Gas Marketing - QUESTION

A Company buys natural gas, uses pipelines for transporting the gas and delivers it to various industrial customers.

Demand
There are four industrial customers that request to be delivered gas by the Company. These potential customers have an estimated demand over a period of one month as follows (numbers given in MWh, which is a common unit of measurement in the gas industry and measures gas on the basis of the energy it provides; for convenience, a month is defined to be a period of 30 consecutive days):

Demand				
	Customer 1	Customer 2	Customer 3	Customer 4
Day 1	751	1,856	3,676	1,163
Day 2	721	1,855	3,556	1,204
Day 3	735	1,756	3,018	1,169
Day 4	698	1,731	3,556	1,217
Day 5	629	1,769	3,528	1,249
Day 6	646	1,650	3,477	1,393
Day 7	669	1,629	3,388	1,409
Day 8	666	1,664	3,498	1,487
Day9	628	1,648	3,379	1,544
Day 10	609	1,568	3,351	1,542
Day 11	611	1,522	3,327	1,618
Day 12	612	1,538	3,262	1,637
Day 13	556	1,598	3,217	1,603
Day 14	558	1,439	3,212	1,797
Day 15	573	1,421	3,208	1,794
Day 16	592	1,488	2,337	1,781
Day 17	590	1,487	3,404	1,672
Day 18	576	1,364	3,369	1,705
Day 19	526	1,301	3,117	1,871
Day 20	522	1,392	3,131	1,827
Day 21	514	1,504	3,278	1,703
Day 22	520	1,550	3,293	1,712
Day 23	515	1,617	2,812	1,693
Day 24	500	1,737	3,328	1,571
Day 25	518	1,803	3,313	1,420
Day 26	471	1,951	3,083	1,441
Day 27	440	2,099	2,966	1,238
Day 28	452	1,917	3,207	1,210
Day 29	513	1,970	3,276	1,211
Day 30	499	1,925	3,118	1,233

The Company must not deliver less gas than the customers require because this would force them to interrupt their production processes. Also, the Company cannot deliver more gas to the customers than they need because the customers have no way of using the additional gas.

However, as one might expect, the demand of a customer can be subject to change due to unforeseen circumstances that may arise during the production processes that the customer carries out. Customers 1, 2 and 3 have agreed to bear the risk of such unforeseen circumstances themselves, i.e. pay to the owners of the network of pipelines all penalties and extra cost that might be incurred by a sudden change in demand. The case of customer 4 will be addressed later.

The locations of the customers' production plants are given in the following table.

Customer	Customer 1	Customer 2	Customer 3	Customer 4
Location	City D	City F	City G	City E

Supply

The Company has two ways of buying gas:

(a) It can enter into contracts with which it commits itself to take delivery of a constant amount of gas on every day during a fixed period of time ('flat band contracts'), and

(b) It can sign a so-called 'swing contract' in which it agrees to take delivery of a fixed minimal amount of gas during a fixed period of time, but has a certain degree of flexibility regarding the amount of gas it actually collects on a specific day.

These two ways of buying gas are not mutually exclusive; the Company is free to choose a number of flat band contracts and can combine them with the swing contract if it wishes to do so.

(a) Flat band contracts

The flat-band contracts that are offered to the Company are characterized by the period of time during which the gas is delivered and the exact amount of gas the Company agrees to collect every day. On the gas market in City A, gas providers offer flat band contracts up to a certain maximum amount of gas per day. All flat band contracts have to be signed at the beginning of the month.

	Period of delivery	**Maximum amount in MWh/day**	**Price (GBP/MWh)**
Contract 01/10	Days 1 to 10	2,000	13.24
Contract 11/20	Days 11 to 20	2,000	12.92
Contract 21/30	Days 21 to 30	2,000	13.10
Contract 01/15	Days 1 to 15	10,000	11.67
Contract 16/30	Days 16 to 30	10,000	11.20
Contract 01/30	Days 1 to 30	50,000	9.64

