Developing the Project and Process at Pyrotech

Assignment #2

Due: June 15th, 2018 at 12:00 using Canvas

The total length of the report should be no longer than 20 pages including appendices and an abstract of no longer than half a page where you summarize your main findings. Your report should include the reasoning when answering the questions in the assignment, such as clearly writing down your models. Please also prepare a PowerPoint presentation that should take no more than 10 minutes (<= 10 slides). Upload the report (as pdf) and the slides (as pptx) at Canvas with name XX_02_1CM15_2018 (with XX the group number).

Introduction

This assignment deals with some of the numerous detailed design problems faced by the Technology Department at each of the control levels (process management level, project management level, and execution level) of the current project of designing GigaTherm GT18, and you are asked to conduct quantitative analyses in order to propose solutions to these problems. In what follows, some representative detailed design problems are introduced.

While Pyro aims for high functional specifications, there are also other important concerns that need to be considered:

- the cost of the project,
- efficient use of the available workforce, and
- timely completion of the project.

The initial project plan resulted in the recognition of the basic work packages, listed in Table 1. The initial project plan also resulted in six optimization work packages, listed in Table 2. The manufacturing cost per product after full optimization is €300.000. We assume that partial execution of the optimization work packages is allowed, in which case the manufacturing costs increase depending on the reduced amount of work spent on the work package. The basic work packages (A, B, C, D and E) have to be conducted to the full extend in order to meet the minimum performance characteristics. The sales price per product is €800.000. The average sales are 25 products per year over 10 years for the product, which is not influenced by partial execution of the optimization work packages.

Table 1. Basic work packages

Work package	Design parameters	Prerequisites	Minimum number of engineers [FTE]	Nominal duration (min-likely-max) [h]
A	L_1, L_2, L_3	None	2	(600-800-1000)
B	C_1, C_2, C_3,C_4	A, D	2	(500-774-1048)
C	H_2, F_2, F_3	D	2	(150-230-310)
D	H_1, U_2, P_1	None	3	(610-926-1243)
E	P_2, P_3, U_1, F_1	B, C	3	(440-670-900)

Along with the six basic work packages, there are also six additional work packages, listed in Table 2, that are related to the manufacturing cost optimization of the units.

Table 2. Optimization work packages

Work package	Related to the optimization of	Prerequisites	Capacity (min-max) [h]
F	P processing unit	E	(120-230)
G	H heating unit	C	(160-275)
H	C cooling unit	B, I	(160-360)
I	L loading unit	A	(160-350)
J	F frame	E	(60-100)
K	U control unit	F, G, H, J	(60-115)

We assume that the engineers work 5 days per week, 8 hours per day (no holidays, no illness), i.e. one week equals 40 hours. The nominal duration for each work package mentioned in Table 1 assumes that only one engineer (or FTE, Full Time Equivalent) is assigned to that work package. In that case the required capacity in hours is equal to the duration. Allocating more engineers will reduce the duration for all basic work packages (Table 1), but allocating more engineers to an optimization work package (Table 2) is not possible. More engineers working on the same work package reduce the efficiency of that task, due to the Ringelmann effect. Each additional engineer reduces the efficiency with 10% (α=0.1), i.e. a task that takes D_0 time for a single engineer (1 FTE) will take D with N parallel working engineers:

$$D = D_0 \frac{(1+\alpha)^{N-1}}{N} \tag{1}$$

A task with a nominal duration of 100 hours will take two engineers (2 FTE) 55 hours to complete, but will require a total of 110 hours ($H = N \cdot D$) from the available budget. Note that N does not have to be integer (part-timers allowed), but we assume that N is at least 1 and not more than 4. You may approximate the number of hours needed in your model with the linear function $H = D_0 \cdot (0.11 \cdot N + 0.89)$. This approximation is reasonably accurate (R^2=0.99) for $N \in [1 - 4]$.

The model and associated parameters for the reduction in manufacturing costs are mentioned in Assignment 1. You should limit the hours spent on optimization between the minimum and maximum capacity listed in Table 2. Note that each optimization package can only be executed by one engineer.

Part A: PERT analysis

Pyrotech wants to get an initial estimate on the feasibility of the required time-to-market of GT18. In this initial phase of the planning and scheduling we assume that all (basic and optimization) work packages are carried out to the full extend. The company wants to get a sensitivity analysis for the effect of using multiple engineers per work package. Assume for the durations of the work packages a PERT Beta distribution. Use for the basic work packages the minimum, most likely and maximum duration as given in Table 1, adjusted for the situation with more engineers using equation (1) on the minimum, most likely and the maximum value. Assume for the durations of the optimization work packages the modified PERT described by Golenko-Ginzburg (1988), with mode = min+(max-min)/3. Use for min and max the minimum and maximum capacity specified in Table 2. Further assume in this phase that the project team has a sufficient number of engineers that can work on all work packages.

<u>Assignment</u>

A1. (5 points) Give the Activity On Node network diagram. What is the critical path for the project, in the situation that we use the minimum number of engineers (FTE), as indicated in Table 1? Highlight the critical path in the AON network diagram.

