

OR428 Assessed Project Gas Marketing --- SOLUTION

General Remark:

Some answers parts of the project necessarily build on results in other parts of the project. Whenever you did a mistake in an earlier part of the project, I continued the marking of later parts as if you had *not* done a mistake before. (This means that a mistake in one part of the project could not lead to lower marks in a later part of the project.)

PART I

Part Ia

Minimal price to charge to customers 1 to 3:

39.6373 GBP/MWh (multiplied with their individual demands)

(Objective Function Value: GBP 6,533,966.20)

Flat band contracts:

- Contract 1, days 01 to 10: 412.648 MWh/day
- Contract 3, days 21 to 31: 343.723 MWh/day
- Contract 4, days 01 to 15: 421.961 MWh/day
- Contract 6, days 01 to 30: 5103.550 MWh/day

Swing contract contracted volume: 2000 MWh (= upper bound)

Pipelines:

Pipeline	Cities connected	Capacity booked [MWh/day]
1	AB	6426.130
2	BC	159.764
3	CD	0
4	DE	758.586
5	EF	122.111
6	AF	0
7	BF	1998.090
8	BG	4363.780
9	EG	644.138

Balancing capacity resulting from booking pipelines 1 and 6: 421.306 MWh/day

Storage:

- volume booked: 324.732 MWh
- injection capacity: 158.167 MWh/day
- release capacity: 12.9893 (= volume/25 = upper bound given by volume booked)

For the marking it was not relevant if you came up with the correct numbers. Marks (32 out of a total of 100) were awarded on the basis of those aspects of the gas marketing problem that were represented in the model. (If you calculated the balancing capacity in a wrong way, for example, you got 2 marks less; if you forgot to model the upper bound of the volume in the storage, you got 1 mark less, etc.)

2 more marks were awarded for making the model run and presenting the results in a proper way.

Part Ib

The solution of the model is not unique because

- gas may be transported in different pipelines as long as capacity is available,
- swing gas, balancing gas and storage gas can substitute each other on a particular day and this can be compensated for on another day (by taking the reverse action)

You could get up to 2 marks for an answer to this question, depending on how detailed your answer was, and on your line of argument.

Part Ic

The answer in part Ib does not affect the contracts (pipeline capacity, storage size, swing contracted volume, flat band contract). This question in part Ic asks if other pipelines or other flat band contracts could lead to a different optimal solution and required you to derive a new LP from the LP used in part Ia.

The lecture covered a method to answer the question (the one developed by Gautam Appa). This method looks for alternative optimal solutions by adding to the constraints of the original LP a constraint that requires the objective function to take the same value as in the original LP. The objective function of the new LP maximizes the sum of all non-basic variables plus the sum of the slacks of all effective constraints.

To answer this question, you could either directly apply this method as it was taught, or modify the method by using an objective function that maximizes the sum of the variables representing the contracts that are not used in the original optimal solution (i.e. "maximize contracted volume flat band 2 + contracted volume flat band 5 + capacity pipeline 3 + capacity pipeline 6"). If and only if this objective function is positive, there must be an optimal solution with other contracts. (The latter approach takes less time to implement as the number of non-basic variables and effective constraints is quite large.)

If you use the original approach as taught in the lecture, you will get a positive objective function due to the phenomena mentioned in part Ib. For achieving full marks (4), you were required to make a connection with your result in Ib in order to show that you knew about the limits of the original method. (You were not required, however, to fully prove that there are no other contracts. This would have gone beyond my expectations.)

If you use the shorter, modified approach, it turns out that the value of the objective function is zero, i.e. there are definitely no other combinations of contracts that lead to the objective function value given in part Ia. In this sense, the solution of the model is unique. Choosing this shorter approach shows your capacity of adapting the methods taught in the lecture in a flexible, creative way and directly leads to 4 marks.

Those of you who wrote a little bit about Gautam Appa's approach but did not prove in the report or by means of the files they handed in that they actually wrote such a model were not given any points. I cannot give marks on the basis of mere claims.

Part Id

This question asks for the dual value of the constraint that was used for the upper bound of the contracted swing volume (which is a binding constraint). The dual value is - 0.967171, i.e. the company should bid 0.97 GBP/MWh for a additional swing capacity (at least within the interval in which the dual value is valid). You could get up to 2 marks for this.

Alternatively, you could have run the model with a different constraint about the upper bound of the contracted swing volume. This is less professional, of course. But if it was explained properly, this was accepted.

Again (and this applies to all similar questions), it was not relevant whether you found the right number. Of course, if your model did not fully represent the gas marketing problem, it was impossible for you to calculate the right number. But if you used the correct dual value for the problem you actually modeled, you got full marks for this question.

If someone did not explain (anywhere in their report) where they got their number from, they got only 1 or 0 marks (depending on the details of what I could find in the report).

Part Ie

This question asks for the reduced cost of the variable that was used for the capacity booked for pipeline 6. The reduced cost is 17.2513. The pipeline is 26.15 GBP/MWh/day for one day of booking the pipeline. Typically, the relevant coefficient in the objective function will be 30 times the daily cost (i.e. the cost for one month). This implies that the price for the pipeline, to be attractive for the company, must not exceed $(26.15 - 17.2513/30)$ GBP/MWh/day = 25.575 GBP/MWh/day for one day of booking the pipeline, which amounts to GBP 767.60 for the entire month.

