"Tell me about the start and I tell you how your project will end." (Gero Lomnitz)

"Having lost sight of our goals, we redouble our efforts." (Mark Twain)

"Hofstadter's Law: It always takes longer than you expect,
even when you take into account Hofstadter's Law."

"If it weren't for the last minute, nothing would get done." (Mark Twain)

Project Controlling from Definition to Planning, Execution and Completion

The control cycle consists of 1) planning, 2) checking and 3) acting: taking control (steering). It takes place during all phases of the generic process of projects: 1) definition, 2) planning, 3) execution and 4) completion.

With the progression of the project and with the breakdown from general to more detailed (sub-)tasks, the planning becomes more detailed and precise. The values measured for controlling become more accurate as well. The effort needed for controlling increases.

1. Project Management and fractal Geometry

The terms *planning* and *controlling* are used both in a general and in a more specific sense. They are both of importance during all four major processing steps of a project, as every phase has to be defined, planned, executed and completed. This same pattern is repeated for every task and subtask. This self-similarity and scale-invariance is known as the fractal view of projects.

But in a narrower sense, *planning* is related to step 2) of the generic process while controlling is related to step 3) *execution*.

2. Defining means Estimating and Exploiting

From a systems engineering point of view, the knowledge about a system is small in the beginning, when there may only be an idea. It is vast and well documented at the end of the process of defining, designing, construction, assembling, testing, maybe redesigning and using the system.

The same is true from a project managements point of view. In the beginning, a detailed picture of all the steps needed to fulfil the assignment simply is impossible (unlike for repetitive and optimised business processes). Inaccurate estimations about the allocation of costs and resources (money, time and working force) are therefore one of the major risks in any project.

To reduce this risk of underestimating the effort needed, one may go into detail especially when it comes to the list of steps and tasks needed during the execution of a project. The more split up these lists are, the closer one comes to a complete picture of the project ahead.

Exploiting experiences from former projects helps on all levels from general to detailed, that is from complete projects of comparable size to individual tasks.

Defining a project does not end in itself, of course. On the contrary, it is the most crucial basis for success. It can be very useful to remember the definition of a project from time to time to keep the goals in sight, e.g. before assigning a task: Is it necessary to achieve the goal of the project? Has it been taken into account for planning and scheduling of the project?

3. Redefining adds a Fractal to the Structure

During execution, one may have to cope with changes for both external and internal reasons:

- costumers' needs: additional / adapted scopes;
- boundary conditions: modification of regulations, changes of decision makers, technical evolution, inflation a.o.
- internal changes: new staff (loss of knowledge), modified policies due to reorganization etc.

This happens most likely during of execution phase (3). See par. 7 for risks and reserves to be taken into account from the beginning.

If the project needs to be redefined (1), the planning (2) and the execution (3) have to be revised as well. Thus, the progress from rough to detailed is repeated. Again: The redefining cycle may also be applied to any phase, task or subtask (fractal view).

4. No Plan without a Schedule

Planning means to define the schedule and therefore the allocation of costs and resources over time: money, time and working force. In other words, the list of tasks becomes more detailed and better formulated when planning for the phase of execution (compared to definition and planning).

5. Steering a project with the Control Cycle

Controlling means to take control of the operation – and not just to measure or inspect (unlike "Kontrolle" in German). This is more accurately expressed by steering a project. Steering consists of three major steps: plan – check – act. This is known as the control cycle.

1) **Planning** (as described above).

2) **Checking** (or monitoring) means to

- measure the actual performance,
- review actual results (system characteristics)

and compare them to planned values and system characteristics (scope and quality) at the current stage of the work.

The **prognosis** (extrapolation of the actual performance till the end of the work) indicates the actual results at the end of the project when fulfilling the agreed scope by maintaining the measured performance. The prognosis either gives certainty to continue as before or it shows the need of action.

3) **Acting: Taking control (steering)** means to define a strategy to meet the expectations and to continue with the execution (3) of the work. If this is not possible, the expectations have to be discussed and redefined (1) with the customer. Planning (2) and execution (3) will then be revised as well.

The last and most important check and review is with the completion (4) of steps. These milestones are decisive: acceptance (carry on with next step), revision of the step or abortion (cancel the project).

Again: The control cycle is also applied for the execution of tasks during all phases of the generic process of projects from definition (1) to planning (2), execution (3) and completion (4).

6. Post Calculation is Part of Completion

With completion (4), post calculation results in aggregated figures, hopefully allowing more accurate estimations next time (exploitation of knowledge to successfully explore new grounds).

7. Experiencing the generic Process of Projects

A training conducted at the ZHAW points out some typical issues when carrying out a project step by step according to the generic process of projects.

Fig. 1 The Ryan NYP-1 papercraft model (1:18.5).

Two classes of students are tasked with assembling papercraft models of the Ryan NYP-1.

1) Assemble the Ryan NYP-1 (1:18.5) in 90 min !

The model consists of 177 parts. See the appendix for the patterns and the assembly instructions.

This training can be seen as a simulation for reality with scales of model for several respects:

- Longitudinal scale 1 : 18.5
  given by the arts-and-crafts-sheets
- Time scale (1 min ≙ ~ 1 day) 1 : 500
- Money scale [kchf] 1 : 1
  1 part costs 1.-
  1 min of work costs 1.-
  Spare-pieces and extra-work cost double.

The model(s) have to be completed within 90 minutes. This is the duration of the execution-phase (3) only. Completed means: The quality has to be good and all parts have to be used and assembled according to the instruction with accurate precision.

Budget and Number of Craftsmen needed

To complete the assignment (step 1: definition of the project), the budget and the number of craftsmen have to be estimated and defined. To do so, the key performance indicator has to be estimated and a brief production plan has to be put up.

Performance Indicator

The simplest performance indicator applicable in this case is minutes of work per piece (for one person at work!). There are several ways to estimate this.

a) A list of production steps is helpful. The longer the list, the longer the estimated duration usually becomes (and the more accurate it will be!).

