National Cheng Kung University

IIMBA

Class: Business Decision Methods

Instructor: Dr. Jeh-Nan Pan

Final Group Report - Fall 2009

CINERGY COAL ALLOCATION

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ABSTRACT

"Cinergy Coal Allocation" is our final group project for Business Decision Methods (BDM), Fall 2009 in the NCKU IMBA program with Instructor Dr. Jeh-Nan Pan. Our group consists of three members: Alfredo De La Guardia, Joshua Bentley, and Kubanychbek Zhaparov.

In this project we select a complex case with which we can exercise some of the very practical and sophisticated problem-solving methods presented and studied this semester in BDM. Our project is based upon a real-world case involving the Cinergy Corporation. Cinergy Corporation is a U.S. producer of electricity for customers in Indiana, Kentucky and Ohio. This project is based on five of Cinergy's coal-fired power plants and the seven coal suppliers from which Cinergy purchases coal to fuel those five plants.

The five plants vary in required electricity production output and also in plant efficiency. Initial purchase cost, BTU content, transportation cost, and processing costs also vary between the seven coal suppliers and with the delivery and use of those seven sources of coal at each of the five power plants. Additionally, coal is purchased through a mix of fixed-tonnage and variable-tonnage contracts.

In the "Cinergy Coal Allocation" project, our group studies the situation, maps the problem processes and constraints, and develops a model utilizing linear programming with the objective of optimizing the purchase and allocation of coal so as to minimize total costs to purchase and use coal while satisfying all purchase contracts and meeting electricity demands. Ultimately, we successfully satisfy the project's initial objective, delivering an optimized coal purchasing/allocation plan which minimizes total costs and delivers substantial savings to the Cinergy Corporation.

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a. Case Overview – Description of Case

Our project is based on a case selected from the textbook *Introduction to Management Science, (10th edition)* by Anderson, Sweeney and Williams. The case is described as follows:

Cinergy Corporation manufactures and distributes electricity for customers located in Indiana, Kentucky, and Ohio. The company spends $725 to $750 million each year for the fuel needed to operate its coal-fired and gas-fired power plants; 92% to 95% of the fuel used is coal. Cinergy uses 10 coal-burning generating plants: five located inland and five located on the Ohio River. Some plants have more than one generating unit. As the seventh-largest coal-burning utility in the United States, Cinergy uses 28-29 million tons of coal per year at a cost of approximately $2 million every day.

The company purchases coal using fixed-tonnage or variable-tonnage contracts from mines in Indiana (49%), West Virginia (20%), Ohio (12%), Kentucky (11%), Illinois (5%), and Pennsylvania (3%). The company must purchase all of the coal contracted for on fixed-tonnage contracts, but on variable-tonnage contracts it can purchase varying amounts up to the limit specified in the contract. The coal is shipped from the mines to Cinergy's generating facilities in Ohio, Kentucky, and Indiana. The cost of coal varies from $19 to $35 dollars per ton and transportation/delivery charges range from $1.50 to $5.00 per ton.

A model is used to determine the megawatt hours (mWh) of electricity that each generating unit is expected to produce and to provide a measure of each generating unit's efficiency, referred to as the heat rate. The heat rate is the total BTUs required to produce 1-kilowatt hour (kWh) of electrical power.

Cinergy allocates coal to its generating facilities based upon management's allocation plan designed to meet energy demands for each generating unit and satisfy coal tonnage contracts. The objective of the coal allocation model is to determine the lowest-cost method for purchasing and distributing coal to the generating units. The supply/availability of the coal is determined by the contracts with the various mines, and the demand for coal at the generating units is determined indirectly by the megawatt hours of electricity each unit must produce.

The cost to process coal, called the add-on cost, depends upon the characteristics of the coal (moisture content, ash content, BTU content, sulfur content, and grindability) and the efficiency of the generating unit. The add-on cost plus the transportation cost are added to the purchase cost of the coal to determine the total cost to purchase and use the coal.

i. Current Problem

Cinergy signed three fixed-tonnage contracts and four variable-tonnage contracts. The company would like to determine the least cost way to allocate the coal available through these contracts to five generating units. The relevant data for the three fixed-tonnage contracts are shown in ***Table 1*** below:

Table 1: Fixed-Tonnage Contracts

Supplier	Number of Tons Contracted For	Cost $/ton	BTUs/lb
RAG	350,000	22	13,000
Peabody Coal Sales	300,000	26	13,300
American Coal Sales	275,000	22	12,600

For example, the contract signed with RAG requires Cinergy to purchase 350,000 tons of coal at a price of $22 per ton. Each pound of this particular coal provides 13,000 BTUs. The data for the four variable-tonnage contracts are shown in ***Table 2*** below:

Table 2: Variable-Tonnage Contracts

Supplier	Number of Tons Available	Cost $/ton	BTUs/lb
Consol, Inc.	200,000	32	12,250
Cyprus Amax	175,000	35	12,000
Addington Mining	200,000	31	12,000
Waterloo	180,000	33	11,300

For example, the contract with Consol, Inc. enables Cinergy to purchase up to 200,000 tons of coal at a cost of $32 per ton. Each pound of this coal provides 12,250 BTUs.

