Experience with Master theses ran as projects

1. Abstract

An experiment with master students in engineering is now performed for the second year. The school involved is KULeuven Campus De Nayer, a renowned school for industrial engineers in Belgium.
The first experiment took place during 2012-2013 and involved about 35 projects and 45 students. This academic year, 2013-2014, involves 41 projects and about 60 students.
The objective of the experiment is to expose the students to modern techniques for project planning and monitoring.
Every master thesis is conceived as a project for which a professional planning has to be set up. These projects are then monitored using the same tools and techniques as used in the professional environment.
In this process the students are exposed to typical topics as

- setting up a clean project structure, the project tree
- defining the logics, the tasks dependencies
- estimating task durations, using rational techniques
- optimising the project flow by organising concurrent tasks
- when working in team, optimise the work load by organising concurrency in the tasks
- comprehend the project processes and discovering their dynamics
- experience the project reporting, learning to analyse the information and discover how one can draw conclusions from these.
- discover on what aspect one can act, when some recovery of delays is needed.

The whole project is intensively reported and all stakeholders, including professors, assistants, promoters and co-students are fully informed.
The paper will develop and explain the concept of this experiment in detail, analyse the results - by the deadline for the final paper, all projects will be terminated - and draw conclusions about what the best course could be to pursue the teaching of quantitative project management techniques.

This project has been initiated as a response to the author's concern about the near complete absence of training in the matters of project management, and more particularly, in the quantitative methods associated with project management. The author considers this to be a major shortcoming in the education of industrial engineers. This is even more true considering the increasing importance of concurrent engineering, which as we know, requires refined and top level project management skills.

2. Author

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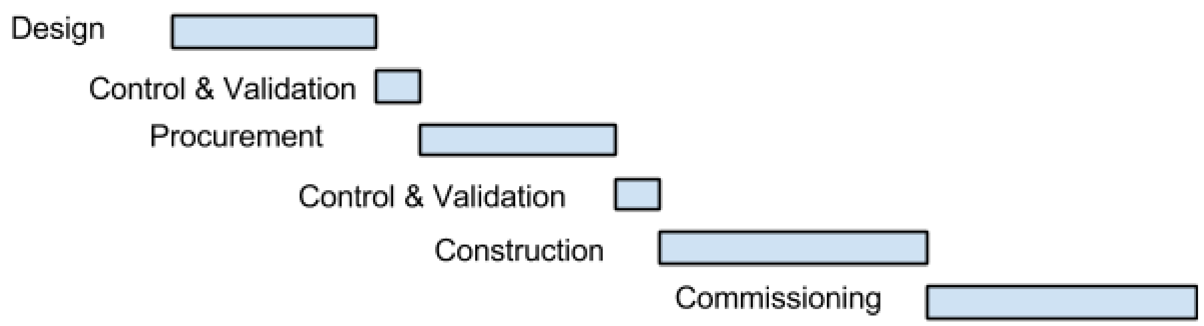
He has more than 40 years of experience in projects covering nuclear engineering, electromechanical engineering, food, pharmaceuticals, petrochemicals, R&D.
He has been developing the DPC method and it's tools for the last 10 years. He has implemented the DPC method and the tools in a number of large and medium sized companies and organizations.
President of a jury for Master Students at the KUL/Campus De Nayer since 20 years.

3. A short history of the project evolution

3.1. The traditional period

Some decennia ago, till the late eighties, it was common practice to manage industrial projects in the classical, say traditional way.

The overall Gantt looked like this:



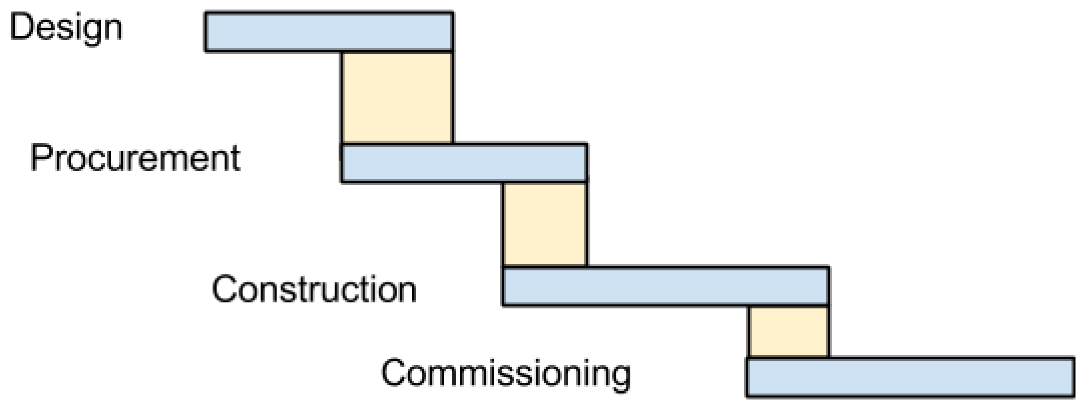
The essential aspect was: all phases were neatly separated by a “control and validation” step. This was an essential part of the overall quality control.
No phase was started before the predecessing phase was completed and validated. This did ensure high quality of the documents, and by extension of the end product, whatever that was: a plant, a machine, a process, etc.