1)	Reading assembly instructions	10
2)	Coordinating with other team members	10
3)	Cutting the sheets into pieces	10
4)	Precisely cutting the pieces	120
5)	Coordinating with other team members	20
6)	Folding the pieces (mountain or valley folds)	20
7)	Applying the adhesive	10
8)	Clamping of pieces and pressing while letting dry Repeat this with some more pieces	240
9)	Self-monitoring of the quality of the work	30
10)	Dealing with unexpected problems	30
	Total	**8.3 min = 500 s**

b) Empirical values from similar work can be compared to the assigned work. An adjustment factor may compensate discrepancies in difficulty or size.

c) If there are no empirical values available from experience, a short simulation with a typical piece of average difficulty can be useful. Piece no. 5D seems to be suitable (see the appendix for the pattern).

d) To improve the accuracy of the estimation, an expert group can discuss the values and consolidate their experience. This is known as a closed meeting for appraisal, consisting of the following steps: 1) Individual estimations; 2) Presentation of minimal, mean and maximum values; 3) Discussion in group, focussing on the extremes; 4) Revision of the individual estimations; 5) Repetition until common consensus is reached.

Of course, any combination of a) to d) is possible.

Actual results of a combination of c) and d) show a shift of the mean value from 4 to 6 minutes (first and second round of individual estimations). Note, that this is the reference value + 50 % = 150 % (!). The minimum and maximum values shifted by one minute each.

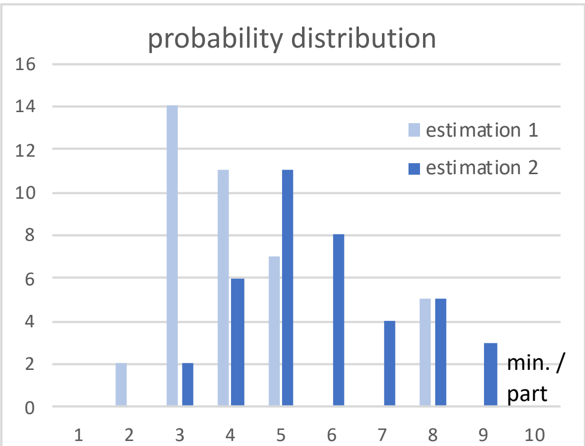


Fig. 2 Probability distribution for a closed meeting for appraisal: Estimated performance for a typical, average piece (5D) in [min/piece] per person.

Note: Discussion participants with experience in papercraft work estimated and justified for higher values.

Budget

The calculation of the budget is based on the given prices and the key performance figure. It has to cover the following costs [kchf]:

material 177 pieces * 1 kchf/piece = 177

labour 177 pc. * 7 min/pc. * 1 kchf/min = 1'239

project mgmt. 360 min * 2 pc. * 1 kchf/min = 720

Project management is assumed to work for 4 * 90 = 360 minutes (90 min for each major step of the generic process of projects, including a reserve of 10 minutes for every step).

Risks and Reserves

Risks and reserves have to be taken into account. The risks can be categorised as follows:

- External risks cannot be prevented: Change of boundary conditions or costumers needs. In case of occurrence, a (partial) revision of the assignment will be needed.
- Internal risks can be partly prevented or reduced by preparation: Poor performance due to poor skills, inadequate organisation, safety issues or misunderstandings and errors etc.

  Obviously, one of the crucial measures to prevent or reduce internal risks is careful preparation and planning (which starts right from the outset, that is the definition phase 1).

  In case of occurrence, any successful over-coming will result in higher costs, e.g. additional personal, spare pieces, repeating of work. In addition, all of these will be time-consuming.

  On the other hand, a planned reserve may cover at least some of the inevitable risks but will often be questioned by decision makers.

After this analysis, the group of students agreed on 7 min./piece for the performance and explicit reserves for both duration and costs in addition. Note that this results in ~ 200 % (!) of the initial estimation.

Production plan

In terms of systems engineering, the main parts A (tail) to E (landing gear) are called subsystems, while the individual parts are called elements (177 pieces). Note: Without understanding the system it would be impossible to define and manage the project successfully. The understanding can be basic in the beginning and must go into more detail later on.

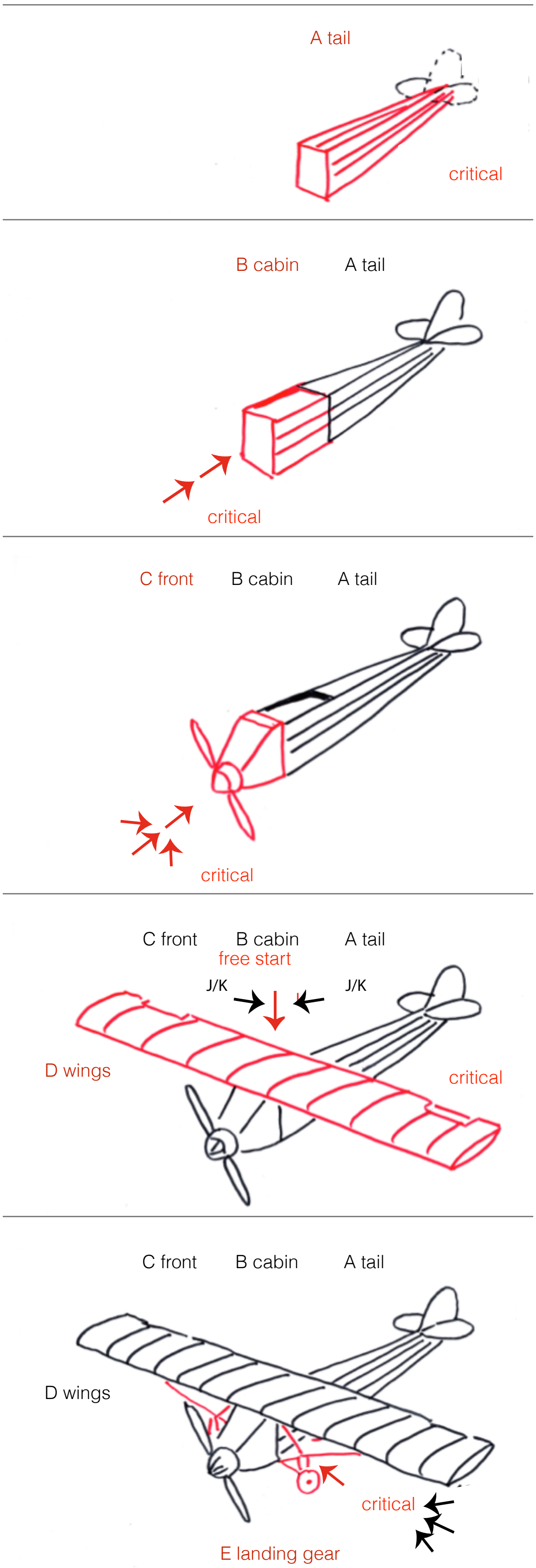
The average number of craftsmen needed is

16 = 177 pieces * 7 min/piece*person / 80 min ,

but the number of craftsmen engaged will vary over time. It must be higher in the beginning, because it will be much lower towards the end by nature. This pattern is true for almost any kind of project or work carried out during a project, but especially during execution (3) and even for the finish of a report.

