Modeling the U. S. Coal Supply Chain

by

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Coal is a key component for electricity production in the United States. In 2003, approximately 92% of all coal mined was used in electricity production [1]. Additionally, 53% of electricity produced was fueled by coal [2]. According to the Energy Information Administration, the amount of coal used in electricity production is expected to rise due not only to increased demand for electricity, but also due to expected increases in the price of natural gas [3]. This continued reliance motivates members of the coal industry (mines, transportation and power plants) to develop methods to lower the overall cost of mining and transporting coal while meeting increasingly stringent environmental regulations. This optimization of the coal supply chain (from mine to power plant) is critical for reducing mining, transportation and storage costs while still meeting all required environmental standards.

This research will help in answering a broad range of questions that will be the focus of the dissertation. These questions include:

1) How should coal supplies be planned and dispatched so as to minimize inventories?
2) How much inventory should a power plant carry in order to be able to respond to surges in demand?
3) How fast can the entire supply chain respond to surges in demand?
4) How should deliveries of different coal types be managed to get the optimal mix to meet environmental emission standards?
5) How to plan for facility capacity expansion?
6) What should be the target level of coal piles at mines, blending terminals and power plants?

7) What should be the control parameters for coal-flow handling (i.e. pile reorder levels and coal quantity orders)?
8) How to determine the frequency and size of coal arrivals by different transportation methods?

B. Comments on the literature

The literature can be divided into two areas. The first is the industry area. This area of the literature will give an overview of the coal industry, from mine to power plant. In particular we will focus on the coal supply chain. The items of interest will be:

1) What modes of transportation are used?
2) Why are some modes used over others?
3) What are the different coal piling methods?
4) What sort of equipment is used to stack/reclaim coal?
5) What are the sources of failure along the supply chain (natural and man-made)?

The other area of literature will focus on developing the background of the methodology that will be used to analytically model the coal supply chain. This area will focus on what types of methodologies have been used to model coal supply chains in the past, or maybe a review on methodologies used to model bulk solids of any type. This area will also focus on continuous flow systems as well on previously created simulation models of coal supply chains. First let's take a look at the industry portion of the coal supply chain.

Coal Storage Methods

There are a number of factors that must be taken into effect when considering the type of storage facilities that will be used to house the coal. These factors include: space availability, weather conditions, dust emissions, and combustibility of coal, to name a few. Another issue that must be considered when storing coal is the mix of coal that will be used in a power plant.

Some power plants use a mix of low-sulphur and high-sulphur coal to get the optimal mix between emissions control, heating value, and cost factors. Let's consider some of the factors that go into determining how much coal to store and how to store it. Since coal is the single most costly input into power generation. Additionally, power plants have to carry a certain amount of inventory, on average 45 days, in order to compensate for interruptions in supply such as miner's strikes/holidays, adverse weather or transportation problems [4].

"The two main factors to be addressed when considering the storage of the coal are the storage capacity of the facility and the selection of a suitable type of storage (circular, longitudinal, covered, or open). Also is the decision on whether or not the coal needs to be homogenized. This depends on the frequency of the different coal grades and when they are delivered [5 – pg 237]." First let's consider the different types of coal storage piles. One method of coal storage is to store the coal in a silo. This method seems to be used in newer power plants that have a lot of capital they are able to invest in construction. A major benefit of the silos is a greater amount of control over the environmental impact of the coal. Unlike open storage areas, silos have greater dust and climate control that eliminates the problems caused by wet or frozen coal (plugged conveyors, problems reclaiming, etc.) and a silo creates a very compact pile which reduces the chance of spontaneous combustion that can occur when there are air gaps in a coal pile. Major disadvantages of having silos are the capital costs that go into building a silo and the limitations in storage capacity if there is a need to expand capacity in the future.

Another method of coal storage is open storage. There are a couple different pile layouts when coal is stored in an open storage configuration. The choice of the layout is going to depend a lot on area for storage, equipment available to stack and reclaim coal, and any mixing needs of the coal for the facility (i.e. if the plant mixes high and low-sulphur coal to control emissions).

One method of outdoor storage is a circular storage pile. This type of pile is arranged exactly as it sounds. Coal is unloaded from whatever transportation mode has brought it, and is dumped onto an existing pile from one stacker. Mobile units (trucks and bulldozers) are used to keep the coal pile in a compact state and to move coal from the "dead" portion of the pile (the portion that cannot be reclaimed) to the "live" portion of the pile. Another option for open coal storage is a longitudinal storage pile. These types of piles are shaped like kidneys. After coal is unloaded a stacker that has the ability to move along the length of the storage facility typically stacks it. Once again, mobile equipment is used to help manage the pile and take over when the stacking or reclaiming facilities break down.