The project management techniques associated with such projects were simple, mostly not computer aided: simple scheduling and project tracking.
Emphasis was put upon the quality of the documents: things were ready, when they were “approved” by senior supervisors. Time was less a concern.

This method came under pressure due to the long turnaround time, and associated higher costs.
This resulted in the advent of the next step in the project evolution: the “fast track projects”.

3.2. Fast track projects

The overall Gantt of fast track projects look like this:



The obvious difference are the overlaps between the major phases.
This is in effect the essence of concurrent engineering: many activities take place in a parallelized way instead of purely sequentially.

A next phase is started while the predecessing phase is still ongoing, hence parallelization of activities.
Controls and validation steps are integrated within the major phases.
The advantage of this style is, obviously, shorter turnaround times.
The management of such project though, is an order of magnitude more complicated than the previous one.
The reason is that there are much more interactions between the phases, and these have to be scheduled and carefully monitored, in order to avoid clashes, interruptions, misunderstandings, faulty information flows, etc.

This need for enhanced project management techniques, with emphasis on the quantitative methods has been often underestimated, under implemented, or simply completely ignored.
The result is a visible, measurable degradation of the overall quality of such projects, when compared to the “classical” period.

There is though no way back: the advantages of concurrent engineered projects are too important. Such approach should, in principle, also guarantee a more optimal usage of the available resources.
So, we are left with the need for highly performing, quantitative, methods for the scheduling and the control of such projects.
We do emphasize the quantitative aspect, because we do not think that the so-called “soft” techniques can play a major role in this environment.

3.3. Crash track projects

Unfortunately, the project evolution didn’t stop at the fast track station. A more hysterical version is now frequently encountered: the crash track project.
These are projects that start behind schedule, i.e. even before the first atom of the first activity has been started, they are already in a status that makes a timely finish reasonably impossible.

The causes that bring such projects into existence are known, and unfortunately, for the moment being they cannot be eliminated: the predominance of the financial world above the engineering world, and in some occasions, the predominance of an ill-informed political world above the engineering world.
The amount of damage that such approach has caused so far has reached such levels, that one may reasonably expect that these forces will have their wings cut once and for all any time soon.

4. More on the implications of CE

Fast track project and the associated concurrent engineering (CE) is there to stay. This is a good thing.

But one must be fully aware of the implications.

We will now address a few of those implication, which we consider to be the most important ones:

- Understanding the processes
- Understanding the interactions
- Coordinating the activities
- Deterministic planning
- Sequentially deterministic planning
- Process monitoring

4.1. Understanding the processes

CE often deals with complicated projects[1].

At the onset of any such project, a global descriptive must be set up. This means that all aspects must be covered, not in detail yet, but as thematic objects. Moreover, the interrelations, the interactions between these topics, must already be charted.

This cannot be done by large teams.

Only small teams of engineers, in the limit a single one, is capable of creating such descriptive.

This means that such team or individual must be capable of envisioning the complete project in all its major components, and to envision all the interactions at once. This demands high level people with a broad spectrum of knowledge and experience.

Example 1: a storm barrier.

This is a complicated object, where technology is pushed to its limits.

From the onset, a comprehensive descriptive must be set up. In this case such descriptive will have to deal with