The subsystems A (tail) to E (landing gear) can be assembled in parallel almost completely. Each of them consists of dozens of individual elements. Thus, it will be easy to start with a big number of craftsmen. See the brief production plan (fig. 3).

The final assembly of the system (consisting of the subsystems) can only be carried out by a few craftsmen. The landing gear (E) is especially delicate. It will need some calm hands working together.



Note: The hints "critical" refer to the schedule in the next paragraph and describe the "critical path" for the assembly of the system (consisting of the subsystems A to E).

Fig. 3 Brief production plan according to the assembly instructions (see appendix).

A reasonable plan would be to engage at least 20 craftsmen in the beginning and to make sure that the most talented two craftsmen will do the last and most tricky steps of the assembling in the end.

Fig. 4 shows an overview of a most basic planning of the four phases (duration 90 min each), the personnel deployment over time and the resulting labour cost (sum curve over time for labour costs only).

This basic planning is part of the definition of the project. It is based on the assignment, the basic understanding of the system and the key performance indicator. Note, that this plan gives an indication of the minimal number of craftsmen, but there still is some flexibility to react if the pool of craftsmen will be bigger.

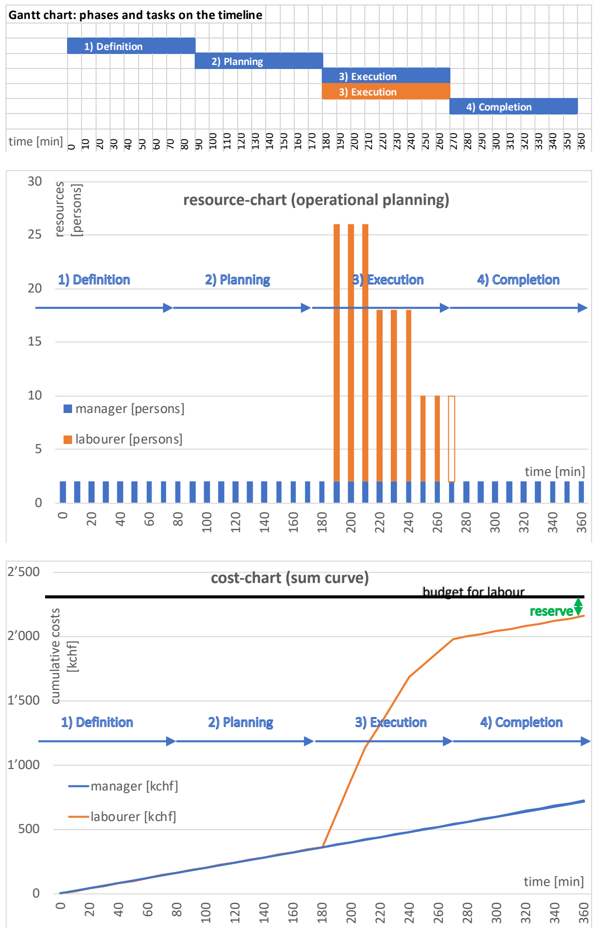


Fig. 4 Very brief production plan over the whole project: Gantt chart (phases and tasks on the timeline); resource chart (operational planning) and cost chart (sum curve, labour costs only).

Completed Assignment

The completed assignment is based on all the considerations about performance, organisation, risks and production.

At the beginning	assignment	reserve	planning
scope [pieces]	177		177
duration [min]	360	40	320
thereof definition		10	80
planning		10	80
execution	90	10	80
completion		10	80
performance [min/pieces*person]			7
price/costs [kchf]	2'420	303	2'117
thereof material		23	177
labour		200	1'300
project mgmt.		80	640
working force [persons]	-		22
thereof labour			20
project mgmt			2
quality	good		good

red: values estimated or chosen by the group.

Fig. 5 Assignment for assembling of the Ryan NYP-1 papercraft-model (scope, costs and deadline) and planning for the complete work (costs and working force a.o.).

Note: In this training, the engineering is already done by the manufacturer of the pattern. Thus, in a more extensive and therefore difficult case, it would be necessary to master the design and engineering work as well as the production of the pattern and the assembling of the system.

Milestone: Completion of Definition (step 1)

2) Schedule: Allocation of Resources over Time

The scheduling defines the actual allocation of costs and resources over time. It consists of five steps. Some of them have to be executed iteratively.

1) **Work packages** have to be defined. Every work package is characterised by its

- Outcome, e.g. complete subsystem A (tail);
- Predecessor packages (none for the tail);
- Successor packages:
  Assembly of the subsystems A and B (cabin).

To do so, one must break the system down to its subsystems and elements to understand dependencies (and independencies) for the reason of assembly (and design and production).

2) **Allocation of rescources** means to assign the tasks (work packages) to teams of defined size or to individual craftsmen. The number of craftsmen per package and the performance indicator have to be assumed. Again, the duration is linked to them.

All calculations for the subsystems are done with 7 min/piece. The assembly of the system is estimated for every work package individually (see fig. 6ab).

A differentiation of the performance indicators for every single work package would be possible, but would need additional estimations and simulations of doubtable benefit (in relation to the effort necessary). Regardless of any further differentiation, it will be far more crucial for the success to carefully steer the project with the control cycle during the execution phase (3) repeatedly.