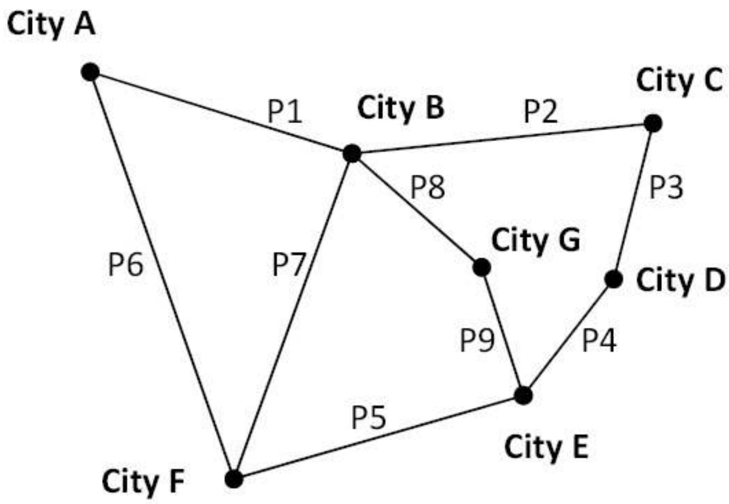
(b) Swing contract

The swing contract is defined by a so-called ‘contracted volume’, which is the maximal amount of gas that the Company can collect within the month under consideration, and must be below 2000 MWh. The contracted volume must be decided at the beginning of the month.

On every single day, the Company can collect a maximum of 1/30 of the contracted volume and must collect at least 60% of this maximal daily amount. The price for the swing contract consists of two components: at the end of the month the Company has to pay a service fee of 1.16 GBP/MWh for the contracted volume that was made available. Moreover, the Company has to pay an amount of 8.80 GBP/MWh for every MWh it actually collected. If the amount of gas actually collected is lower than 80% of the contracted volume, however, the company has to pay for 80% of the contracted volume instead.

All gas delivered by virtue of flat band contracts and the swing contract must be collected by the Company in City A.

Transportation
The gas is transported via a network of pipelines between 7 cities that is part of a larger network and connects the cities as follows:



Transporting the gas via one of the 9 pipelines requires the Company to enter into a contract that is valid for the entire period of 30 days and specifies the maximal amount of gas that the Company is allowed to transport via the pipeline per day (‘contracted capacity’).

This capacity must be lower than the maximal capacity of the pipeline and can be used into both directions, i.e. the capacity booked for pipeline P3, for example, can be used for transporting gas from City C to City D as well as for transporting gas from City D to City C.

The Company has to pay a service fee that is proportional to the contracted capacity and a fee that is proportional to the volume of the gas that it actually transports through the pipeline. All transportation contracts must be signed at the beginning of the month.

The relevant data are given in the following table:

Pipeline	Pipeline Maximal capacity (MWh/day)	Price of contracted capacity (GBP/MWh/day)	Price of volume (GBP/MWh)
P1	10,000	16.75	1.15
P2	30,000	2.20	0.20
P3	30,000	18.75	1.90
P4	30,000	5.90	0.80
P5	30,000	12.40	1.25
P6	10,000	26.15	1.50
P7	20,000	8.50	0.40
P8	20,000	3.80	0.80
P9	5,000	5.60	0.20

Transporting gas through a pipeline requires energy for running compressor stations that make sure that there is the necessary pressure in the pipelines to push the gas forward. This energy is provided by a fraction of the gas flowing in the pipelines (so-called ‘technical gas’ or ‘fuel gas’).

This means that in each pipeline the Company loses 1% of the gas that it transports through the pipeline as fuel gas.

Note that in reality, gas cannot be transported through a pipeline into both directions at the same time. Attempting to transport the same amount of gas into both directions at the same time would just increase the pressure in a pipeline, without transporting any gas at all.

However, it can be assumed to be sufficient an approximation for modeling purposes that gas can actually be transported through a pipeline into both directions at the same time.

This implies that, if the same amount of gas is being transported into both directions, the Company can be assumed to lose gas during this ‘transport’ due to burning fuel gas, i.e. at both ends of the pipeline the company will have less gas than it would have had without going ahead with this ‘transport’.

(As losing gas means losing money, such a ‘transport’ into both directions occurs only rarely as a solution of optimization models and might therefore, despite not being realistic, be allowed to happen in a model.)

Storage

The company has the option to use a natural gas storage located in City C. For using this storage, it has to reserve in advance (i.e. at the beginning of the month) the storage space it needs (the maximal 'size' of the storage that can be used during the month), and the capacities for injecting gas into and withdrawing gas from the storage.

Storage space costs 2.20 GBP/MWh, while the injection and withdrawal capacities are 25.50 GBP/MWh/day and 30.20 GBP/MWh/day, respectively.

On each day, the amount of gas that the company decides to withdraw from the storage must not exceed 1/25 of the storage space it reserves (i.e. the maximal withdrawal capacity the company can book is given by dividing the storage space by 25 days).

This implies that it might make sense for the company to book additional storage space just to make sure that they have an optimal withdrawal capacity.

There is no additional charge for the amount of gas that the company actually injects into and withdraws from the storage.

Balancing

The pressure within a natural gas network does not have to be entirely constant. Therefore, the company is not required to inject into the network precisely the amount it withdraws from the network.