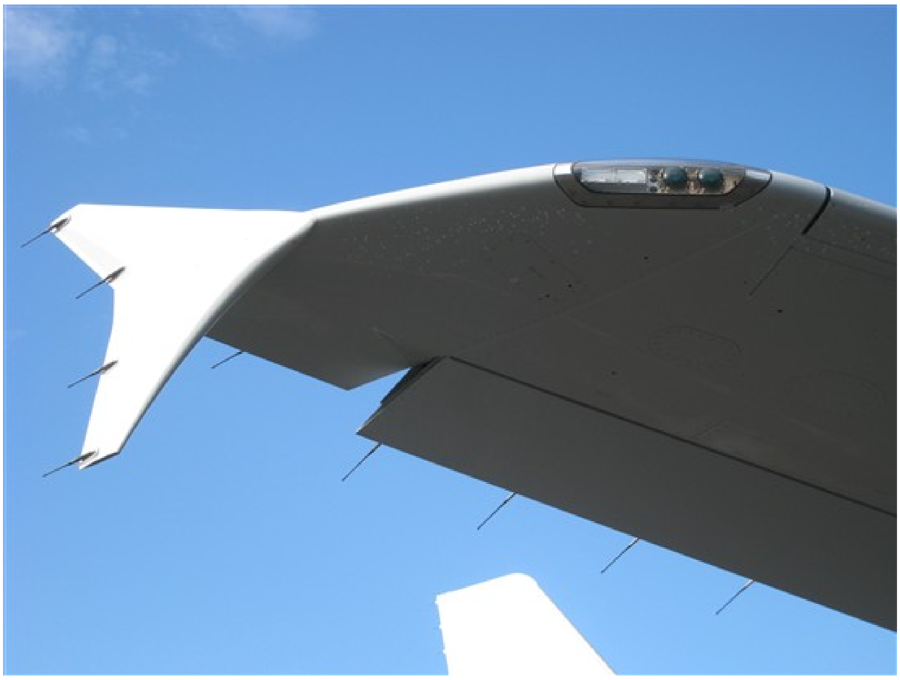
- geology
- hydraulics

[1] We do not use the term “complex” because it is now accepted that complex must be associated with chaotic, not-manageable. When a project becomes complex, it is because control over it has been lost.

- civil constructions
- steel structures
- guiding mechanisms
- hoisting mechanisms
- power supply
- controls,

as well as with the interactions:
- geology on civil constructions
- steel structure on civil construction
- guiding mechanisms on steel structure and civil constructions,
- etc.

Example 2: navigation light for an airliner



This object is small and not so complicated. Nevertheless, from the onset of the development, one must be capable of envisioning all aspects and their interactions:
- photometry
- colorimetry
- heat transfer
- mechanical vibrations
- high frequency power supply
- etc

In summary: those involved in CE projects must understand the processes in all their aspects, must understand the interrelationships and interactions between those aspects, and finally they must be able to coordinate later detail work performed by the specialists.

Again, this demands high level, broad spectrum engineers.

It is a big mistake to think that large groups can operate efficiently in the context sketched above.

4.2. The planning and monitoring

Whatever the type of project is, we always need project controls. Without controls, there is no project, but an adventure.
The project controls always consist of the schedule-monitoring pair. Without monitoring, no need to schedule.

When the processes are linear, when they follow paths that can be described by networks (graph theory), with well-defined activities and reasonable estimations of their durations, then we can speak of deterministic scheduling. Even when such schedule becomes large and complicated, it will be possible to produce reliable forecasts, risk analysis and reports on the dynamic behaviour of any part of the project.

When the processes are not linear, i.e. when iterations are needed within one discipline and / or between different disciplines, then deterministic schedules cannot be set up.
This is because it cannot be predicted how many iterations will be needed till final solution is reached (roughly speaking).
In such case one should provide

- tight iteration monitoring
- convergence forcing mechanisms
- overall monitoring of the project with dynamic analysis of consequences.

A way out when confronted with non-linear processes, is to “linearize” the system. This can be done by setting up small deterministic schedules, spanning short periods of time, within which the process can be considered to be linear. Then progressing in sequence, from small part to the next.
The result will still be a larger degree of uncertainty on the final outcome, but at least we will be able to schedule and monitor sequences in a deterministic way.

4.3. On the educational needs for the future engineers

From the above, we know understand that the problem is not to find the engineers capable of solving the details of a CE project, but to find those capable of conceiving such project in all its dimensions, to coordinate the activities, and to schedule and monitor the processes.
Such engineers must master a broad spectrum of technologies and be capable in the field of project planning and monitoring.

5. The DPC method

5.1. Introduction

The DPC method - Dynamic Project Control - has been developed from within and for the professional project world. Most of those projects are in the sphere of industry and infrastructure. Most of those projects use CE as the driving mechanism.

The method is primarily known for its tools, basic and advanced, for the monitoring of the physical progress of a project both in its static and dynamic behaviour.
There is ample documentation available on this subject. The most comprehensive documents can be found here:

- site: www.jptollenboom.com
- blog: www.jptollenboom.org

We start from the assumption that any project can be considered as being built from a collection of processes. Every process consists of a collection of activities.
The physical progress of every process can be monitored by observing the physical progress of every of its activities and then applying a suitable aggregation algorithm.

