

Effect of Truck Cost

The following table shows the effects of changing the various costs associated with truck transportation. There are a few things that stand out. First as expected as you increase the various costs, the total cost also increases. However, it seems that increase in Fixed Cost per Shipment had less of an affect than the increase in Fixed Cost per Truck. It seems that the change in Fixed Cost per Mile had the most effect on the Total Cost.

Table 6 Effect of Truck Cost

Coal Plant 2234 Ortega, CA									
Truck Parameter			Results						
Fixed Cost per Truck	Fixed Cost per Shipment	Fixed Cost per Truck Mile	Radius	Total Arcs	Truck Arcs	Rail Arcs	Demand	Total Cost	Cost per Unit
\$ 1,211.54	\$ 1,159.32	\$ 1.38	50	1	1	0	116	\$11,197.14	\$ 96.53
\$ 1,100.00	\$ 1,159.32	\$ 1.38	50	1	1	0	116	\$10,862.52	\$ 93.64
\$ 1,300.00	\$ 1,159.32	\$ 1.38	50	1	1	0	116	\$11,462.52	\$ 98.81
\$ 1,500.00	\$ 1,159.32	\$ 1.38	50	1	1	0	116	\$12,062.52	\$ 103.99
\$ 1,700.00	\$ 1,159.32	\$ 1.38	50	1	1	0	116	\$12,662.52	\$ 109.16
\$ 1,211.54	\$ 1,100.00	\$ 1.38	50	1	1	0	116	\$11,137.82	\$ 96.02
\$ 1,211.54	\$ 1,300.00	\$ 1.38	50	1	1	0	116	\$11,337.82	\$ 97.74
\$ 1,211.54	\$ 1,500.00	\$ 1.38	50	1	1	0	116	\$11,537.82	\$ 99.46
\$ 1,211.54	\$ 1,700.00	\$ 1.38	50	1	1	0	116	\$11,737.82	\$ 101.19
\$ 1,211.54	\$ 1,159.32	\$ 1.20	50	1	1	0	116	\$10,361.94	\$ 89.33
\$ 1,211.54	\$ 1,159.32	\$ 1.45	50	1	1	0	116	\$11,521.94	\$ 99.33
\$ 1,211.54	\$ 1,159.32	\$ 1.70	50	1	1	0	116	\$12,681.94	\$ 109.33
\$ 1,211.54	\$ 1,159.32	\$ 1.95	50	1	1	0	116	\$13,841.94	\$ 119.33

Effect of Rail Cost

The following table shows the effects of changing the various costs associated with train transportation. It was puzzling at first to see that there was no change in cost at all regardless of the changes made. Then it became apparent. The reason for this is because the model is still using truck transportation because none of the changes listed make it more efficient to use a train. This is due to the low quantity being shipped which is due to the weekly demand and the single coal plant being serviced.

Table 7 Effect of Rail Costs

Coal Plant 2234 Ortega, CA									
Train Parameter			Results						
Fixed Cost per Train	Fixed Cost per Shipment	Fixed Cost per Train Mile	Radius	Total Arcs	Truck Arcs	Rail Arcs	Demand	Total Cost	Cost per Unit
\$1,159.32	\$ 624.25	\$ 63.58	50	1	1	0	116	\$11,197.14	\$ 96.53
\$1,100.00	\$ 624.25	\$ 63.58	50	1	1	0	116	\$11,197.14	\$ 96.53
\$1,300.00	\$ 624.25	\$ 63.58	50	1	1	0	116	\$11,197.14	\$ 96.53
\$1,500.00	\$ 624.25	\$ 63.58	50	1	1	0	116	\$11,197.14	\$ 96.53
\$1,700.00	\$ 624.25	\$ 63.58	50	1	1	0	116	\$11,197.14	\$ 96.53
\$1,159.32	\$ 500.00	\$ 63.58	50	1	1	0	116	\$11,197.14	\$ 96.53
\$1,159.32	\$ 700.00	\$ 63.58	50	1	1	0	116	\$11,197.14	\$ 96.53
\$1,159.32	\$ 800.00	\$ 63.58	50	1	1	0	116	\$11,197.14	\$ 96.53
\$1,159.32	\$ 900.00	\$ 63.58	50	1	1	0	116	\$11,197.14	\$ 96.53
\$1,159.32	\$ 624.25	\$ 50.00	50	1	1	0	116	\$11,197.14	\$ 96.53
\$1,159.32	\$ 624.25	\$ 70.00	50	1	1	0	116	\$11,197.14	\$ 96.53
\$1,159.32	\$ 624.25	\$ 80.00	50	1	1	0	116	\$11,197.14	\$ 96.53
\$1,159.32	\$ 624.25	\$ 90.00	50	1	1	0	116	\$11,197.14	\$ 96.53