If you did not take into account the factor 30 in the objective function, you arrived at 8.8987 GBP/MWh/day for one day of booking the pipeline, and got only 1 out of the total of 2 marks.

The marking for this question was done similar to the rules outlined for part Id.

Part If

Including the demand of customer 4 into the model leads to an objective function value of GBP 8063550, and to an offer of 38.4056 GBP/MWh to all 4 customers. This price is about 1.23 GBP/MWh lower than the price calculated in 1f.

The fundamental reason for this consists in the fact that including the demand of customer 4 leads to a less volatile overall demand pattern. (The demand pattern of customer 4 has been designed such that the demand of customer 4 is low when the sum of the demands of customers 1 to 3 is high, and vice versa.) A less volatile overall demand leads to lower cost for achieving flexibility in gas supply (via swing and storage contracts). Also, the capacity booked for the pipelines is used in a more efficient way because the gas demand of customer 4 can be transported by using free pipeline capacity on days on which customers 1 to 3 do not have a high demand (pipeline capacity must be booked on the same level for the entire month). As a consequence, the costs per MWh gas demand incurred by customer 4 are lower than those incurred by customers 1 to 3. These economies of scale lead to a lower offer for all 4 customers.

You could get up to 4 marks for this question, depending on how detailed your interpretation of the 4-customer-solution was (1 mark was given for running the model for 4 customers, the other 3 were for your interpretation).

PART II

Part IIa

You were required to build a two-stage Stochastic Programme with 3 scenarios. If customers 1 to 3 pay for the gas according to the result of part Ia, customer 4 must be charged at least GBP 40.415377. The total costs are as follows:

- Scenario A (25%): GBP 8349000
- Scenario B (50%): GBP 8338450
- Scenario C (25%): GBP 8339060

The expected total cost for all 3 scenarios is GBP 8341240.

Again, it was not the numbers that mattered (see similar remarks above). What mattered for achieving a total of 9 marks here was whether you constructed a proper 2-stage Stochastic Programme and had the right approach for calculating the additional cost of customer 4. Marks were deducted if you made 1st-stage variables depend on the scenarios.

Quite a few of you did not write a proper SP. The main mistake was that some of you wrote the model in a way that it calculated each scenario independently and then looked at the expected value of the result. Those of you who did this mistake either used the original model from part Ia three times – once for each scenario – or made all variables have the scenario as an index, which leads to the same result. This is a “Wait and See” approach and only advisable if you are a magician. A proper SP approach requires you to distinguish between those decisions that have to be made before you know the scenario (1st stage) and those decisions that have to be made after you know which scenario you are in (2nd stage). Only the latter variables must have a scenario index. (In one case, someone made all variables scenario-dependent, but required the 1st stage variables to take the same value for all scenarios. This is not a professional approach (because it makes you have more variables than necessary and thus makes life for the pre-solver more difficult than necessary), but it was ok for getting full marks.)

The 1st stage variables were: contracts for booking the capacity of pipelines, the flat band contracts, the overall contracted swing volume, the upper bound of the storage volume, storage injection and release capacity, and the balancing capacity (because it depends only on the pipeline capacity). The 2nd stage variables were all flow-related phenomena, i.e. in particular the flows in the pipelines, the swing volume actually taken, storage injection and release flows, the actual volume of gas in the storage, and the balancing flows.

Part IIb

This question did not require you to calculate anything. Instead you were asked to comment on the management’s suggestion to use a model based on the expected demand of customer 4 (without distinguishing between 3 scenarios). This topic was discussed in the lecture and you were taught that the real cost of using the average demand in a model can be calculated as the “implemented average”, i.e. the expected cost for all 3 scenarios when the solution of a model with average demand is implemented.

Full marks (5) could be achieved, for example, by mentioning that the average demand will be realistic only with probability 0.5 (because it is identical with the demand in scenario B), that using the average demand does not take into account the risk that a different scenario might occur (i.e. it does not take into account the uncertainty of the future), that the model of the “implemented average” would reveal the real cost of using the model with average demand, that the latter model never leads to better solutions than the Stochastic Programming model, and that therefore the company is well advised NOT to calculate cost on the basis of the average demand. (Full marks could be achieved also when you gave a similarly detailed explanation.)

Honestly speaking, it was disappointing for me that only a few of you saw how stupid the management’s suggestion is. Using the average demand is one of the main mistakes practitioners make, and I talked about this in the lecture. This is a very dangerous mistake! I just hope that no-one of you will ever do this mistake somewhere in a company. (If you do so nevertheless, please let me know because, should I have any shares in that company, I would like to sell them all before your model has any impact.)

