Statistics for Engineering, 4C3/6C3

The final (optional) Quest

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This question must be handed in electronically on Wednesday, 23 April, at or before 18:30. Late hand-ins will not be accepted as the solution will be displayed right after that. An additional 5% will be added as a bonus to your course grade if you complete this project successfully. Poorly completed projects will receive little or no additional grade.

Your company is working on a secretive new product. This is a case where the right-hand (you) doesn't know what the left-hand (them) is doing; more common than you might think in a large company. Anyway, you've been asked to assist with the experiments, because "apparently you know about factorials".

Your employer wants to maximize profit, y [$/hour]. This is the net profit, and takes process operating costs, energy requirements, raw material costs, and selling price (based on the purity of the final product) into account. If you are ever looking for a good y-value to optimize in the future, it is a safe bet that "net profit" is what you should use.

Other than that, here's some information you have overheard:

- The product is created in a continuous reactor (a CSTR), there are multiple competing reactions, and the main reaction is exothermic. The CSTR temperature has to be carefully controlled: too much flow and you release large amounts of heat, which requires extra cooling costs, but it might cause the equilibrium to shift to the left, reducing the amount of product, if not carefully controlled.
- After the reactor, there is a liquid-liquid extractor (LLE) step that purifies the final liquid product.
- The solvent phase from the LLE is mixed using a novel impeller technology, part of the trade-secrets of your company. The solvent flow rate has been found to be an important variable affecting the process profitability under certain conditions, but you don't know much more than this. The solvent is continuously recycled, stripped and re-used.

[Note to non-chemical engineering students in the class: you will not be at a disadvantage if you do not understand the above concepts].

There are some constraints on the system:

- **A** = flow rate of raw material into the reactor where the product is created. The minimum flow allowable is 2.0 kg/min, and the maximum is 6.5 kg/min. These constraints arise from the production levels required (the minimum production level requires 2.0 kg/min) and the heat released by the reaction (the maximum level).
- **B** = recycle flow rate of the solvent and varies between 15 L/min (the minimum allowable value) and can be at most 34 L/min limited by the maximum pump speed.
- **C** = type of impeller used in the LLE step. Your secretive colleagues refer to the choices as impeller Z and impeller Q.

Each experiment takes 30 minutes to implement the new settings, but then an additional 2.5 hours are required for the reactor and LLE separator to stabilize at its new steady-state. So 8 experiments, at most, can be run in a 24 hour period. Each experiment costs about $7,500 per experiment for operator time and materials. Your company has given you a budget of $200,000 to find the process settings (conditions) that give the highest profit. At the end of the year you will get a raise, proportional to the *unused* budget.

Your task

You are expected to use all the tools learned in this course to solve this problem; in particular: using clear visualization plots, such as contour or gradient plots and interaction plots, linear models, design of experiments and particularly response surface methods.

A simulation of the process has been computerized, and is available on the course website.

Email me with the following information:

- Your name and student number
- Your partner's name and student number (if you choose to work with someone; you may work alone)
- A name for your group; which will be publicly displayed on the course website; e.g. *The Maximizers*

I will respond with a login address for your group. Once you sign into the account you will be able to specify the levels of the 3 factors and the server will return the response (i.e. the server will "run" the experiment for you).

Grading and report

Submit a short 5 page report, using Google Docs (preferred) or a PDF shared through Google Docs. The grading for this question will be marked mostly on the **systematic methodology** used to approach the optimum.

Since the cost of each experiment is so high, you must plan your strategy and clearly explain it to your manager (me). You must justify to your manager why you chose *every experiment's conditions*, and what you planned to do with that new result. In particular, you should predict the result of the next experiment before you run it (of course this doesn't apply to the first few experiments). Then use that result in the way you planned, and see if it met your expectations. **Please reread this paragraph again**.

You might realize after you complete this question that you would have done things differently. If so, report what you would have done.

Your final answer must report:

1. why you decided to stop with the particular number of experiments you actually ran
2. the optimum operating levels for factors **A**, **B**, and **C** that you will recommend to your secretive colleagues that will give maximum profit
3. give the expected profit at this optimum
4. describe why you are convinced you are at or near the optimum, showing a plot of the expected contours at the optimum
5. provide a detailed list of things you learned about this process as you were doing the experiments.

The grade you earn for this question will be further adjusted according by adding (or subtracting) the following amount:

$$5.0 \times \frac{\text{Your optimum} - \text{Baseline}}{\text{True optimum} - \text{Baseline}} - 0.25N + 3.0$$

where N is your number of experiments.

Please note:

- There is error in the response variable in the order of 10 $/hour; please take this into account.
- For the same levels of **A**, **B** and **C**, the simulation will return different results for different groups.
- Please enter your conditions carefully – if you use the wrong settings you will have to work with those results. The operators cannot change the process once they changed the impeller and flow rate settings.
- You must wait 3 hours between each experimental condition; please plan your time accordingly.
- The server will also keep track of and display all your previous experiments on a results sheet.
- Do not try to retroactively justify your experiments. The order in which the experiments were performed is clear from the time stamps on the results sheet. "Trial and error" is not a systematic methodology to approach the optimum, and is wasteful of your budget.

Once you have completed the question, print out the result sheet and submit that with your answer as the final, 6th page. (The true optimum and operating point for the optimum will be be available after this is handed in).

END