A2. (5 points) Using PERT, determine the projection completion time and the 90% confidence interval around the project completion time. If you are allowed to add **one** engineer to one of the basic work packages, to which work package would you add 1 FTE and why would you choose that work package?

A3. (5 points) By assuming that the whole project consists of the critical path and **one** almost critical path, we get a so-called second-order approximation, which could lead to more reliable results. What is the probability that the project will be finished in 36 weeks, using the <u>minimum</u> number of engineers per work package, according to this second-order approximation? How appropriate is PERT for this problem given the outcome of this second-order approximation?

A4. (5 points) Using simulation, determine the 90% confidence interval around the project completion time, first by using the minimum number of engineers and second by using one more engineer for the work package you selected in question A2. Discuss the differences compared with using PERT.

A5. (5 points) How appropriate is the assumed PERT Beta distribution, according to the literature?

A6. (5 points) What are the appropriate deadlines for the individual work packages, using just 1 engineer per work package, based on the insights of Gutierrez & Kouvelis (1991)?

Table 3. Sub-work packages.

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Work package	Prerequisites	Duration (min-likely-max) [h]
A1	None	(20-40-90)
A2	A1	(320-360-640)
A3	A1	(260-320-800)
A4	A1	(200-410-500)
A5	A2, A3, A4	(8-8-8)
B1	A5, D	(100-160-340)
B2	B1	(250-400-700)
B3	B1	(300-400-650)
B4	B1, B2, B3	(8-8-8)
C1	D	(40-60-110)
C2	C1	(80-130-210)
C3	C1	(30-60-90)
C4	C2	(4-4-4)
C5	C2, C4	(30-60-210)
E1	B4, C5	(80-80-80)
E2	E1	(40-90-140)
E3	E1	(120-160-200)
E4	E1	(260-320-380)
E5	E1	(40-70-100)
E6	E2, E3, E4, E5	(8-8-8)

Part B: Sub-work packages

Based on the initial estimates on the feasibility of the required time-to-market of GT18, Pyrotech wants to explore adjustments to achieve the desired goals. Based on the time pressure, the management has asked and received updates, resulting in division of some work packages in sub-work packages and new work package duration estimates. These updates have changed the functional specifications within certain limits. Work packages A, B, C and E are now divided into sub-work packages. There is a significant uncertainty on the sub work packages due to addition-/deletion/repetition of work packages which depend on the outcome of previous or parallel work packages.

We now assume that all (sub) work packages are carried out by one engineer, with the exception of work package D, which is carried out by 3 engineers. Assume for the durations of the new (sub) work packages a PERT Beta distribution with the minimum, most likely and maximum duration as given in Table 3. The project team has a sufficient number of engineers that can work on all work packages (omni-skilled resources). The relations between the sub-work packages are as follows.

Work package A

A1 is the work package that must be completed to continue with the other sub-work packages in A. Activities A2, A3, and A4 can be conducted in parallel. A2 is the least important of those, and in case A3 and A4 are both completed before A2, then A2 can be abandoned. A5 is the final test of work package A.

Work package B

B1 is the work package that must be completed to continue with the other sub-work packages in B. Whether B2 and B3 will be conducted depends on the quality of the design until then. There is a 50% chance that B2 will be started, a 30% chance that B3 will be started and a 20% chance that both B2 and B3 will be started. B4 is the final test of work package B.

Work package C

C1 is the work package that must be completed to continue with the other sub-work packages in C. Whether C2 will be conducted depends on the outcome of C1. C3 can also be initiated only upon the completion of C1, but it is decided that C3 has to be conducted in any case, while C2 will be initiated only if certain conditions are not satisfied at the end of C1, which is estimated to have a probability of 50%. In case C2 is to be conducted, it must be completed successfully in order to continue with the project. It is estimated that C2 will be successfully completed with 50% probability. A test (C4) will be conducted at the end of C2 to see if it has been successful. In case it is not, C2 must be repeated, which will result in success with 80% probability this time. In case it still fails the test, a third attempt will (almost) surely result in success. C5 is the last sub-work packages for C, and all the other active sub-work packages in this work package must be finished for it to start.

Work package E

Work package E starts with a review (E1) that takes 80 hours. This review will decide how to proceed with the project, depending on the quality of the design so far. It is estimated that, once the review is completed E2 and E5 will be initiated with a probability of 45%, and E3 and E4 will be initiated with a probability of 60%. It is desired that E2 and E5 are conducted by a team of engineers in a parallel manner. Therefore, there is a correlation (with an estimated coefficient of 0.65) between the process times of these two work packages. Since some of the smaller design issues in E3 will depend on the quality of E4, the process times of E4 and E5 are thought to be negatively correlated with a coefficient of -0.4. In other words, if much time is spent on E3 for a better output, this is likely to decrease the time that will be spent on E4, and vice versa. E6 is the final test of work package E.