The decision on which type of open storage pile configuration a facility should have all depends on a cost-benefit analysis. Longitudinal storage piles require large stacking equipment that has a short boom to deposit the coal. Circular storage piles require have less distance to travel, however require large stacking equipment with longer boom lengths. This is important because "the cost of a unit of stacking/reclaiming equipment is related to its boom length and hourly capacity [5 – pg 238]." Shorter boom lengths can handle a greater volume, however they require frequent adjustments that increase wear and decrease efficiency of the equipment [5].

Another factor that must be considered when deciding on open pile storage is the degree of homogenization a plant requires to operate. Homogenization of the coal can be obtained by two methods. If there are circular piles, the different types of coal can be stacked in two different circular piles. The coal is reclaimed in a set proportion between the two piles and then combined on a common conveyor belt which feeds the coal to the power plant to be processed. If there are longitudinal piles, the coal is stacked in a given proportion when it is delivered to the plant. This way when the coal is reclaimed the chunk that is taken out of the piles has the required mixture of the different coal types. The decision to combine coal types leads us to the topic of current transportation methodologies of the coal supply chain.

Coal Transportation Methodologies

In order to understand the current coal supply chain transportation methods, it is important to understand how policy issues have affected the development of the coal supply chain. Implementation of CAAA90, coupled with different mining methods, is a major contributor to the transportation of coal. This section of the paper will focus on policy changes in railroad, electrical generation and the Clean Air Act Amendment of 1990. Next we will look at the different types of transportation methods and when and where they are used. Finally, we will look at coal supply and demand centers and how the policy issues listed above have influenced the structure of the coal supply chain. This portion of the discussion will focus on how cost comes to play a huge role in transportation methodologies and contains a brief look into the future for coal and how this future is shaping the coal supply chain today.

Policy Actions

A number of policy actions have contributed to the structure of the current coal supply chain. In the late 1970's, early 1980's, the structure of the nations railroads was being reorganized. The Railroad Revitalization and Regulatory Reform Act of 1976 and the Staggers Rail Act of 1980 "substantially deregulated U.S railroads and have given them wide latitude to set their own rates. The Staggers Act also legalized confidential rail contracts and facilitated railroad mergers [6 – pg. 1]." These two policy actions had lead to a decline in rail rates as the railroads started to compete for business with each other.

In 1990, the Clean Air Act Amendments were introduced. As mentioned in the background section, the CAAA90 was implemented in two phases. During Phase I certain units were required to begin implementing measure that would decrease their SO_2 and NO_2 emissions. Most of these units were in the Eastern portion of the U.S. where there are large deposits of high-sulphur bituminous coal. Though it has an extremely high heating value, it also contains large amounts of sulphur, the cause of the problem. These units began to decrease their emissions by using either installing new scrubbing technologies, switching to low-sulphur coal, using the allowances provided or bought from units that did not need them, or a combination of these methods. "Compared with purchasing allowances of investing in flue gas scrubber technologies, the lowest cost option for the greatest number of utilities was found to be switching from high-sulphur to low-sulphur coal [6 – pg 22]." The increased demand for low-sulphur coals caused a shift in the structure of the coal supply chain. Low-sulphur coal shipped under contract by rail increased by 389 percent at Phase I affected units [6]. As will be discussed later, most low-sulphur coals are located in the Western U.S. The location of the low-sulphur coal lead to an increase in the amount of these coals demanded as well as the total distance traveled by rail. Increased demand lead to even more competition amongst the railroads, which further contributed to lower rail rates.

The electricity generation sector is also currently undergoing a deregulation of its own. As is typical, as a market becomes more and more deregulated, the market gets more and more competitive. Coal is a huge input into the production of electric power, as electricity prices get more and more competitive, the price of coal is also going to have to get more competitive. This means that the price of coal is going to have to decrease. This pressure on coal providers will lead to development of more efficient mining methods as well as shopping around for the best rail rates, which will in turn make the rail market prices even more competitive.

Different Coal Transportation Methods

There are basically four different methods in which coal is transported. These methods are by rail, barge, truck and other. The other category includes methods such as conveyors, tramways, slurry pipelines, and via the Great Lakes. In 1997, nearly 62% of all coal shipments were handled by rail. Barge and truck shipments accounted for about 25%, and some other form, as mentioned above, carried out the remaining shipments [6]. Over the years, transportation of coal by rail has been steadily increasing while transportation of coal by other methods has remained about the same or started to decrease. Let's look at the different circumstances under which the different transportation systems are used and where in the country they are utilized.

