New Bedford Steel Coking Coal Supply Problem [1]

New Bedford Steel (NBS) is a small steel manufacturing company. Coking coal is a necessary raw material in the production of steel, and NBS procures 1.0 - 1.5 million tons of coking coal per year. It is now time to plan for the 1997 production, and Stephen Coggins, coal supply manager for NBS, has solicited and received bids from the following eight suppliers for next year. He has organized the information about the bids in the following table.

Bids Received from Potential Coking Coal Suppliers

	Ashley	Bedford	Consol	Dunby	Earlam	Florence	Gaston	Hopt
Capacity (mtons)	300	600	510	655	575	680	450	490
Union/ Nonunion	U	U	N	U	N	U	N	N
Truck/ Rail	R	T	R	T	T	T	R	R
Volatility (%)	15	16	18	20	21	22	23	25
Price ($/ton)	49.50	50.00	61.00	63.50	66.50	71.00	72.50	80.00

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[1] This case and the following lecture notes have been prepared and written by Professor Rob Freund, MIT Sloan School of Management.

Based on market forecasts and 1996 production characteristics, NBS is planning to accept bids for 1,225 mtons (1.225 million tons) of coking coal. This coal must have an average volatility of at least 19% (volatility is the percent of volatile or burnable matter in the coal). Also, as a hedge against adverse labor relations, NBS has decided to procure at least 50% of its coking coal from union mines (United Mine Workers). Finally, Steve Coggins needs to keep in mind that capacity for bringing in coal by rail is limited to roughly 650 mtons per year, and capacity for bring in coal by truck is limited to 720 mtons per year.

Questions:

1.   How much coal should Coggins contract for from each supplier?

2.   What will be NBS's total cost of supply?

3.   What will be NBS's average cost of supply?

Excel Spreadsheet for New Bedford Steel

•In the third row we have defined the decision cells. In the fourth row we give the capacity limits for each source.

• Rows 7 - 11 denote constraints on the procurement plan. The second column gives the limit or target for the constraint. The third column is the value for the constraint for the given purchase decisions. The rest of the columns denote the coefficients for the constraints.

• Row 14 records the cost for the procurement policy; column 3 will give the total cost, while columns 4 - 11 give the per ton cost from each supplier.

			Ashley	Bedford	Consol	Dunby	Earlam	Florence	Gaston	Hopt
	Amount from		0	0	0	0	0	0	0	0
	Capacity		300	600	510	655	575	680	450	490
	Limit									
Supply	1225	0	1	1	1	1	1	1	1	1
Volatility	0	0	-4	-3	-1	1	2	3	4	6
Union	0	0	1	1	-1	1	-1	1	-1	-1
Truck	720	0		1		1	1	1		
Rail	650	0	1			1			1	1
	TOTAL									
COST		0	49.50	50.00	61.00	63.50	66.50	71.00	72.50	80.00

Excel Spreadsheet for New Bedford Steel
Optimal Solution

• The third row gives the optimal values for the decision variables.   The optimal value of the objective function is row 14, column 3: the minimum total cost.

• Rows 7 - 11 denote constraints on the procurement plan. The second column gives the limit or target for the constraint. The third column now gives the value for the constraint for the given (optimal) purchase decisions.

			Ashley	Bedford	Consol	Dunby	Earlam	Florence	Gaston	Hopt
	Amount from		55	600	0	20	100	0	450	0
	Capacity		300	600	510	655	575	680	450	490
	Limit									
Supply	1225	1225	1	1	1	1	1	1	1	1
Volatility	0	0	-4	-3	-1	1	2	3	4	6
Union	0	125	1	1	-1	1	-1	1	-1	-1
Truck	720	720		1		1	1	1		
Rail	650	505	1		1				1	1
	TOTAL									
COST		73267	49.50	50.00	61.00	63.50	66.50	71.00	72.50	80.00

Excel Solver Output for NBS

Target Cell (Min)