The number of megawatt hours of electricity that each generating unit must produce and the plant heat rates are provided in ***Table 3***:

Table 3: Generating Unit Output Requirement and Heat Rate

Generating Unit	Electricity Produced (mWh)	Heat Rate (BTUs per kWh)
Miami Fort Unit 5	550,000	10,500
Miami Fort Unit 7	500,000	10,200
Beckjord Unit 1	650,000	10,100
East Bend Unit 2	750,000	10,000
Zimmer Unit 1	1,100,000	10,000

For example, Miami Fort Unit 5 must produce 550,000 megawatt hours of electricity, and 10,500 BTUs are needed to produce each kilowatt hour.

The transportation and add-on costs in dollars per ton are shown in ***Table 4*** and ***Table 5***:

Table 4: Transportation Cost

Transportation Cost ($/ton)					
	Miami Fort Unit 5	Miami Fort Unit 7	Beckjord Unit 1	East Bend Unit 2	Zimmer Unit 1
RAG	5.00	5.00	4.75	5.00	4.75
Peabody	3.75	3.75	3.5	3.75	3.5
American	3.00	3.00	2.75	3.00	2.75
Consol	3.25	3.25	2.85	3.25	2.85
Cyprus	5.00	5.00	4.75	5.00	4.75
Addington	2.25	2.25	2.00	2.25	2.00
Waterloo	2.00	2.00	1.60	2.00	1.60

Table 5: Add-On Cost

Add-On Cost ($/ton)					
	Miami Fort Unit 5	Miami Fort Unit 7	Beckjord Unit 1	East Bend Unit 2	Zimmer Unit 1
RAG	10.00	10.00	10.00	5.00	6.00
Peabody	10.00	10.00	11.00	6.00	7.00
American	13.00	13.00	15.00	9.00	9.00
Consol	10.00	10.00	11.00	7.00	7.00
Cyprus	10.00	10.00	10.00	5.00	6.00
Addington	5.00	5.00	6.00	4.00	4.00
Waterloo	11.00	11.00	11.00	7.00	9.00

b. Model Description

First, we defined our objective in solving the case problem:

Objective: optimize the purchase and allocation of coal so as to minimize total costs to purchase and use coal while satisfying all purchase contracts and meeting electricity demands.

Then we tried to understand the cost composition of the problem. Our original data expresses factors in a variety of measures: $/ton, BTUs/lb, mWh, and BTUs per kWh. For purposes of analysis, we decided to standardize the units of measure. It was most logical and convenient to use BTUs instead of tons or pounds, because the heat energy generated by burning coal depends on the quality of coal and suppliers offer different kinds of coal with different quality. In-so-far-as the electricity generating units require a certain amount of heat, measured in BTUs, to produce electricity, it is better to standardize data in terms of BTUs rather than in tons or pounds. Also, the efficiency of the generating units is different, because they use different technology to produce electricity. Accordingly, using BTUs as the unit of measure becomes more practical necessity than convenience.

Our objective function is to minimize the total cost of coal purchased from suppliers and the total cost of shipping and burning coal for the five electricity generating units. A linear programming model can be used to find the solution.

$$Minimize C = \sum_{i=1}^{n} \sum_{j=1}^{n} C_{ij} X_{ij}$$

In the objective function, C_{ij} , is the cost of purchasing coal from supplier *i*, shipped and burned at generating unit *j*.

X_{ij} = amount of coal purchased from supplier i, shipped and burned at generating unit *j*

In computing the objective function coefficients, three inputs must be added: the purchase cost of the coal, the transportation cost to the generating unit, and the cost of processing the coal at the generating unit. Our objective function is shown in ***Table 6.*** The coefficients of the objective function are expressed in terms of total cost ($)/ ton, which includes the combined purchase cost, transportation cost and processing cost.

Table 6: Objective Function Grid in Dollars Per Ton

	Miami 5	Miami 7	Beckjord	East Bend	Zimmer
RAG	37.00	37.00	36.75	32.00	32.75
Peabody	39.75	39.75	40.50	35.75	36.50
American	38.00	38.00	39.75	34.00	33.75
Consol	45.25	45.25	45.85	42.25	41.85
Cyprus	50.00	50.00	49.75	45.00	45.75
Addington	38.25	38.25	39.00	37.25	37.00
Waterloo	46.00	46.00	45.60	42.00	43.60

Below, in ***Table 7***, you will see the objective function already converted to Dollars per BTU.