Conveyor systems, trams, slurry pipelines and the Great Lakes are all methods of transportation that have distance limitations. These methods are only cost effective to operate over a certain distance. Therefore, power plants that typically use these methods are very close to the mine source. These types of systems are seen more in the New England states. Trucks, though having a greater cost effective delivery distance than the previously mentioned methods, are still limited in their range. Typically trucks are used to transport coal only if there is "no adequate infrastructure available [5 – pg. 237]."

Barges are perhaps the most economical method to transport coal because of the capacity they can carry at one time. One barge load is equivalent to 15 jumbo hoppers (type of rail car), which have a 100-ton capacity or 58 truckloads. One barge tow is equivalent to 2 _ unit trains (one unit train contains 100 rail cars), which is equivalent to 870 truckloads [7]. Even though barge transport is one of the most economical methods of transportation for coal, its use is limited, of course, to large rivers that can support deliveries by large barges. Power plants located along or very close to the Mississippi or Missouri Rivers are typically units that receive coal shipments via barge. However, many of these plants also have the capability of receiving coal by rail.

The last transportation system utilized to carry coal is the railroad system. While not as economical as barges, it is the leading transportation method used for coal. We have already discussed a few reasons why the rail is used so predominantly. One reason is the deregulation of the railroads that have made them more competitive in the transportation industry. Also the CAAA90 emission control requirements leading to increased demand for low-sulphur coal has lead to railroads trying to promote their product. Western railroads invested a lot of equipment and infrastructure in order to convince the southern and eastern markets that their coal would be worthwhile to import to meet the CAAA90 regulations, despite the lower heating value of the low-sulphur coal [6]. Another reason rail is so predominantly used for coal transportation is because of the widespread accessibility it offers. It can get to pretty much anywhere in the country. Competition amongst rail companies also leads to long-term contracts with suppliers that reduce transportation costs. "Contract coal transportation rates for rail deliveries vary among different pairs of origins and destinations and with factors such as distance, coal tonnage, and length of contract [6 - pg 16]."

The most important factor in the organization of the coal supply chain is the delivery price of the coal. This price is going to determine how much coal a plant requests at a time, where this coal is delivered from and, to some extent, what type of transportation method is used. There are two factors that go into the delivery price of coal. The first factor is minemouth price. The minemouth price is exactly what it sounds like; it is the price of the coal at the mine. The minemouth price is a factor of the methods of extraction at the mine and how efficient that extraction is. Recall our discussion on surface and underground mining. Surface mining is far cheaper than underground mining, so coal from surface mines have a lower minemouth price. In addition, the more updated and modern the extraction equipment is at the mine site, the lower the minemouth price. The minemouth price accounts for a large portion of the delivery price of the coal. For the purposes of continuing research, the minemouth price is going to be considered to be an exogenous input. Future research will focus on optimizing the costs of the supply chain through other methods including the second factor of the delivery price and that factor is the transportation rates.

The Current Coal Supply Chain

With the implementation of the railroad deregulation and the CAAA90 initiatives, the types of coal that are now being used in electricity generation have changed over the past decade. Since a majority of the units that were affected by Phase I of CAAA90 were located in the Eastern portion of the United States, a lot of the changes have taken place in this region of the country. With the options of installing scrubbers, changing coal or purchasing allowances and the discovery that transporting the low-sulphur coal from the western area of the U.S. was in most cases the most economical, the increase in use of low-sulphur coal, especially from the Powder River Basin (PRB) region has increased dramatically and expected to continue to increase. The low sulphur coal from the PRB is the cheapest because of their extremely low mining costs (selling price $5.67 per short ton). The low-sulphur coal from the central Appalachia region is more expensive to mine, thus resulting in a higher minemouth price ($27.87 per short ton). However, despite the higher selling costs, when one considers the average heat content in the Central Appalachia and the Rockies region, the prices for these coals, which are slightly more expensive to mine, are very competitive with the PRB coal [6 – pg 20].

The increase of the use of low-sulphur coal, and the fact that most of the low-sulphur coal from the PRB and the Rockies regions are mined via surface mining (efficient and low cost) means that the minemouth price of the delivered coal for the western coals has been decreasing and will continue to decrease. Furthermore, the cost effectiveness of the mining practices of these regions means that the minemouth prices in these western regions are considerably lower than the eastern regions and are expected to remain as such [2].