Cell	Name	Original Value	Final Value
$C$19	COST TOTAL	0	73268

Adjustable Cells

Cell	Name	Original Value	Final Value
$D$8	Amount from Ashley	0	55
$E$8	Amount from Bedford	0	600
$F$8	Amount from Consol	0	0
$G$8	Amount from Dunby	0	20
$H$8	Amount from Earlam	0	100
$I$8	Amount from Florence	0	0
$J$8	Amount from Gaston	0	450
$K$8	Amount from Hopt	0	0

Constraint

Cell	Name	Cell Value	Formula	Status	Slack
$C$12	Supply	1225	$C$12=$B$12	Binding	0
$C$13	Volatility	0	$C$13>=$B$13	Binding	0
$C$15	Truck	720	$C$15<=$B$15	Binding	0
$C$16	Rail	505	$C$16<=$B$16	Not Binding	145
$C$14	Union	125	$C$14>=$B$14	Not Binding	125
$D$8	Amount from Ashley	55	$D$8>=0	Not Binding	55
$E$8	Amount from Bedford	600	$E$8>=0	Not Binding	600
$F$8	Amount from Consol	0	$F$8>=0	Binding	0
$G$8	Amount from Dunby	20	$G$8>=0	Not Binding	20
$H$8	Amount from Earlam	100	$H$8>=0	Not Binding	100
$I$8	Amount from Florence	0	$I$8>=0	Binding	0
$J$8	Amount from Gaston	450	$J$8>=0	Not Binding	450
$K$8	Amount from Hopt	0	$K$8>=0	Binding	0
$D$8	Amount from Ashley	55	$D$8<=$D$9	Not Binding	245
$E$8	Amount from Bedford	600	$E$8<=$E$9	Binding	0
$F$8	Amount from Consol	0	$F$8<=$F$9	Not Binding	510
$G$8	Amount from Dunby	20	$G$8<=$G$9	Not Binding	635
$H$8	Amount from Earlam	100	$H$8<=$H$9	Not Binding	475
$I$8	Amount from Florence	0	$I$8<=$I$9	Not Binding	680
$J$8	Amount from Gaston	450	$J$8<=$J$9	Binding	0
$K$8	Amount from Hopt	0	$K$8<=$K$9	Not Binding	490

Sensitivity Report from Solver for NBS Problem

Microsoft Excel 4.0 Sensitivity Report
Worksheet: New Bedford

Changing Cells

Cell	Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowable Decrease
$D$8	Amount from Ashley	55	0	49.5	0.5	1
$E$8	Amount from Bedford	600	-1.5	50	1.5	1E+30
$F$8	Amount from Consol	0	2.5	61	1E+30	2.5
$G$8	Amount from Dunby	20	0	63.5	0.167	0.05
$H$8	Amount from Earlam	100	0	66.5	0.05	0.2
$I$8	Amount from Florence	0	1.5	71	1E+30	1.5
$J$8	Amount from Gaston	450	-1	72.5	1	1E+30
$K$8	Amount from Hopt	0	0.5	80	1E+30	0.5

Constraint

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
$C$12	Supply	1225	61.5	1225	5	25
$C$13	Volatility	0	3	0	20	100
$C$15	Truck	720	-1	720	20	3.33
$C$16	Rail	505	0	650	1E+30	145
$C$14	Union	125	0	0	125	1E+30

Shadow Price for a constraint is how much the objective function for the optimal solution will increase if we increase the RHS (right-hand-side) of the constraint by one unit.

Reduced Cost for a decision variable can be interpreted to be the shadow price on the non-negativity constraint for that decision variable, provided the decision variable is not at its upper bound in the optimal solution.

If the variable is at its upper bound in the optimal solution, then the convention of the Excel Solver sets the reduced cost to be the shadow price on the upper bound constraint.

If the decision variable equals zero in the optimal solution, then the reduced cost is the amount by which the objective function coefficient for the variable can increase before the variable may become non-zero in the optimal solution; that is, the variable will remain at zero if the objective function coefficient is changed by as much as the reduced cost. For changes greater than the reduced cost, the variable may become non-zero in the optimal solution.

If the decision variable equals its upper bound in the optimal solution, then the reduced cost is the amount by which the objective function coefficient for the variable can increase before the variable may drop below the upper bound in the optimal solution.