3) **Finding the critical path** means to put together a production plan by "calculating backwards" with the work packages. This is done beginning with the last step – the assembly of the wheels. Then, one work packages is added after another, always answering the question: What is needed, to start with this package that was put on the timeline last? The answer in this case would be: To mount the wheels, the landing gears (E) has to be in place. In other words: The assembly is thought through from the bottom up according to fig. 3 and every work package starts and ends as late as possible.

Doing so, one will find one or several paths with no waiting times. These are the critical paths. They cannot be compressed in duration by definition.

4) An **optimisation of the production plan** is needed, if it turns out after step three, that:

- the number of involved craftsmen at a time is fluctuating or higher than the available number of craftsmen (20);
- the duration of the production process does not meet with the deadline (90 min or 80 min respecting the reserve).

There usually is a margin for every work package to either accelerate or decelerate by assigning more or less working force to it, of course. It might also possible to split or merge some working packages. Optimising the production plan means to take advantage of these margins with the goal of respecting both deadlines (and reserves, of course) and resource restrictions. This can be a quite creative task and will not be done by any kind of AI.

The critical path(s) may not the be same after optimisation.

5) **Finalisation of the schedule is done by calculating forward**: Starting with the first work package(s), this time the assembly is thought through from the top to the bottom according to fig. 3 and every work package starts and ends as early as possible.

The reserve is now at the end of the timeline. If it were not there, it would not be a reserve but only a (quite useless) break (!).

If a work package has more than one predecessor of different end time, the duration between the earlier end of a package and the beginning of the successor package can be seen as waiting time (wasted) or a reserve for the predecessor work.

Fig. 6ab shows the planning (scheduling) for the NYP-1 papercraft. Note several findings.

The differentiation between the assembly of the subsystems A (tail) to E (landing gear) and the system as a whole gives a clear picture of the levels of integration.

There are three priorities: 1) critical path, 2) suppliers to the critical path and 3) (almost) independent sub-systems: rear wings (A)1 and pilot (F). These independent packages can be used as disposition work at any time (instead of just waiting).

It is confirmed that the number of craftsmen will steadily decrease towards the end by nature, as assumed in the definition phase (1). This is due to the dependencies within the system.

Note, that further optimisation could be done, e.g. assigning more craftsmen to the subsystems C and D. But is the effort worth it as the key performance figures might turn out as imprecise? Controlling will show.

Finally, the **cost chart** is developed by multiplying the number of employees at a time with the costs per time unit and summing these up over the duration of the considered work. See fig 6c: cost-chart (sum curve).

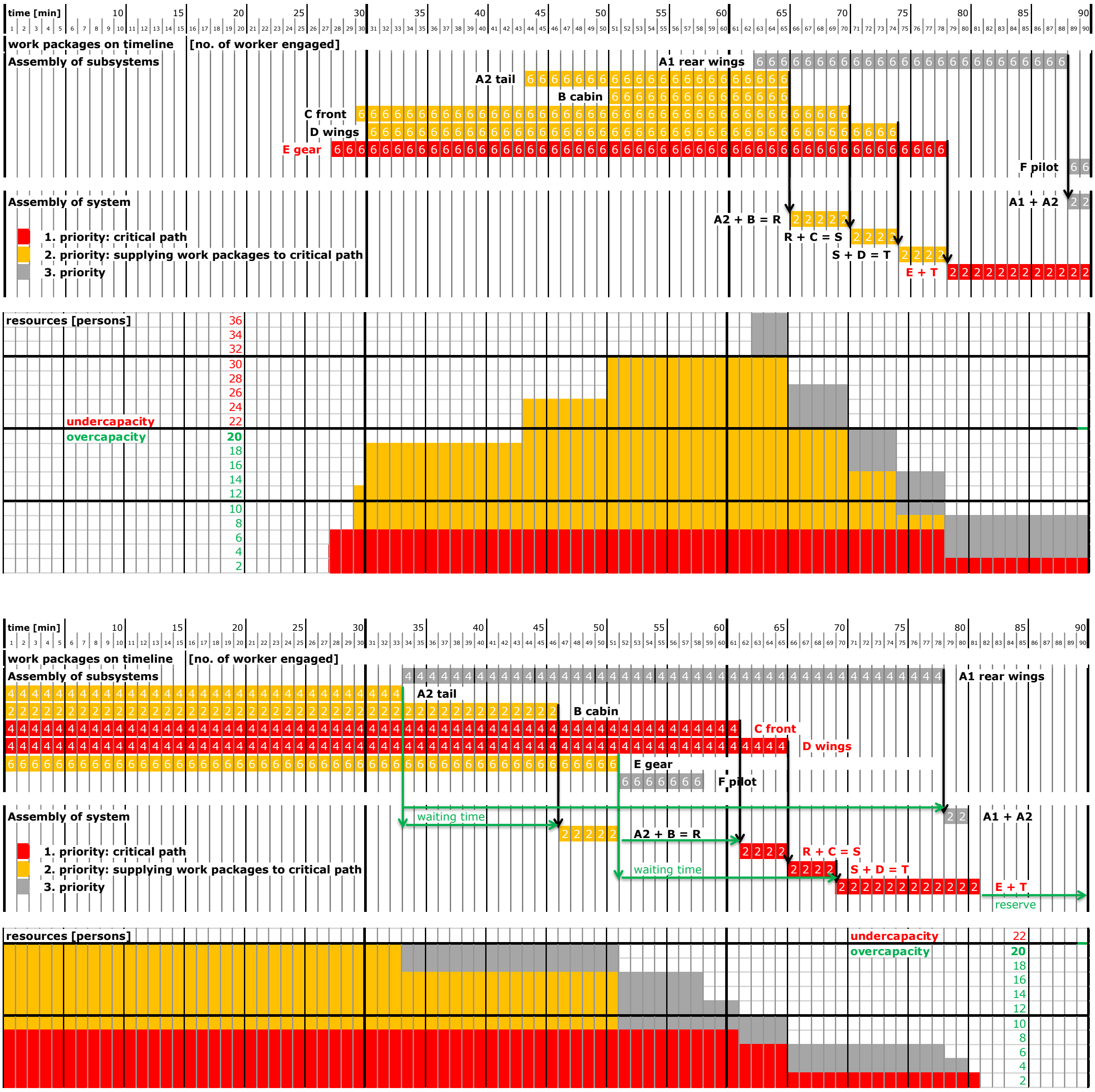


Fig. 6ab Schedule for the assembly of the NYP-1 papercraft model, steps 1 to 5 (before and after optimisation and iteration).