Other relations

The optimization work package J will be terminated with 70% probability in case work package H is completed before J.

Penalty costs

The penalties for timely completion are as follows: when the project duration takes longer than 1440 hours, the penalty is €10.000, and when the project duration takes longer than 1600 hours, the penalty increases to €50.000.

<u>Assignment</u>

B1. (10 points) Present the situation described above in a AON project diagram, using the extensions of Dawson & Dawson (1998). Note that uncertainty is ignored in the traditional project diagrams, while there is a significant uncertainty on the work packages due to addition/deletion/repetition of work packages which depend on the outcome of previous or parallel work packages in this case. Your project diagram should be reflecting those uncertainties and conditions.

B2. (10 points) Build a simulation model from your project diagram. What is the expected project duration? Build a 90% confidence interval around the mean. What is the probability that the whole project will be completed in 1440 hours? What is the probability that it will take longer than 1600 hours? What is the expected penalty cost? Relate your results with the findings of Roemer & Ahmadi (2004).

B3. (10 points) Pyrotech has the option to replace the engineers with more experienced engineers from outside the company. These experienced engineers cost €250 per hour (instead of €100 per hour), but will guarantee that all of their work packages are conducted with success, eliminating the necessity to conduct the work packages that would be required in case some certain standards are not met. List the work packages that would be eliminated. What are the expected additional costs and expected savings for hiring these engineers?

Part C: Optimization of resources

In this phase of the planning and scheduling you will be dealing with the task of determining how many engineers should be assigned to each basic work package, plus the determination of the duration of each optimization work package (with just one engineer), given the aggregate resource constraints on engineering hours. The answers to these questions collectively determine the duration and the expected cost of the project. For the tractability of the problem, we assume deterministic durations of the work packages in this part of the assignment. The durations for the basic work packages are assumed to be equal to the mean activity durations according to the PERT Beta distribution, which can be derived from the nominal duration values in Table 1, adjusted for the situation with more engineers (up to 4) using equation (1). You should limit the hours spent on optimization between the minimum and maximum capacity listed in Table 2. The model and associated parameters for the effect of the number of hours spent on optimization on the reduction in manufacturing costs are mentioned in Assignment 1.

We have an aggregate limit on the available engineering hours in this planning phase. We acknowledge that not all work packages can be conducted by the entire available workforce. In particular, there are two groups of engineers, categorized by their skill sets. The skills are related to the design parameters of the basic work packages and the optimization work packages. The data on the skills and availability is listed in Table 3. The availability is only in hours and not in number of persons. The cost of the available hours is sunk. For engineers with skill type 2, it is possible to get additional hours. The cost of additional engineering hours, beyond the given availability, is 250 €/h for skill type 2. The scheduling of the engineers is out of scope.

Table 4. Data on engineers.

Type	Skills	Availability [h]
1	L, C	2350
2	P, H, F, U	2650

Timely completion of the project is also very important in order to gain a competitive advantage in the market. Therefore, it is required that the project does not exceed 1200 hours (= due date). Each hour that the project takes longer comes with a due date penalty of 100 €/h. Note that this is a different penalty structure from Part B.

<u>Assignment</u>

Formulate the resource allocation problem (RAP) as a continuous linear programming model (no integer decision variables!) that finds an allocation of the available engineering hours to work packages. The objective function should minimize the expected cost of the project. Use approximation techniques such as problem decomposition and piecewise linearization of non-linear functions to keep the model tractable.

C1. (5 points) Construct the Activity On Arc (AOA) network for this project, using a minimal number of dummy activities.

C2. (10 points) Write down the continuous linear programming model for the RAP. Explain all decision variables and parameters that you use in your model formulation.

C3. (10 points) Solve your model for the RAP using Simplex-LP and report the found solution (objective value and values for all decision variables).

In the following assignment questions, we assume that you succeeded in modelling and solving the RAP as a continuous LP. If you failed these steps, you can try to answer the questions with what-if scenarios instead of the sensitivity report from Simplex-LP.

C4. (5 points) Discuss the effect of the approximation error of the used approximation techniques on the solution value.

C5. (5 points) What is the value of more available engineering hours for skill type 1 (the shadow price for the workforce availability)? Discuss the managerial implications.

C6. (5 points) What is the value of full workforce flexibility in terms of the ability to allocate engineers to all work packages, i.e. all types of engineers have all the required skills?

References

Dawson, R.J., C.W. Dawson (1998). Practical Proposals for managing uncertainty and risk in project planning, *International Journal of Project Management* 16 (5), 229-310**.**

Golenko-Ginzburg D (1988). On the Distribution of Activity Time in PERT. Journal of the Operational Research Society, 39(8) pp. 767-771.

Gutierrez, G.J., P. Kouvelis (1991). Parkinson's law and its implication for Project Management, *Management Science* 37 (8), 990-1000.

Roemer, T. A., R. Ahmadi (2004). Concurrent Crashing and Overlapping in Product Development, *Operations Research* 52 (4), 606-622.