Caution: Different solvers may use different conventions, particularly with the signs of the shadow prices or the reduced costs. You always need to check your economic intuition to assure that you are making the right interpretation. Also, different solvers may refer to dual prices, rather than shadow prices: they are the same.

Now, let's consider the volatility constraint from the NBS case. Suppose that we re-write the constraint as follows:

$$0.15A + 0.16B + ... + 0.25H \geq 0.19(A + B + ... + H)$$

That is, the LHS is the amount of volatile matter supplied, measured in mtons, and the RHS is the required level of volatile matter measured in mtons. The constraint says that the amount supplied needs be greater than the amount required.

The shadow price on this constraint will convey the change to the objective function for the optimal solution when we re-solve with the above constraint replaced with the following constraint:

$$0.15A + 0.16B + ... + 0.25H \geq 0.19(A + B + ... + H) + 1$$

When we do this, the objective function would increase by 300 units ($300,000 in this case). Note a unit increase to the above constraint is comparable to adding 100 to the RHS for the original constraint as formulated earlier; thus, we expect that adding 1 to the original constraint would increase the objective function by 3, which is the reported shadow price.

Interpretation: At the margin for the optimal solution, the additional cost to supply 1 mton of volatile matter is $300,000 (or $300 for 1 ton of volatile matter).

We can reinterpret this in terms of the volatility content of coal. Each percentage point of volatility will supply 0.01 tons of volatile matter per ton of coal. Since the cost to supply 1 ton of volatile matter is $300, each percentage point of volatility has a value of $3 per ton of coal.

4.   What is the cost of coking coal on the margin? I.e., how much does an extra ton of coking coal cost NBS? (Why is this a valuable question to ask?)

5.   How should NBS value a nonunion/union supplier on a cost basis? Should they pay a premium fee for a union supplier? Is this a legitimate way to think about the problem?

6.   How should NBS value a low-vol./high-vol. supplier on a cost basis? Should they pay a premium for an extra % volatility? Is this a legitimate way to think about the problem?

7.   Should NBS consider expanding their trucking capacity? If so, how much should they be willing to spend?

8.   Should NBS consider expanding their rail capacity? If so, how much should they be willing to spend?

9.   Should Coggins be willing to negotiate a higher price in order to get more coal from Bedford and/or Gaston? If so, how high should he be willing to go?

10.   If Florence is uneconomical, how much must NBS insist that they lower their price before they would take them on as a supplier?

11.   If NBS contracts with Earlham, and their actual volatility rating goes down, how much of a penalty should NBS insist on in their contract?

New Bedford Steel Coking Coal Supply Problem - Addendum

From the optimal solution we can use the shadow prices on the resource and quality constraints to infer an **ex-post** imputed cost for each coal source. The shadow prices tell us that there is an opportunity cost of $1/ton for usage of truck capacity and that each percentage point in volatility can be valued at $3 per ton. We can then compare the (imputed) costs for coal as follows:

	Ashley	Bedford	Consol	Dunby	Earlam	Florence	Gaston	Hopt
price/ton	$49.50	$50.00	$61.00	$63.50	$66.50	$71.00	$72.50	$80.00
trucking costs		+1.00		+1.00	+1.00	+1.00		
net volatility cost	+12.00	+9.00	+3.00	-3.00	-6.00	-9.00	-12.00	-18.00
imputed cost/ton	$61.50	$60.00	$64.00	$61.50	$61.50	$63.00	$60.50	$62.00

Note -- the net volatility cost (or premium) for a coal source is the difference between its volatility and the target of 19%, multiplied by $3/ton.

Observations:

• In the optimal solution, coal sources A, D and E are used but are not at their upper bounds. They all have an imputed cost of $61.50, the shadow price for the supply constraint.

• In the optimal solution, coal sources B and G are at their upper bounds. The difference between their imputed costs and $61.50 (shadow price for the supply constraint) is their reduced costs.

• In the optimal solution, coal sources C, F and H are at their lower bound of 0. The difference between their imputed costs and $61.50 (shadow price for the supply constraint) is their reduced costs.