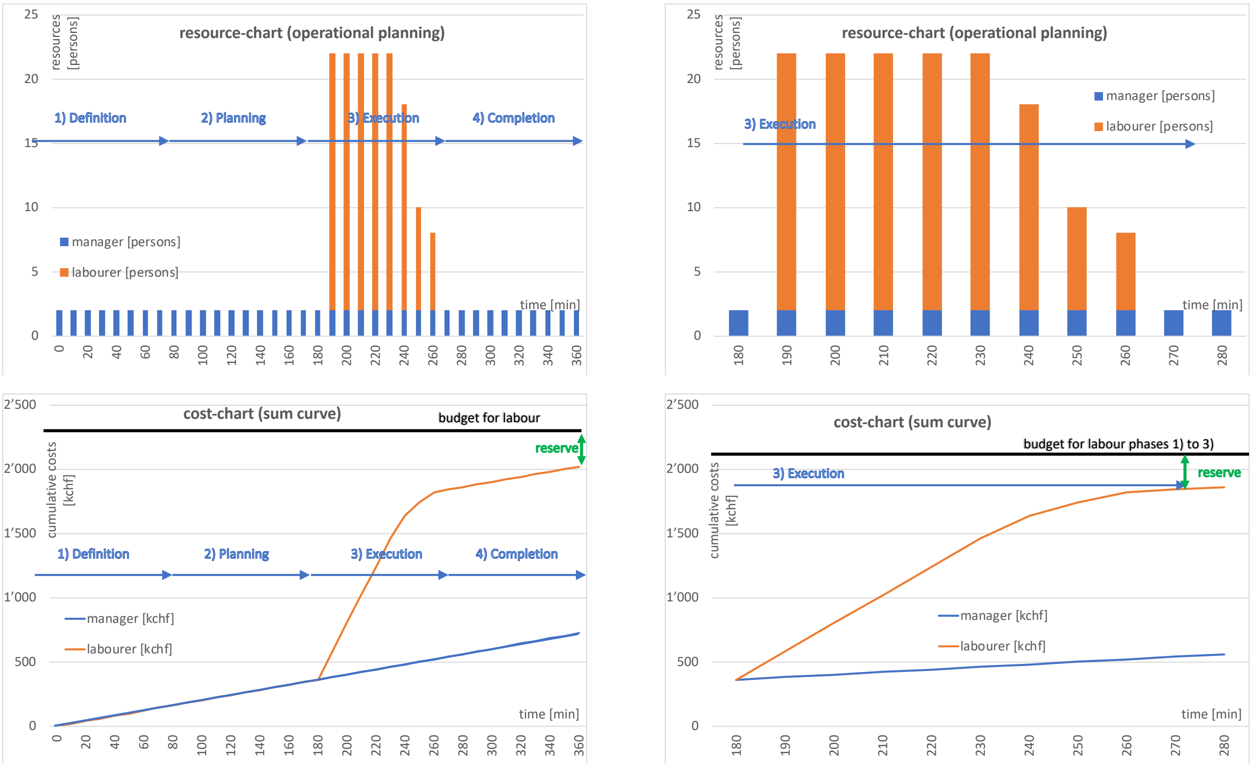


Fig. 6c More detailed production plan over the whole project and with a focus on the execution phase (3).

Note the minor difference to the definition phase (1). **Milestone: Completion of Planning (step 2)**

3.1) Execution: The first 30 minutes

Class A (wisely) agreed to build one plane with 36 craftsmen (instead of two planes with 18 craftsmen each). Class B started with 24 craftsmen. The planned values in fig. 7abc are (re-)calculated accordingly.

To make the tasks of project management visible to all participants of the training, the execution phase is split up in three subphases of 30 minutes each. During the breaks in between, the control-cycle (see paragraph 5) is executed. Thus, the execution phase takes 2 * 3 * 30 = 180 min. In reality, this would have to take place during 90 min in parallel to the execution.

In both cases the actual expenses to date after 30 min are significantly higher than planned: 180 % and 120 % of the planned value (!) On the other hand, more work than planned is already done: 121 (group A) and 124 pieces (group B) instead of 86 pieces. The count of assembled pieces is simple: any piece in progress is counted with a factor of 1/2, assuming this represents the average progress.

So is there something to worry about? Only the complete picture can tell: Actual results (scope and quality) and performance with a prognosis (extrapolation of the actual performance till the end of the work). See fig. 7a (performance) and fig. 7c (prognosis).

After 30 min (A)	planned	measured	remaining
scope [pieces]	(86)	with 20 p. at work	
	154	121	56
time [min]	30	30	??
perf. [min/piece]	7	8.9	8.9
labour costs [kchf]	(600)	with 20 p. at work	
	1'080	1'080	500
quality [RAMS]	good	good	good

After 30 min (B)	planned	measured	remaining
scope [pieces]	(86)	with 20 p. at work	
	103	124	53
time [min]	30	30	??
perf. [min/piece]	7	5.9	5.9
labour costs [kchf]	(600)	with 20 p. at work	
	720	720	313
quality [RAMS]	good	good	good

Fig. 7a Project controlling groups A and B: Comparison of planned values for the work so far and measured values and prognosis for the complete work by extrapolating the progress till the end of the work.