Conclusions and Future Work

I was able to create a user friendly DSS that addressed the logistical issues of transporting biomass to coal plant plants. The model focused on transporting biomass to an individual coal plant using rail and truck shipping options. It was seen that the truck option was most commonly used because of the small quantities being shipped and the lower fixed costs associated with the truck shipping option. The sensitivity analyses showed that changes to the rail costs had no effect on the total cost because the rail option was never used. When it comes to truck costs, the fixed cost per mile had the most effect on the total cost.

In regards to future work a few areas in particular come to mind. First, the model could be expanded to accommodate multiple coal plants instead of just one. Second, the user could also be allowed to change the demand and supply at each of the locations in

the network. Finally, the model could be adjusted to allow the user to select the range in which trucks can be used instead of having it preset at 50 miles.

REFERENCES

- Abduljabbar, W. K., & Tahar, R. M. (2012). A case study of petroleum transportation logistics: A decision support system based on simulation and stochastic optimal control. *African Journal of Business Management*, 4350-4361.
- Acharya. (2012). AN EXCEL-BASED DECISION SUPPORT SYSTEM FOR SUPPLY CHAIN DESIGN AND MANAGEMENT OF BIOFUELS.
- Alter, S. (1980). *Decision Support Systems: Current Practice and Continuing Challenges*. Reading, Mass.: Addison-Wesley, Inc.
- Austin, A. (2011, August 23). *Biomass and Coal: A Powerful Combination*. Retrieved from Biomass Magazine: <http://biomassmagazine.com/articles/5751/biomass-and-coal-a-powerful-combination>
- Bellis, M. (2013, June 13). *The History of Computers*. Retrieved from About: <http://inventors.about.com/library/blcoindex.htm>
- Bonsor, K. (2001, June 14). *How Airlines Work*. Retrieved from How Stuff Works: <http://science.howstuffworks.com/transport/flight/modern/airline3.htm>
- Bryan, D. L., & O'Kelly, M. E. (1999). Hub-and-Spoke Networks in Air Transportation: An Analytical Review. *Journal of Regional Science Vol. 39 No.2*, 275-295.
- Ciolkosz, D. (2010). *Renewable and Alternate Energy Fact Sheet*. Retrieved from Agricultural Research and Cooperative Extension: <http://pubs.cas.psu.edu/freepubs/pdfs/ub044.pdf>
- Congress, U. S. (1999, 4 30). *Biomass Research and Development Act of 2000*. Retrieved from The Library of Congress: <http://thomas.loc.gov/cgi-bin/bdquery/z?d106:SN00935:@@D&summ2=m&>
- Congress, U. S. (2005, May 26). *Clean Coal Research, Development, Demonstration, and Deployment Act of 2005*. Retrieved from Library of Congress: <http://www.gpo.gov/fdsys/pkg/BILLS-109s1133is/pdf/BILLS-109s1133is.pdf>
- Congress, U. S. (n.d.). *Energy Policy Act of 1992*. Retrieved 3 23, 2013, from The Library of Congress: <http://thomas.loc.gov/cgi-bin/bdquery/z?d102:HR00776:@@D&summ2=m&>