As discussed above, the second portion of the delivery cost is the transportation costs. As we have mentioned, the deregulation of the railroads and the implementation of CAAA90 have shifted the use of certain coal types. The efforts of the railroads had made the low-sulphur coal from the west even more attractive to the eastern power market. The transportation rates are highest in the low-sulphur coal category constituting about 49-51% of total delivery price (primarily due to the long distances the coal must travel). These rates are lowest in the high-sulphur coal (about 21%). Over the years the percentage for low-sulphur coal has remained relatively stable thanks to decreasing rail costs and lower minemouth prices. The percentage for the other coal types have increased due to a lesser decrease in the rail rates per ton delivered [6 – pg 19]. In addition to the efforts of the rail companies to restructure their infrastructure, the deregulation of the railways allowed more freedom in contracts between rail companies and their customers. The competitions for customers lead to contracts that have even more competitive rates.

The increased demand for low-sulphur coal has lead to an increase in rail being used to transport coal because of the location of the low-sulphur coal compared to the location of the power units that are primarily affected by the emissions standards. Some plants in the Midwest have decided to expand from strictly producing power to also becoming transshipment points between the eastern and western markets. One such example is the Meramac Plant just south of St. Louis. This power plant has been a major power generator for the St. Louis area. The primary coal delivery method is by barge via the Mississippi River. Though the plant is close to a main railroad spur, in the past, this has not been a cost effective method for delivery. However, with the implementation of CAAA90, and the increased demand for low-sulphur coal, the owners of the plant, Ameren UE, decided to switch to a homogenization plan starting to buy low-sulphur coal to decrease emissions. Because of their location in the heart of the country, they decided that this location would be an ideal rail-to-barge transshipment facility for the low-sulphur coal originating primarily from the Powder River Basin. This is the sort of supply chain reorganization that has been happening since the policy changes [8].

The next portion of the literature review (to be included at a later date) will include a review of the analytical and simulation techniques that have been used to model coal supply chains.

C. Specific methodology

Our goal is to create a robust mathematical model of an abstract coal supply chain in the United States using a methodology known as continuous flow modeling (CFM), and verify using simulation. The CFM approach to modeling was chosen because a coal supply chain can be viewed as continuous in nature, similar to fluid flow modeling. The model will consist of a series of valves and buffers that will regulate the flow of the coal through the supply chain based on a certain set of input parameters. For example a stock pile of coal at the mine is viewed as a buffer while the conveyors that bring the coal to the pile and the apparatus that removes the coal from the pile are seem as the valves. As in the real world, these valves will have a set of input parameters including flow rate, failure rates, time between failures, etc. This analytical tool will provide us with performance metrics of the coal supply chain. Once the model is formulated, optimization techniques will detect which variables in the supply chain can be tweaked to find the most cost effective method of operating a supply chain and the completed model will be robust enough to work for any coal supply chain in the US regardless of actual components of the supply chain.

We will build the simulation model using the simulation software, Arena, and the model will be verified using actual industrial data to be sure that our formulation makes sense in the real world. The optimization portion of the study will seek to optimize the key performance measures with the goal of reducing overall costs of the coal supply chain. This optimization portion will be limited by the constraints that face any coal supply chain to include policy issues, environmental regulations, transportation issues, etc.

D. Implications

This methodology will reduce costs and inefficiencies all along the supply chain from mine, through transportation process to power plant and will provide an easy and accurate way to model and manage such large scale operation.

E. Bibliography

1. "Annual Coal Report." Energy Information Administration. Fred Freme. Mar. 2004. 20 Apr 2004. <http://www.eia.doe.gov/cneaf/coal/page/acr/acr_sum.html>.

2. "U.S. Coal Supply and Demand 2003 Review." Energy Information Administration. Fred Freme. 19 Apr. 2004. 21 Apr 2004. <http://www.eia.doe.gov/cneaf/coal/page/special/feature.html>.

3. "Annual Energy Outlook 2004 with Projections to 2025." Energy Information Administration. Jan. 2004. 22 Apr. 2004. <http://www.eia.doe.gov/oiaf/aeo/ >.

4. Chakraborti, S. "An Overview of AEP's Coal Handling Systems." Bulk Solids Handling 19 (1999): 81-88.

5. "Coal Handling Plant for Power Stations Optimised by Systems Capability." Bulk Solids Handling 19 (1999): 236-242.

6. "Energy Information Administration/Energy Policy Act Transportation Rate Study: Final Report on Coal Transportation." Energy Information Administration. 5 Feb. 2002. 20 Apr 2004. <http://www.eia.doe.gov/cneaf/coal/coal_trans/epact2000.html>.

7. Associated Electric Cooperative, (2003 October). *Iowa Planning and Research division powerpoint slide*, Accessed on April 25, 2004 from slide http://www.aeci.org/wcta/fall2003/ppts/

8. Schimmelpfennig, M. and D. Mahr. "Ameren UE's New Coal Unloading and Transshipment Facilities at the Meramec Plant." Bulk Solids Handling 22 (2002): 28-33.