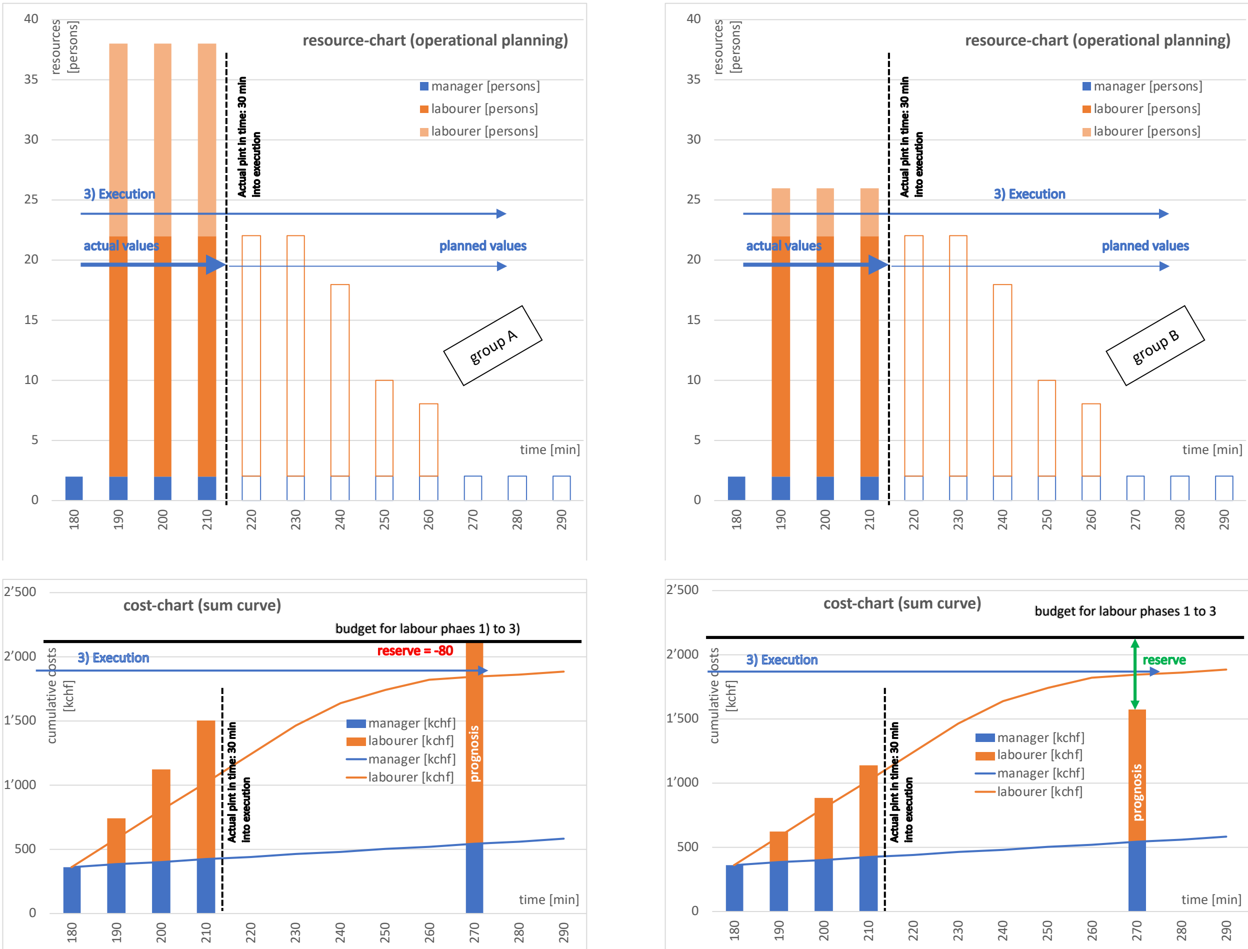


Fig. 7b Project controlling: Comparison of planned values for the work (so far) and actual values after 30 min.

After 30 min (A)		assignment	reserve	prognosis
deadline	[min]	360	40	320
thereof definition		reached		
planning		reached		
execution		90	0	90
completion			10	80
budget	[kchf]	2’420	- 37	2’457
thereof material			23	177
labour			- 80	1’580
project mgmt.			20	700

After 30 min (B)		assignment	reserve	prognosis
deadline	[min]	360	40	320
thereof definition		reached		
planning		reached		
execution		90	10	80
completion			10	80
budget	[kchf]	2’420	510	1’910
thereof material			23	177
labour			467	1’033
project mgmt.			20	700

Fig. 7c Prognosis for the complete work by extrapolating the actual progress till the end of the work.

3.2) Taking Control for the remaining Works

Group A reviewed the results and found, that much time was lost coordinating or waiting for instructions respectively. Thus, it was agreed that every labourer has to take more self-responsibility and, more importantly, that anyone having finished their assigned tasks would have to leave the project immediately.

Note, that it is quite common in large business companies to report the working hours to the project with the least pressure (monitoring activity) from the project leader (instead of reporting them to the correct project).

Group B saw no need to take any steering action.

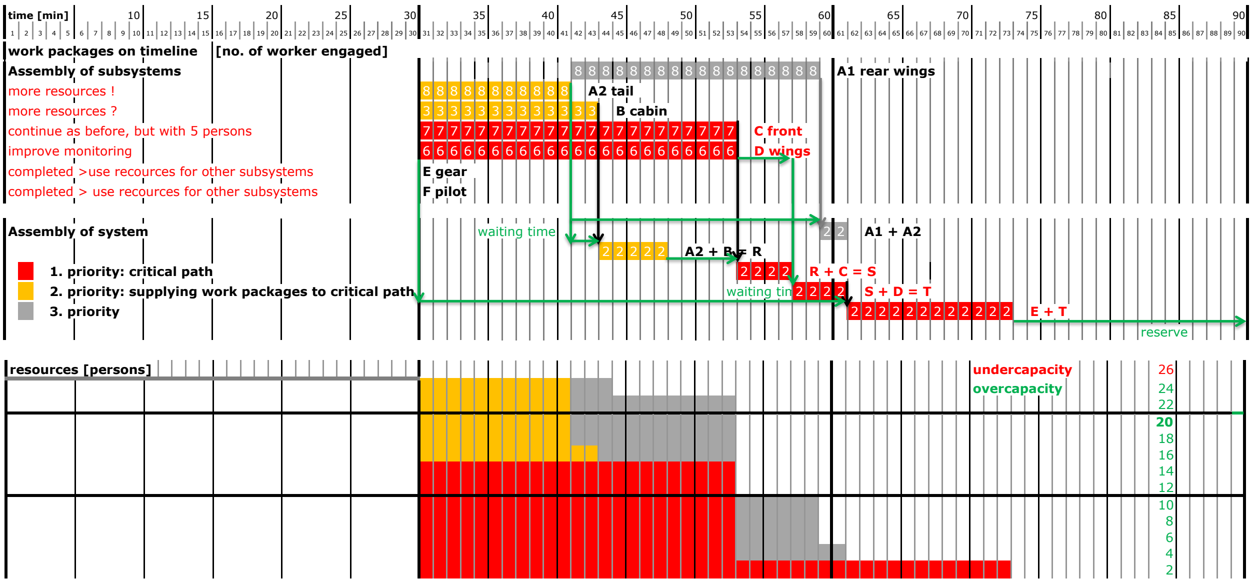


Fig. 8 Revised schedule for the assembly of the NYP-1 papercraft model, minutes 31 till the end (steps 2, 4 and 5: after optimisation and iteration).