Table 7: Objective Function Grid in Dollars Per BTU

	Miami 5	Miami 7	Beckjord	East Bend	Zimmer
RAG	1.42	1.42	1.41	1.23	1.26
Peabody	1.49	1.49	1.52	1.34	1.37
American	1.51	1.51	1.58	1.35	1.34
Consol	1.85	1.85	1.87	1.72	1.71
Cyprus	2.08	2.08	2.07	1.88	1.91
Addington	1.59	1.59	1.63	1.55	1.54
Waterloo	2.04	2.04	2.02	1.86	1.93

We converted Cost ($)/ ton to Cost ($)/ BTU, by dividing $/ton by BTU/ton:

$$C_{\$/BTU} = \frac{C_{\$/Ton}}{BTU/Ton}$$

Thus the objective function equation is expressed as follows:

Objective function equation:

$X_{11} * 1.42 + X_{12} * 1.42 + X_{13} * 1.41 + X_{14} * 1.23 + X_{15} * 1.26 + X_{21} * 1.49 + X_{22} * 1.49 + X_{23} * 1.52 + X_{24} * 1.34 + X_{25} * 1.37 + X_{31} * 1.51 + X_{32} * 1.51 + X_{33} * 1.58 + X_{34} * 1.35 + X_{35} * 1.34 + X_{41} * 1.85 + X_{42} * 1.85 + X_{43} * 1.87 + X_{44} * 1.72 + X_{45} * 1.71 + X_{51} * 2.08 + X_{52} * 2.08 + X_{53} * 2.07 + X_{54} * 1.88 + X_{55} * 1.91 + X_{61} * 1.59 + X_{62} * 1.59 + X_{63} * 1.63 + X_{64} * 1.55 + X_{65} * 1.54 + X_{71} * 2.04 + X_{72} * 2.04 + X_{73} * 2.02 + X_{74} * 1.86 + X_{75} * 1.93$

i. Constraints

In the case, there are two types of constraints: coal supply constraints and electricity demand constraints.

1. Supply Constraint Series

The company signed fixed tonnage contracts with three suppliers and variable tonnage contracts with four suppliers. According to the contracts, Cinergy is contractually obligated to buy the exact amount specified from the three fixed-tonnage contract suppliers: RAG, Peabody and American. From the four variable-tonnage contract suppliers, Consol, Cyprus, Addington and Waterloo, the company can buy any amount up to a specified maximum amount.

The supply constraints can be written as follows:

$$FixedContract = \sum_{i=1}^{n}\sum_{j=1}^{n} X_{ij}$$

$$VariableContract <= \sum_{i=1}^{n}\sum_{j=1}^{n} X_{ij}$$

The contract specifies coal quantities in tons, so we have to convert tons to BTUs by multiplying tons by BTU/ton. The equation is shown below:

$$AvailableCoal_{BTU} = Tons\left(BTU/_{Ton}\right)$$

Following are the coal supply constraint equations expressed in its original values.

Fixed tonnage supply constraint:

1) RAG:

$X_{11} + X_{12} + X_{13} + X_{14} + X_{15} = 350\ 000$

2) Peabody:

$X_{21} + X_{22} + X_{23} + X_{24} + X_{25} = 300\ 000$

3) American:

$X_{31} + X_{32} + X_{33} + X_{34} + X_{35} = 275\ 000$

Variable tonnage supply constraint:

1) Consol:

$X_{41} + X_{42} + X_{43} + X_{44} + X_{45} <= 200\ 000$

2) Cyprus:

$X_{51} + X_{52} + X_{53} + X_{54} + X_{55} <= 175\ 000$

3) Addington:

$X_{61} + X_{62} + X_{63} + X_{64} + X_{65} <= 200\ 000$

4) Waterloo:

$X_{71} + X_{72} + X_{73} + X_{74} + X_{75} <= 180\ 000$

2. Demand Constraint Series

The electricity demand constraint specifies the amount of electricity, measured in MWh, that must be generated by each generating unit.

$$Electricity\ Production = \sum_{i}^{n}\sum_{j}^{n} e_{ij} X_{ij}$$

In the equation, e_{ij} is the amount of electricity in MWh generated by the amount of coal purchased from supplier *i* and used by generating unit *j*.

$$Electricity\ Production_{BTU} = Electricity\ Production_{KwH}\left(BTU/_{KwH}\right)$$

The amount of required electricity generated was expressed in MWh, so we converted MWh to BTU. By first multiplying MWh by 1,000 we get the corresponding figure in kWh, and then multiplying kWh by BTU/kWh, we get the electricity produced in BTU.

Below, we show the electricity demand constraint equations using the original values.

1) Miami 5:

$1.24\,X_{11} + 1.27\,X_{12} + 1.2\,X_{13} + 1.17\,X_{14} + 1.14\,X_{15} + 1.14\,X_{16} + 1.08\,X_{17} = 550\,000$

2) Miami 7:

$1.27X_{12} + 1.3\ \ X_{22} + 1.24\,X_{32} + 1.2\,X_{42} + 1.18\,X_{52} + 1.18\,X_{62} + 1.11\,X_{72} = 300\,000$

3) Beckjord:

$1.29X_{13} + 1.32\,X_{23} + 1.25\,X_{33} + 1.21\,X_{43} + 1.19\,X_{53} + 1.19\,X_{63} + 1.12\,X_{73} = 275\,000$

4) East Bend:

$$1.3X_{14} + 1.3\,X_{24} + 1.26\,X_{34} + 1.23\,X_{44} + 1.2\,X_{54} + 1.2\,X_{64} + 1.13\,X_{74} = 200\,000$$

5) Zimmer:

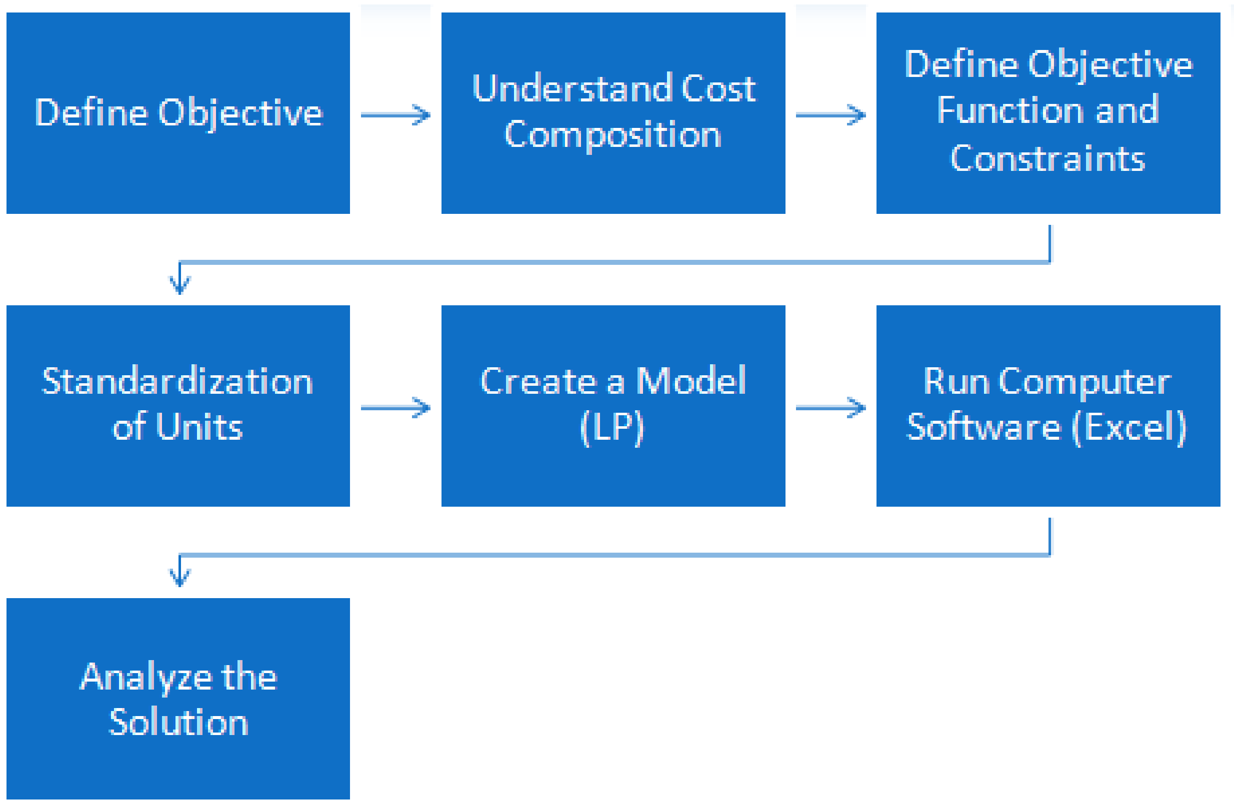
$$1.3X_{15} + 1.3\,X_{25} + 1.26\,X_{35} + 1.23\,X_{45} + 1.2\,X_{55} + 1.2\,X_{65} + 1.13\,X_{75} = 175\,000$$

Below you will find a constraint grid representing a the constraints converted to BTU's. As you can see, by converting to BTUs the electricity production coefficient becomes implicit in the figure, thus simplifying the problem, as the equation terms are stated using coefficient 1. The programming is then easier as a single table can be used the objective range of cells, eliminating the need for complex linking of values, which can conduct to convergence errors.

Table 8: Constraint Grid in Million BTUs

Suppliers (i)	**Electricity generating units (j)**					**Millions of BTUs purchased**
	Miami 5	Miami 7	Beckjord	East Bend	Zimmer	
RAG	X_{11}	X_{12}	X^{13}	X^{14}	X_{15}	9 100 000
Peabody	X_{21}	X_{22}	X_{23}	X_{24}	X_{25}	7 980 000
American	X_{31}	X_{32}	X_{33}	X_{34}	X_{35}	6 930 000
Consol	X_{41}	X_{42}	X_{43}	X_{44}	X_{45}	4 900 000
Cyprus	X_{51}	X_{52}	X_{53}	X_{54}	X_{55}	4 200 000
Addington	X_{61}	X_{62}	X_{63}	X_{64}	X_{65}	4 800 000
Waterloo	X_{71}	X_{72}	X_{73}	X_{74}	X_{75}	4 068 000
Millions of BTUs generated	5 775 000	5 100 000	6 565 000	7 500 000	11 000 000	

2. Systematic Problem Solving Flowchart



3. Analysis of Results
    a. Comparative Analysis
    b. Sensitivity Analysis (What-if Analysis)

a. Comparative Analysis

Before linear programming was applied to Cinergy Corporation's coal purchases and allocation, the total annual cost of purchasing, transporting and using coal was USD 67.06 million, with a total purchased quantity of 1,680K tons of coal. Cinergy Corporation was using the totality of the coal available and overproducing electricity. In fact, as can be seen in ***Table 9***, between Miami 5, Miami 7 and Beckjord, there was an overproduction of around 6.04 Billion[1] BTUs. The corresponding over-purchase of coal, as displayed in ***Table 10***, is calculated to be 328.08 thousand tons.