This phenomenon can be used to adapt to changes in supply and demand of gas, i.e. has a function that is similar to using storage space. However, the difference between what the company injects into and withdraws from the network must not be too large and must be balanced out during the period of 30 days.

On a single day, the company is allowed to withdraw from the network an amount of gas that is up to **z** MWh higher or lower than the amount of gas injected into the network. The number **z** is called 'balancing capacity' and is defined as

- 10% of the sum of the contracted capacities of those pipelines that are used for injecting gas into the network, up to an amount of 2,000 MWh/day, plus

- 5% of the amount that the sum of the contracted capacities of these pipelines exceeds 2,000 MWh/day.

(Note that the sum of the contracted capacities of the pipelines that are used for injecting gas into the network is equal to the sum of the contracted capacities of the pipelines P1 and P6.)

The difference between injection and withdrawal (which can be positive or negative) is carried forward on a balance sheet for the entire period of 30 days. On each single day the balance of injection and withdrawal since day 1 must not exceed 3 times the balancing capacity. At the end of the entire period of 30 days, the difference between injection and withdrawal that has been carried forward must be balanced out, i.e. the final monthly total balance must be zero.

The difference between injection and withdrawal that is relevant for the balancing scheme is measured in City A. This means that any amount of excess gas in the network has to be transported through the network and 'paid' into the 'balancing account' in City A. Similarly, any gas deficit in the network is balanced out by 'debiting' the 'balancing account' in City A, from where the gas is transported further via the network of pipelines. In other words: City A is the only place within the network where any excess in injection or withdrawal can be balanced out via the balancing scheme.

The project

The company wishes to minimize the amount of money it has to pay for satisfying the demand of their prospective customers and has several questions related to this, which are given in part I, part II and part III below.

In order to provide an answer to part II, you must extend your model to become a Stochastic Programming model, while you must extend your model to become an Integer Programming model for answering part III.

NOTES

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On two occassions, the problem descriptions mentions
prices in GBP/MWh/day:
(a) for the contracted capacity of the pipelines and
(b) for the injection and withdrawal capacities of the storage.

Regarding (a) -- pipelines:
I have realized that I have presented the data in the way that the price for the contracted capacity of piplines is only 1/30 of the amount that it should be.

(This means that with the prices for pipeline P1, for example, currently given in the table, you would have to pay GBP 16.75 ON EVERY DAY in order to be allowed to transport through the pipeline 1 MWh on every day of the month.)

Therefore, please proceed in the following way:

(1) Interpret the price of the contracted capacity in the following way:
paying this price AT THE BEGINNING OF THE MONTH means that you are allowed to transport through the pipeline 1 MWh on every day of the month.
(This means: same interpretation of "GBP/MWh/day" as in the storage case.)

(2) Multiply the prices of the contracted capacity (given in the third column of the table on the pipelines P1 to P9, page 4) by 30.

(If you do not want to change the data in your EXCEL table, put the multiplier "30" in front of the prices you use in the objective function.)

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Part I

The Company wishes to make an offer to customers 1, 2 and 3 to supply the demand given in the table on page 5. It intends to offer the same price per MWh to all three customers.

a) Which is the minimal price per MWh the Company could offer to its three prospective customers such that all costs for buying, transporting, storing and balancing gas are covered? Which contracts should the Company enter into?

b) Is the solution to your model unique? If no, interpret the solution and explain in terms of the gas marketing problem (not in mathematical terms) why this is not the case.

c) Is the optimal combination of contracts that the model in a) has found (be it transport contracts, flat band contracts, the swing contract, the storage contract or any combination of these) unique or is it possible that a transport via other pipelines or buying gas on the basis of other types of contract, for example, could also lead to an optimal solution? To determine the answer, use a mathematical model derived from the one you used in a).

d) The Company has the opportunity to bid on an auction for an additional amount of contracted swing capacity. Which is the maximum the company should be willing to pay for an additional capacity of 1 MWh/day?

e) The Company considers entering into negotiations with the consortium that owns pipeline P6. Which is the maximal amount per unit of contracted capacity (GBP/MWh/day) that the consortium should charge to make P6 interesting for the company?

f) Customer 4 is hesitating to have gas delivered by the Company. If the Company could convince customer 4 to sign a contract under the same conditions that customers 1, 2 and 3 are willing to agree to, which price per MWh could the Company offer to all four customers? Please provide, on the basis of the model data, an intuitive explanation of the sign of the change of the price per MWh. (I.e. if the new price that results from delivering all 4 customers is higher than the price calculated in a), please explain why. If this price turns out to be lower than the price calculated in a), provide an intuitive explanation of why it is lower.)