The revised schedule (fig. 8) for the minutes 31 to completion (deadline: 90 min, example for 24 craftsmen) is done the same way as the initial planning (steps 2, 4 and 5). Note the trade-off between "larger teams and better (theoretical performance indicator)" and "continuation in well-coordinated teams".

Again, the **cost chart** can be derived by multiplying the number of employees at a time with the costs per time unit and summing these up over the duration of the considered work. This is already roughly depicted in fig. 7b (cost-chart (sum curve): Prognosis at the end of phase 3 at 270 minutes.

Secondary Milestone: Completion of Execution including the Control Cycle, part 1, (step 3.1)

4) Completion: success of failure?

In the training, the execution of the rest is done without another break. Thus, the steps 3.2 and 4 of the generic process of projects are summarised after 90 minutes:

- completion of step 3 (execution),
- completion of the whole project.

These results (see fig. 9abc) show the importance of steering: The effort of group A was successful, while the laisser-faire of group B was penalised.

The performance of group A has improved, while the budget and the deadline were complied with (87 min to completion).

This can be seen as a complete success, although the budget reserve was used to compensate poor overall performance.

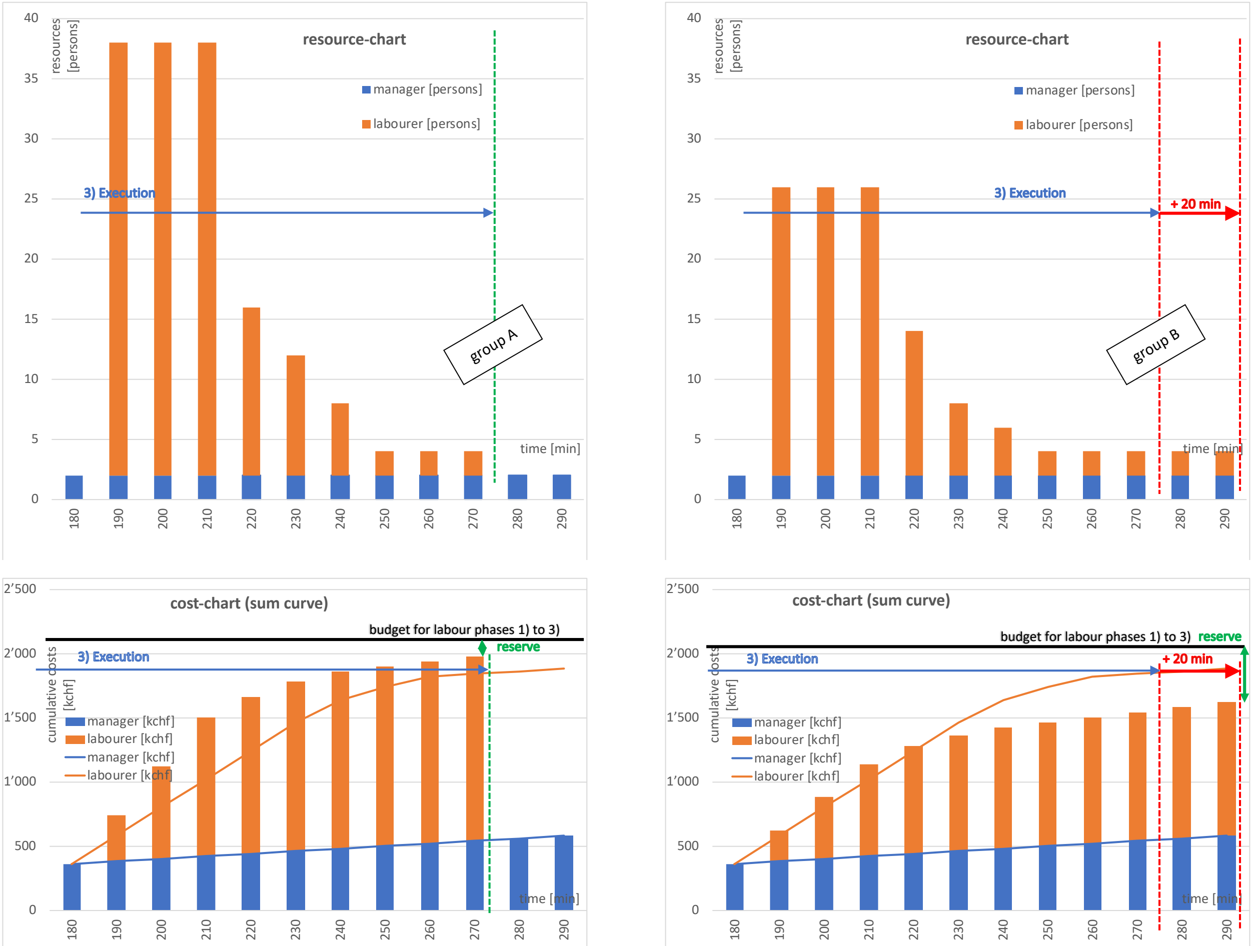
Group B also complied with the budget, even without the use of any budget reserve. But the overstepped deadline by 20 min (!) is a clear failure. The performance declined and was especially poor for the last tricky steps.

Note, that the overall performance and costs are mainly determined by the first 30 minutes of the execution phase (3), when much of the work is done, while the duration is the result of the overall performance as well, but of the last steps towards completion in particular.