Table 9: Pre-Optimization Total BTUs Purchased in Billions

Total Amount of BTU Purchased (Billions)								
	Miami 5	Miami 7	Beckjord	East Bend	Zimmer	Total Purchased	BTUs/contract in millions	Surplus/ Deficit
RAG	5.77	1.72	1.61	0.00	0.00	9.10	9.10	0.00
Peabody	0.43	1.54	1.86	1.68	2.47	7.98	7.98	0.00
American	0.09	1.39	2.19	1.50	1.77	6.93	6.93	0.00
Consol	0.00	0.83	1.12	1.37	1.57	4.90	4.90	0.00
Cyprus	1.71	0.70	0.58	0.23	0.98	4.20	4.20	0.00
Addington	0.00	0.00	0.26	2.14	2.40	4.80	4.80	0.00
Waterloo	0.49	0.69	0.49	0.59	1.80	4.07	4.07	0.00
Total Pruchased	8.49	6.87	8.12	7.50	11.00			
Required BTUs	5.78	5.10	6.57	7.50	11.00			
Surplus/Deficit	2.72	1.77	1.55	0.00	0.00			

[1] According to long scale number, 1 billion = 10^{12}

Table 10: Pre-Optimized Total Coal Purchased in Thousands of Tons

Total Amount of Coal Over Purchased (Thousand Tons)					
	Miami 5	**Miami 7**	**Beckjord**	**East Bend**	**Zimmer**
RAG	222	66	62	0	0
Peabody	16	58	70	63	93
American	3	55	87	59	70
Consol	0	34	46	56	64
Cyprus	71	29	24	10	41
Addington	0	0	11	89	100
Waterloo	22	31	22	26	80
Total Pruchased	**334.77**	**272.68**	**321.41**	**303.07**	**448.06**
Surplus/Deficit	**157.61**	**94.48**	**75.99**	**0.00**	**0.00**

Table 11: Pre-Optimization Total Cost of Purchased Coal in Millions of Dollars

Total Cost of Purchased Coal ($ Millions)						
	Miami 5	**Miami 7**	**Beckjord**	**East Bend**	**Zimmer**	**Total Cost**
RAG	8.21	2.45	2.28	0.00	0.00	12.93
Peabody	0.64	2.30	2.84	2.25	3.39	11.42
American	0.13	2.09	3.46	2.02	2.37	10.07
Consol	0.00	1.54	2.10	2.37	2.68	8.69
Cyprus	3.57	1.45	1.19	0.43	1.87	8.52
Addington	0.00	0.00	0.43	3.31	3.70	7.44
Waterloo	1.01	1.41	0.98	1.10	3.48	7.98
						67.06

Table 12: Pre-Optimization Total Coal Purchased in Thousand Tons

Total Purchased Coal (Thousand Tons)						
	Miami 5	**Miami 7**	**Beckjord**	**East Bend**	**Zimmer**	**Total Purchased**
RAG	221.78	66.26	61.96	0.00	0.00	350.00
Peabody	16.22	57.74	70.05	62.98	93.00	300.00
American	3.41	55.00	87.00	59.37	70.21	275.00
Consol	0.01	33.99	45.90	55.99	64.10	200.00
Cyprus	71.46	29.03	23.99	9.61	40.92	175.00
Addington	0.00	0.00	10.94	88.96	100.10	200.00
Waterloo	21.89	30.66	21.57	26.15	79.72	180.00
						1680.00

Table 13: Pre-Optimization Total Coal Over-Purchased in Thousand Tons

Total Amount of Coal Over Purchased (Thousand)					
	Miami 5	**Miami 7**	**Beckjord**	**East Bend**	**Zimmer**
RAG	222	66	62	0	0
Peabody	16	58	70	63	93
American	3	55	87	59	70
Consol	0	34	46	56	64
Cyprus	71	29	24	10	41
Addington	0	0	11	89	100
Waterloo	22	31	22	26	80
Total Pruchased	**334.77**	**272.68**	**321.41**	**303.07**	**448.06**
Surplus/Deficit	**157.61**	**94.48**	**75.99**	**0.00**	**0.00**

As a first approach to try to reduce the costs, we used the West Corner Method to see if we could get any cost improvement. The result of this operation was ***Table 14***. On this first stage we have already eliminated the excess of coal consumed, as shown in ***Table 15***, and reduced the costs by USD 11.82 million for a total cost of USD 55.24

million, as shown in ***Table 16***. The total amount of coal purchased in this scenario is 1,418 thousand tons, which is an impressive reduction of 262K tons of coal.