- Congress, U. S. (n.d.). *Energy Policy Act of 2005*. Retrieved 3 23, 2013, from The Library of Congress: <http://thomas.loc.gov/cgi-bin/bdquery/z?d109:HR00006:@@D&summ2=m&>
- De Mol, R., Jogems, M., Van Beek, P., & Gigler, J. (1997). Simulation and optimization of the logistics of biomass fuel collection. *Netherlands Journal of Agricultural Science*, 219-228.
- Druzdzel, M. J., & Flynn, R. R. (2002). *Decision Support Systems*. Pittsburgh, PA: University of Pittsburgh.
- Energy, D. o. (2004, June). *Federal Energy Management Program*. Retrieved from National Renewable Energy Laboratory: <http://www.nrel.gov/docs/fy04osti/33811.pdf>
- Eom, S. B. (2001). *Decision Support Systems*. London, England: International Encyclopedia of Business Management.
- Jeong, S.-J., Lee, C.-G., & Bookbinder, J. H. (2007). The European freight railway system as a hub-and-spoke network. *Transportation and Research Part A: Policy and Practice*, 523-536.
- Kuo, R. (2002). A decision support system for selecting convenience store location through integration of fuzzy AHP and artificial neural network. *Computers in Industry*, 199-214.
- Laboratory, N. E. (2013, April 4). *Coal-Fired Power Plants (CFPPs)*. Retrieved from National Energy Technology: <http://www.netl.doe.gov/technologies/coalpower/cfpp/CFPPs/CFPPLocations.htm>
- Laboratory, N. E. (n.d.). *Coal-Fired Power Plants (CFPPs)*. Retrieved 4 7, 2013, from <http://www.netl.doe.gov/technologies/coalpower/cfpp/CFPPs/HowCFPPsWork.htm>
- Laboratory, O. R. (2012, August). *Center for Transportation Analysis*. Retrieved 4 7, 2013, from <http://www-cta.ornl.gov/transnet/RailRoads.html>
- Nero, G. (1999). A note on the competitive advantage of large hub-and-spoke networks. *Transportation and Research Part E: Logistics and Transportation Review*, 225-239.
- O'Leary, D. (n.d.). *Decision Support System "Evolution"*. Los Angeles: University of Southern California.
- Pantaleo, A. M., & Shah, N. (2013). The Logistics of Bioenergy Routes for Heat and Power. *Intech*, 217-245.

- Power, D. (2003, May 31). *A Brief History of Decision Support Systems*. Retrieved from DSSResources.com: <http://dssresources.com/history/dsshistoryv28.html>
- Power, D., Burstein, F., & Sharda, R. (2011). Reflections on the Past and Future of Decision Support Systems: Perspective of Eleven Pioneers. pp. 25-28.
- Roni, M. (2013). *A hub and spoke supply chain design for long-haul, and high-volume transportation of densified biomass*. PhD Thesis.
- Sandra D. Eksioglu, M. M. (2011). *Developing Spreadsheet Based Decision Support Systems*. Dynamic Ideas.
- Silverstein, K. (2013). Biomass Breathing New Life Into Coal Plants. *Forbes*.
- Smith, S. (2013). *What is the Hub and Spoke Model?* Retrieved from wiseGEEK: <http://www.wisegeek.org/what-is-the-hub-and-spoke-model.htm>
- Sokhansanja, S., Kumarc, A., & Turhollowa, A. F. (2006). Development and implementation of integrated biomass supply analysis and logistics model (IBSAL). *Biomass & Energy*.
- United States Regions*. (2006, October). Retrieved from <http://users.tellurian.com/teach/regions/>
- Voegle, E. (2013, August 2). *Drax outlines continued progress in financial statement*. Retrieved from Biomass Magazine: <http://biomassmagazine.com/articles/9285/drax-outlines-continued-progress-in-financial-statement>
- World, M. o. (2013, April 4). *USA Rail Map*. Retrieved from Maps of World: <http://www.mapsofworld.com/usa/usa-rail-map.html>
- Zapfel, G., & Wasner, M. (2002). Planning and optimization of hub-and-spoke transportation networks of cooperative third-party logistics providers. *International Journal of Production Economics*, 207-220.