Power Plant Fuel Purchasing Using Multiple Objective Linear Programming (MOLP)

Sometimes we have conflicting goals, and we must figure out a way to resolve the conflict and reach a reasonable compromise. Such situations call for Multiple Objective Linear Programming (MOLP). To demonstrate this technique, we will use a hypothetical problem in which the owners of a conventional fossil-fuel power plant have two grades of fuel available. One grade of fuel is less expensive than the other, but it also generates less heat per ton and produces larger amounts of air pollution. So the owners need to trade off total fuel cost against total amount of resulting pollution to achieve a reasonable compromise.

Here is the setup of the initial problem, where the heat energy generated by the fuels is measured in Gigajoules (GJ) per metric ton of fuel. [One metric ton = 1,000 kilograms (kg); and one kg = 1,000 grams (g).] In addition to organic compounds and particulate matter, the other forms of resulting pollution include carbon dioxide (CO_2), sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and carbon monoxide (CO). Numbers for the constraints/limits on the amount of energy required, the maximum pollution allowed and the amount of fuel available are shown in red; numbers for the decision variables (amount of coal to be consumed) are shown in green; numbers for the objective functions (amount of pollution created and cost of fuel) are shown in blue:

Power Plant Fuel Problem

Fuel Characteristics	Fuel Type A	Type Type B	Totals
Energy Content (GJ/metric ton) =	35.30	28.47	
Energy Required (GJ) =			50,000.00
Energy Generated (GJ) =	0.00	0.00	0.00
Pollutants			
CO2 (g/GJ) =	94,600	101,000	
SO2 (g/GJ) =	765	1,361	
NO2 (g/GJ) =	292	183	
CO (g/GJ) =	89	89	
Organics (g/GJ) =	5	8	
Particulates (g/GJ) =	1,203	3,254	
Total (g/GJ) =	96,954.02	105,894.88	
Total (kg/metric ton) =	3,422.48	3,738.09	
Allowable Pollution (metric tons) =			5,500.00
Total Pollution (metric tons) =	0.00	0.00	0.00
Cost ($/metric ton) =	$70.00	$55.00	
Total Cost ($) =	$0.00	$0.00	$0.00
Tons Available =	1,300.00	1,000.00	
Tons Required =			0.00
Tons Consumed =	0.00	0.00	0.00

In the above example, we need to generate 50,000 Gigajoules of energy provided by two different grades of fuel (Type A and Type B). Type A fuel provides more heat energy per metric ton, and it produces somewhat less pollution; but it is also more expensive than fuel Type B. So the plant owners need to figure out the proper mix of fuels to use. They also must not exceed the total maximum of 5,500 metric tons of atmospheric pollution allowed, based on generating 50,000 Gigajoules of heat energy. [Note: <u>one</u> ton of fuel actually produces <u>several</u> tons of pollution. This is because a huge amount of atmospheric oxygen is used in the combustion of the fuel. The oxygen combines with the carbon in the fuel to produce large amounts of carbon dioxide (CO_2) during combustion.]

The plant has 1,300 tons of Type A fuel and 1,000 tons of Type B fuel available to produce the needed 50,000 GJ of heat energy. There are two competing objectives involved: (a) minimize pollution and (b) minimize fuel cost. Here is a model that <u>minimizes pollution</u>:

Power Plant Fuel Problem			
	Fuel	Type	
Fuel Characteristics	Type A	Type B	Totals
Energy Content (GJ/metric ton) =	35.30	28.47	
Energy Required (GJ) =			50,000.00
Energy Generated (GJ) =	45,890.00	4,110.00	50,000.00
Pollutants			
CO2 (g/GJ) =	94,600	101,000	
SO2 (g/GJ) =	765	1,361	
NO2 (g/GJ) =	292	183	
CO (g/GJ) =	89	89	
Organics (g/GJ) =	5	8	
Particulates (g/GJ) =	1,203	3,254	
Total (g/GJ) =	96,954.02	105,894.88	
Total (kg/metric ton) =	3,422.48	3,738.09	
Allowable Pollution (metric tons) =			5,500.00
Total Pollution (metric tons) =	4,449.22	539.64	4,988.86
Cost ($/metric ton) =	$70.00	$55.00	
Total Cost ($) =	$91,000.00	$7,939.94	$98,939.94
Tons Available =	1,300.00	1,000.00	
Tons Required =			1,444.36
Tons Consumed =	1,300.00	144.36	1,444.36

Examination of the table reveals that:

We have used up all 1,300 available tons of Fuel A and 144.36 of the 1,000 available tons of Fuel B to produce the required 50,000 Gigajoules of heat energy at a total cost of $98,939.94. We have also generated 4,988.86 tons of pollutants.

Now let's look at the second model that <u>minimizes fuel cost</u>:

Power Plant Fuel Problem

Fuel Characteristics	Fuel Type A	Type Type B	Totals
Energy Content (GJ/metric ton) =	35.30	28.47	
Energy Required (GJ) =			50,000.00
Energy Generated (GJ) =	31,007.57	18,992.43	50,000.00
Pollutants			
CO2 (g/GJ) =	94,600	101,000	
SO2 (g/GJ) =	765	1,361	
NO2 (g/GJ) =	292	183	
CO (g/GJ) =	89	89	
Organics (g/GJ) =	5	8	
Particulates (g/GJ) =	1,203	3,254	
Total (g/GJ) =	96,954.02	105,894.88	
Total (kg/metric ton) =	3,422.48	3,738.09	
Allowable Pollution (metric tons) =			5,500.00
Total Pollution (metric tons) =	3,006.31	2,493.69	5,500.00
Cost ($/metric ton) =	$70.00	$55.00	
Total Cost ($) =	$61,488.11	$36,690.67	$98,178.78
Tons Available =	1,300.00	1,000.00	
Tons Required =			1,545.50
Tons Consumed =	878.40	667.10	1,545.50

This second model also generates 50,000 Gigajoules of heat energy. It uses 878.4 tons of Fuel A and 667.1 tons of Fuel B, at a total cost of only $98,178.78; and it produces the maximum allowable amount of pollution (5,500 tons). Now it is up to the plant owners to make whatever adjustments they feel are appropriate to arrive at a final compromise answer. For example, although they are allowed to produce up to 5,500 tons of pollution, do they really want to do that? In addition to damaging the environment, it might create a poor public image for the company; and might also lead to closer scrutiny by regulatory bodies, and possibly tighter regulation.

Although we will not show it here, there is actually an additional optimization option called "minimax" that can help us arrive at a final decision by assigning weighted deviation variables to each goal, to control how much we can deviate from each goal when attempting to adjust the goals. The MOLP model can incorporate these weighted deviations as additional inputs to arrive at a final solution.