Part III

This part required you to build a MIP model for a new storage, for which you needed binary variables to model logical conditions. The minimal amount of binary variables needed is 120. (30 days, 2 binaries per day for injection capacity, 2 binaries per day for withdrawal capacity.) Each binary variable corresponds to one threshold given by the percentage of the storage volume used on the day under consideration (thresholds for injection: $x > 50\%$, $x > 80\%$, thresholds for withdrawal: $x < 20\%$, $x < 50\%$).

Alternatively, you could use the thresholds 20%, 50%, 80% for both injection and withdrawal, which leads to at least 90 binary variables. This way of modeling is not entirely accurate as the injection capacity depends on the condition “volume in storage $\leq 50\%$ ”, while the withdrawal capacity depends on the condition “volume in storage $< 50\%$. However, if you mentioned that you simplified the problem, this was accepted; otherwise 1 mark was deducted.

The optimal solution is given by:

Cost: 39.3399 GBP/MWh

Objective function value: GBP 6484944.982168

Flat band 01 to 10: 279.524 MWh/day, and flat band 01 to 30: 5525.300 MWh/day.

The model books a storage space of 3049.55 MWh at the new storage. The old storage is not used anymore.

The capacities booked for the pipelines remain the same as in part Ia, except the fact that pipeline 2 from city B to city C (where the other storage is located) is not needed anymore.

As the rules for calculating the balancing capacity have changed in part III, the new balancing capacity is 621.306 MWh/day.

It must be noted that the solver, due to the high amount of binary variables, might not arrive at a solution when you made mistakes when modeling part Ia. Therefore, the marks of part III do not include a mark that would require you to have a model that actually works. (Learn from this how limited MIP models actually are.)

Marks for the report and extra marks:

Marking scheme:

1. Up to 5 marks were given for the general readability and structure of your report. 2 marks were deducted if I had to search the files for finding hints of what you actually did.

2. Up to 5 marks were given for explaining the models. Most of you did not spend much effort on it. For me, this meant hours of extra work of finding out what your model actually does. For some of you, it would have made a difference between M and D, or P and M, because these points would have been easy to score.

Note that I did not expect you to write a novel here. For getting 5 marks, it was, roughly speaking, sufficient to write one sentence for each parameter, variable and constraint. Of course, if the rest of your report was already very detailed with respect to your models, you could get full marks with even fewer remarks. In the end, these points were – more or less – a function of how much time I needed to understand your models.

3. Up to 5 marks were given for the way in which you wrote the AMPL files. If you wrote your files in a way similar to the files given in the lecture notes (that means: clear names for the variables, using many comments, putting related constraints next to each other, using a lot of space, etc.) you were given full marks. I am very happy to see that most of you scored high here. When you use Mathematical Programming in a company there is no way around this.

4. You could achieve up to 5 extra marks. These were given for particularly creative ways of modeling something, particularly detailed explanations or analyses of the results (a correlation analysis of the demand pattern in conjunction with part If, for example, or a calculation of the range in which the dual value of part Id is valid, diagrams that give you an immediate idea of a relevant phenomenon, etc.). Most of you got at least 1 of these extra marks.

Some general remarks on the report:

a) The marks for the report were actually more than the 20 marks I have just described. The reason for this is that the marks awarded for your answers to the questions Ia to If, IIa, IIb and III also depended on how detailed and well reflected they were. Taking this into account, you could say that that an excellent report – in one way or the other – could finally lead to up to around 37 marks.

b) Some of you felt they had to come up with numbers their models did not deliver, i.e. they just copied numbers from other people to make their report look “better”. (It was not really difficult to discover this as I had to check every model line by line anyway, but it took a lot of time to really sort it out.) This was the most annoying experience I had had in the past twelve months!

In those cases, I gave 0 marks for the answers concerned, no matter what else someone wrote because making up results counts as one of the highest crimes in academia. In other words: it is not cool, but disappointing and &£\$&£*\$!!! (Remember, if you had just given the numbers based on your model, you would have been given full marks. Also, when someone had the guts to frankly state that their model did not work properly and they could not provide an answer to a question because of this, they got marks for such a statement.)

c) The quality of the report turned out to be highly correlated with the quality of the modeling. There were a few exceptions, however. In view of the high correlation between the quality of the models and the quality of the report, no one (except for one student) got a Distinction, for example, when they did not write an (almost) correct Stochastic Programme for part IIa. This one student, however, did the common SP mistake I described above, but wrote such an incredibly detailed, well written report that her/his final result turned out to be Distinction. (This implies that some of you could have got a better mark if they had spent more time on the report – given that their modeling was not really excellent.) So the quality of your report could make a real difference.

d) The problem statement of the assignment mentioned (as one among seven aspects) that marks will be awarded on the basis of a “description of how your EXCEL files are related to the entities in your AMPL model”. Almost no-one wrote about this in their report. As the project was rather long and required a lot of work from you anyway, I decided not to make this an official requirement in the marking scheme. But you could get extra marks for it. Those, however, who provided such a description got extra marks or more marks in the “explanation of the model” section – depending on where there was room for adding some more marks for you.

Finally, again congratulations to all of you. The project was long and demanding, and I am very happy to see that in the end you rightfully earned 11 Ds, 11 Ms, 12 Ps and no Fs, which is an unusually good result for our Model Building course.