Part II

Having carried out a more detailed analysis of their pattern of gas consumption, customer 4 has arrived at the conclusion that it is wise to base their contract with our company on three demand scenarios, which are given in the table on page 12. The scenarios A, B and C are assumed to have a probability of 0.25, 0.5 and 0.25, respectively.

a) If the Company has already signed supply contracts with customers 1, 2 and 3 based on the price calculated in question a) in Part I, which price per MWh could it offer to customer 4? (The Company wishes to offer to customer 4 the minimal expected cost per MWh that is incurred by delivering gas to customer 4 in addition to delivering gas to customers 1, 2 and 3.)

b) The management of the Company is skeptical about using the scenarios provided by customer 4 and suggests basing the offer on the demand given in the table on page 5, which would result in a lower offer and hence increase the probability of doing business with customer 4. Comment on this suggestion in your report. (Hint: the demand given for customer 4 on page 5 is the expected value of the demand according to scenarios A, B and C.)

Demand Customer 4			
	Scenario A	**Scenario B**	**Scenario C**
Day 1	1,276	1,163	1,050
Day 2	1,456	1,204	952
Day 3	1,318	1,169	1,020
Day 4	1,456	1,217	978
Day 5	1,428	1,249	1,070
Day 6	1,577	1,393	1,209
Day 7	1,588	1,409	1,230
Day 8	1,698	1,487	1,276
Day 9	1,679	1,544	1,409
Day 10	1,751	1,542	1,333
Day 11	1,827	1,618	1,409
Day 12	1,862	1,637	1,412
Day 13	1,817	1,603	1,372
Day 14	1,912	1,797	1,682
Day 15	1,908	1,794	1,680
Day 16	2,037	1,781	1,525
Day 17	2,004	1,672	1,340
Day 18	2,069	1,705	1,341
Day 19	2,117	1,871	1,625
Day 20	2,231	1,827	1,423
Day 21	2,078	1,703	1,328
Day 22	2,093	1,712	1,331
Day 23	1,812	1,693	1,574
Day 24	1,628	1,571	1,514
Day 25	1,513	1,420	1,327
Day 26	1,483	1,441	1,399
Day 27	1,466	1,238	1,010
Day 28	1,307	1,210	1,113
Day 29	1,376	1,211	1,046
Day 30	1,318	1,233	1,148

Part III

The Company has negotiated with the consortium that owns the network of pipelines that the balancing capacity is not 10%, but 20% of the sum of the contracted capacities of those pipelines that are used for injecting gas into the network (up to an amount of 2,000 MWh/day, see page 9).

At the same time it has been offered the option of using a different storage, which is located in City B. This storage, which is a subterranean cave, seems to be less expensive than the storage in City C. The storage space costs 0.20 GBP/MWh and has to be reserved at the beginning of the month. The maximal withdrawal capacity that can be used is given by dividing the storage space by 15 days, and the maximal injection capacity is given by dividing the storage space by 8 days (i.e. reserving a storage space of 8,000 MWh would imply an injection capacity of 1,000 MWh/day). There are no additional fees for injecting gas into or withdrawing gas from the storage.

However, the injection and withdrawal capacities also depend on the so-called ‘injection and withdrawal characteristic’ of the storage, which means that these two capacities depend on the amount of gas that is being stored at particular point of time. This phenomenon is caused by the fact that – due to the pressure in the storage – it is much more difficult to inject gas into a storage when it is nearly full, while it is comparably easy to withdraw gas from a storage that is under high pressure.

The injection characteristic of the storage is given as follows:

- On each single day, the injection capacity of the storage is 100% of the maximal injection capacity if the Company uses at most 50% of the storage space at the beginning of the day,
- it is 80% of the maximal injection capacity if the amount of gas that is in the storage at the beginning of the day is more than 50% of the storage space, but no more than 80%, and
- it is 60% of the maximal injection capacity if the Company uses more than 80% of the storage space at the beginning of the day.

Similarly, the withdrawal characteristic is given as follows:

- On each single day, the withdrawal capacity is 100% of the maximal withdrawal capacity if the Company uses at least 50% of the storage space at the beginning of the day,
- it is 60% of the maximal withdrawal capacity if the amount of gas in the storage at the beginning of the day is at least 20%, but less than 50% of the storage space, and
- it is 25% of the maximal withdrawal capacity if the Company uses less than 20% of the storage space at the beginning of the day.

In view of the new market conditions (i.e. the increased balancing capacity and the offer to use the storage in City B), the Company wishes to know if, when delivering gas to customers 1, 2 and 3 as in question a) in part I, it should sign a contract with the owner of the storage in City B. Adapt the model used for question a) in part I to this case.