Table 14: Coal Reallocated Using West-Corner Method

Total Purchased Coal (Thousand Tons)						
	Miami 5	**Miami 7**	**Beckjord**	**East Bend**	**Zimmer**	**Total Purchased**
RAG	222.12	127.88	0	0	0	350.00
Peabody	0	66.73	233.27	0	0	300.00
American	0	0	14.29	260.71	0.00	275.00
Consol	0	0	0	37.96	162.04	200.00
Cyprus	0	0	0	0	175.00	175.00
Addington	0	0	0	0	117.92	117.92
Waterloo	0	0	0	0	0	0.00
						1,417.92

Table 15: Coal Over-Purchase Eleminated By West-Corner Method

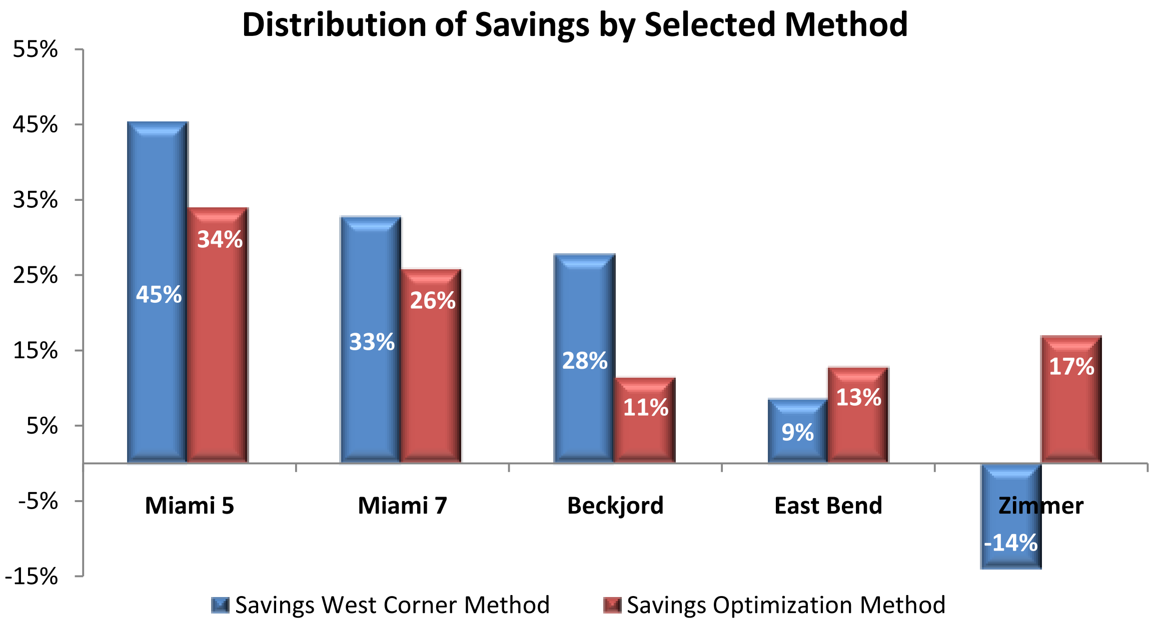
Total Amount of Coal Over Purchased (Thousands of Tons)					
	Miami 5	**Miami 7**	**Beckjord**	**East Bend**	**Zimmer**
RAG	222	128	0	0	0
Peabody	0	67	233	0	0
American	0	0	14	261	0
Consol	0	0	0	38	162
Cyprus	0	0	0	0	175
Addington	0	0	0	0	118
Waterloo	0	0	0	0	0
Total Pruchased	**222.12**	**194.61**	**247.56**	**298.67**	**454.96**
Surplus/Deficit	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Table 16: Total Cost of Coal Using West-Corner Method Allocation

Total Cost of Purchased Coal ($ Millions)						
	Miami 5	Miami 7	Beckjord	East Bend	Zimmer	Total Cost
RAG	8.22	4.73	0	0	0	12.95
Peabody	0	2.65	9.45	0	0	12.10
American	0	0	0.57	8.86	0.00	9.43
Consol	0	0	0	1.60	6.78	8.39
Cyprus	0	0	0	0	8.01	8.01
Addingtor	0	0	0	0	4.36	4.36
Waterloo	0	0	0	0	0	0.00
						55.24