Completion (A)	planned	measured	over all
scope [pieces]	56	56	177
time [min]	60	57	87
perf. [min/ piece]	8.9	7.9	8.6
labour costs [kchf]	500	440	1'520
quality [RAMS]	good	good	good

Completion (B)	planned	measured	over all
scope [pieces]	53	53	177
time [min]	60	80	110
perf. [min/piece]	5.9	9.3	6.9
labour costs [kchf]	313	490	1'210
quality [RAMS]	good	good	good

Fig. 9a Comparison of planned values (minutes 31 to completion) and measured values after completion.



Comletion (A) assignment			planned	measured
scope	[pieces]	177	177	177
deadline (3)	[min]	90	80	87
price/costs	[kchf]	2'420	2'117/2'457	2'414
thereof material			177	177
labour			1'300/1'580	1'520
project mgmt.			640	717
working force	[persons]	-	22	22
thereof labour			20	36 to 2
project mgmt.			2	2
quality		good	good	good

Comletion (B) assignment			planned	measured
scope	[pieces]	177	177	177
deadline (3)	[min]	90	80	110
price/costs	[kchf]	2'420	2'117/1'910	2'127
thereof material			177	177
labour			1'300/1'033	1'210
project mgmt.			640	740
working force	[persons]	-	22	22
thereof labour			20	24 to 2
project mgmt.			2	2
quality		good	good	good

Fig. 9bc Post calculation: Comparison of budget, planned values and actual values after completion.

8. Conclusion and Findings

The application of the generic process of projects to the quite simple papercraft model of the NYP-1 is suitable for training, because the steps can easily be monitored and understood. One cannot be deceived by fictious results.

The example points out the importance of:

- Careful planning from a wider to a narrower sense during the steps 1 (definition), 2 (planning) and 3 (execution);
- The control cycle during all steps, but in particular repeatedly during step 3 (execution).
- The completion of each step (milestones).

See also the quotes above the title of the paper.

Double Milestone: Execution (step 3.2) and Completion (step 4) completed

Appendix: Cartoons with a Meaning

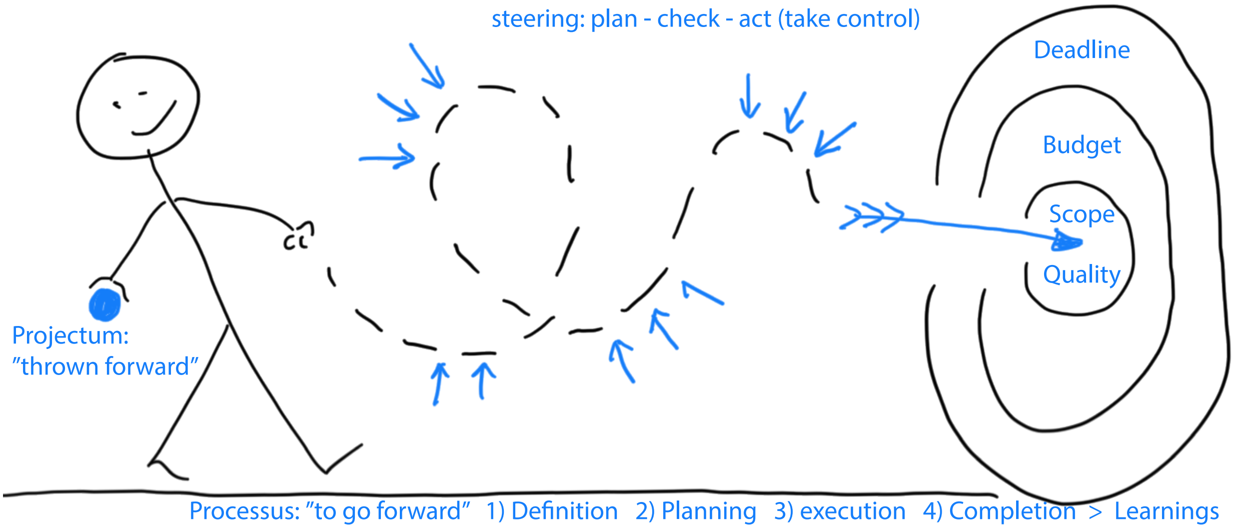


Fig. 10 What if . . . the target is moved after the arrow is fired, . . . gusts blow from the side or . . . ? Note, that there are different possibilities to prioritise the goals: deadline, budget, scope and quality.

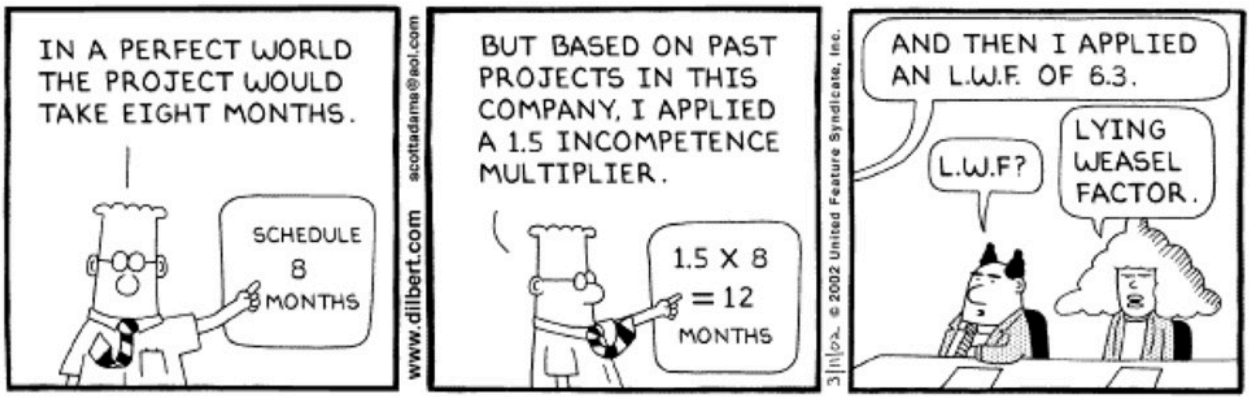


Fig. 11 How to estimate the performance if no one really cares?

Fig. 12 If this was a project for a real football field: What went wrong? Did customer, contractor, projects managers and craftsmen communicate properly during definition, planning and execution? What about the control cycle?