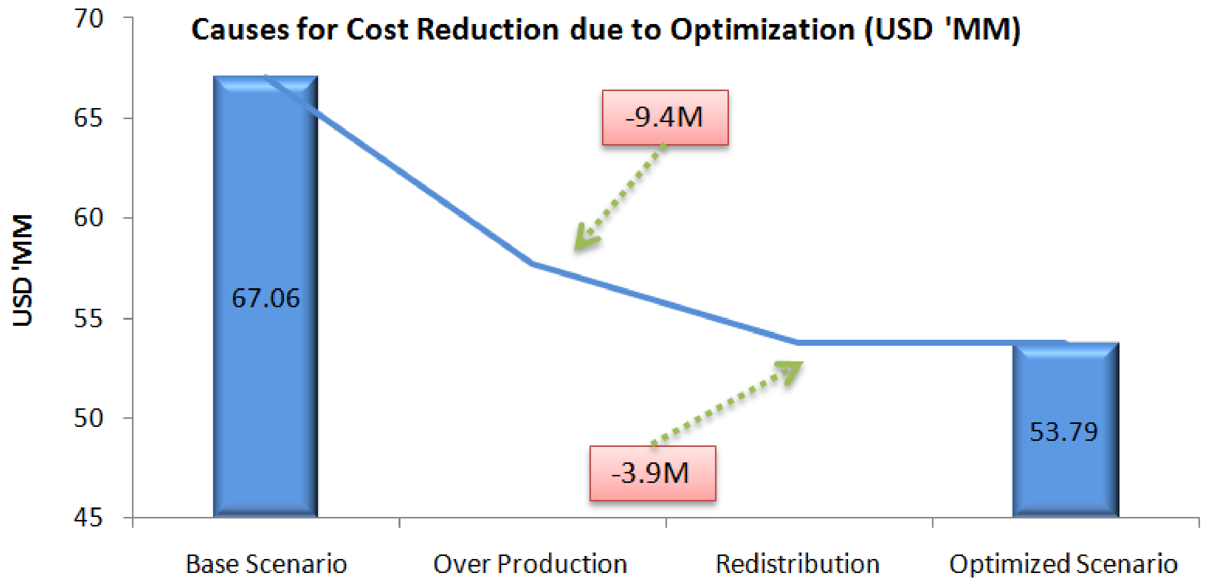
Even though we have achieved savings of 18% after applying the West Corner Method, we thought that maybe an optimization approach using linear programming might provide further savings. Indeed, after applying optimization using linear programming with Excel Solver, we found savings increased to a total of 20% savings from original expenditures (a 2% improvement beyond the West Corner Method allocation). Moreover, savings were redistributed more evenly between plants as you can see in ***Graph 1***. Note that when using the West Corner Method, Zimmer actually shows increased costs, while with the linear programming optimization method no extra cost is incurred, which means that the distribution of resources is more efficient. Therefore, the most significant improvement (in this case) of LP Excel optimization over the West Corner Method is assignation of resources.

Graph 1: Distribution of Savings

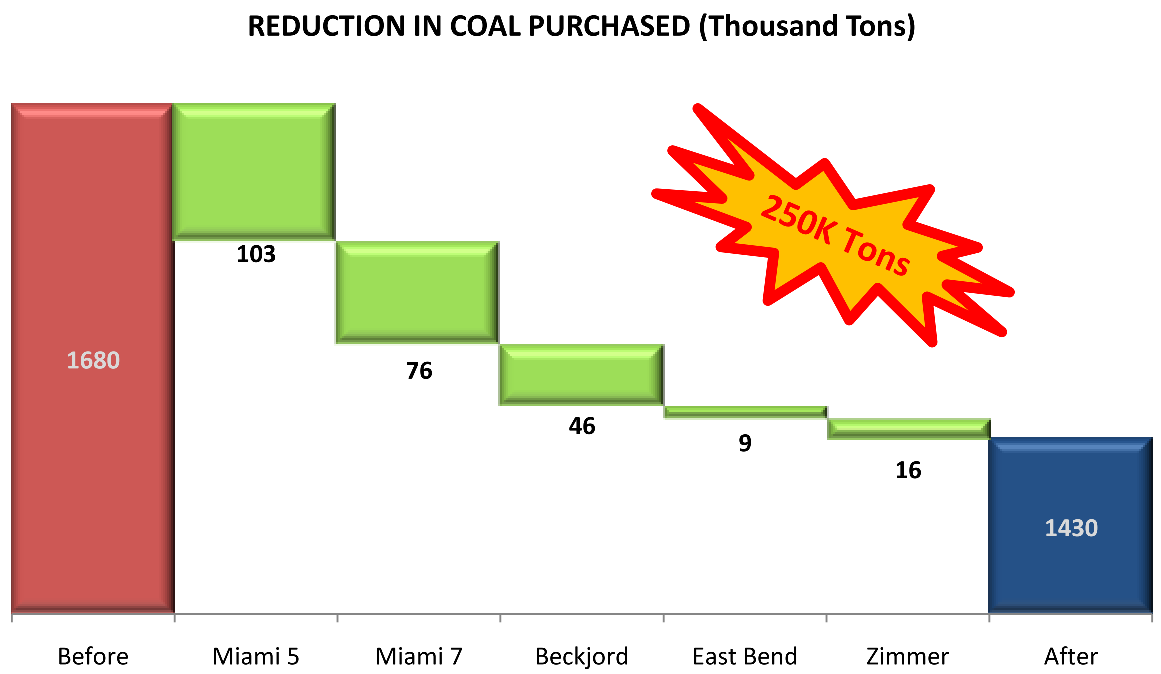


Comparing the results obtained by using the optimization approach against the base scenario, we can see how cost is improved by USD 13.3 million though a reduction in coal purchases of 250K tons. Out of this USD 13.3 million, USD 9.4 million is due to elimination of over-production of electricity and USD 3.9 million is due to better distribution of supplier-plant purchase allocation for East Bend and Zimmer plants. The following waterfalls in ***Graphs 2, 3,*** and ***4*** show the causes for the reduction in costs, the distribution of the reduction in coal purchased by plant, and the reduction in cost by plant.

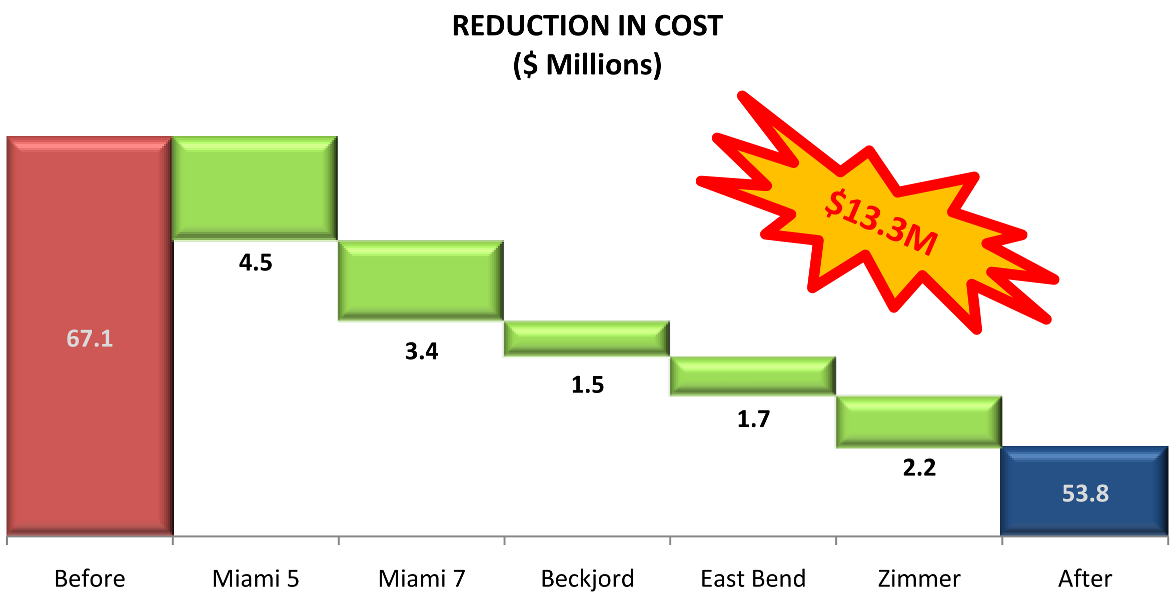
Graph 2: Causes for Cost Reduction



Graph 3: Reduction in Coal Purchased Tonnage



Graph 4: Reduction in Cost in Millions of Dollars



b. Sensitivity Analysis

Because of the amount of data points the software will not perform the analysis. In order to solve this problem we manually evaluated some possibilities by changing coal unitary prices for non-mandatory restrictions, in order to find lower and upper limits for the coefficients of the objective function. Our findings are shown in ***Table 17*** below.

Table 17: Limits for Coefficients of the Objective Function

	Lower Limit ($/ton)	Upper Limit ($/ton)
RAG	N/A	N/A
Peabody	N/A	N/A
American	N/A	N/A
Consol	-∞	40
Cyprus	-∞	30
Addington	-∞	43
Waterloo	-∞	48

Please note that for mandatory contracts the analysis was omitted, as, according to the restrictions, all the available coal must be purchased. The upper limit column shows the unitary price values that will cause the plant to be excluded from the model. As you can see, if the unit cost of Cyprus is more than 30 USD/ton the model will not take it into account for the optimal solution.

When analyzing the impact of more available resources we found out for each additional ton of coal purchased from RAG we would realize a savings of USD 41.9 thousand. From the other plants, any tonnage increase would actually increase total cost. As was expected, all factors equal, an increase in the tons available through variable contracts would have no effect on the solution due to the significantly higher per-ton costs of variable-tonnage contracts relative to fixed-tonnage contracts.

Table 18: Marginal Contributions

	Marginal Contribution
RAG	41,959
Peabody	-151,010
American	-222,814
Consol	0
Cyprus	0
Addington	0
Waterloo	0

Table 19: Impact of Increased Available Resources

	Marginal Contribution ($)	Limit Increase
RAG	41,959	1 unit
Peabody	-151,010	0 units
American	-222,814	0 units
Consol	0	0 units
Cyprus	0	0 units
Addington	0	0 units
Waterloo	0	0 units

4. **Conclusions**
   a. **Managerial Implications**
   b. **Feedback obtained from the observed results**

Managerial Implications

Through the application of resource allocation methodologies we achieved savings of USD 13.3 million, of which USD 9.4 million was due to corrections in the production output and USD 3.9 million was due to optimized resource reallocation. Overall coal purchases were reduced by 250 thousand tons per year, which represent an improvement of 20%.

Feedback obtained from the observed results

Wrapping up our analysis, we can conclude that even simple allocation techniques can have a considerable impact in the cost structure of any company. Not only total purchasing cost, but also proper rationalization of resources can contribute to improve the efficiency of raw materials consumption. For the Cinergy Corporation cost minimization problem we used a linear programming approach to optimize the overall cost of purchasing, transportation and processing of coal. To apply linear programming, expensive software is not necessary. Standard, widely available software like Microsoft Excel is more than enough to develop fairly robust models that can help management assess complex decisions in a timely manner.