The progress of every process has two aspects:

- a static value: the current progress value
- a dynamic value: the current progress rate, or progress speed.

Bot values can be used to asses the present status as compared it to the originally scheduled status and to produce reliable predictions on the final outcome.
In this sense, the values produced are feedback values that can be used according to the paradigm known in process control.

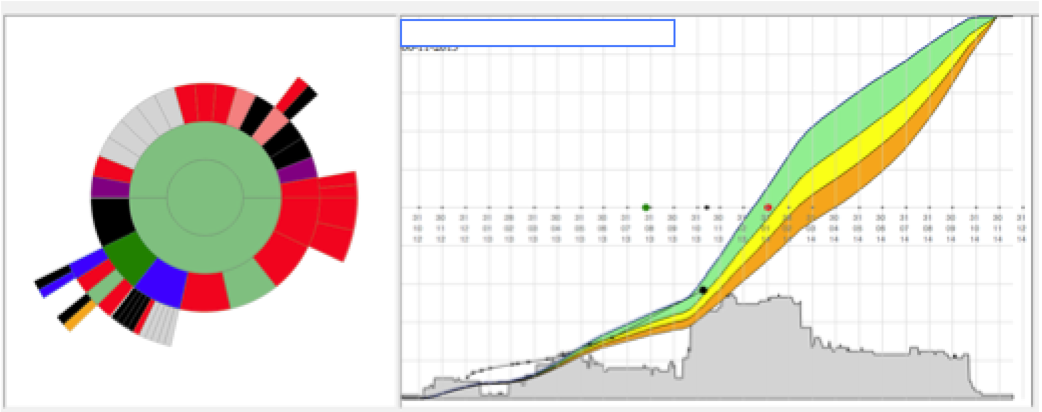
5.2. A brief overview of the DPC tools.

5.2.1. S-curves

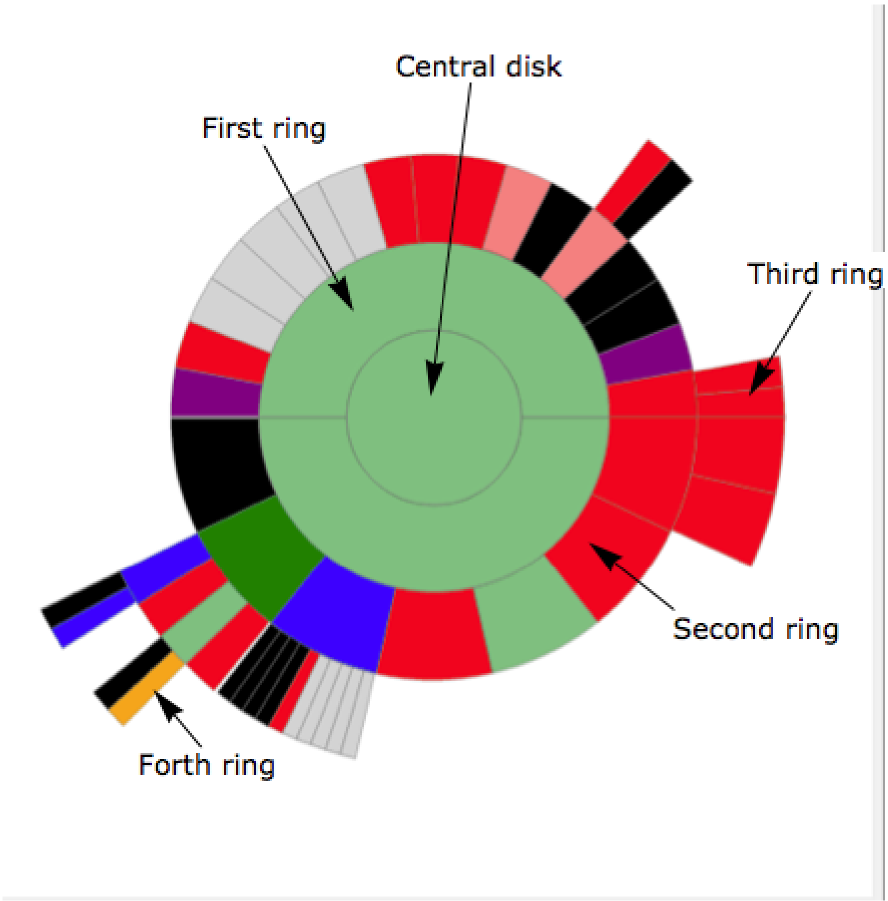
The iconic tool of the DPC method is the S-curve, as shown below:
Progress reports come in two formats:

- html for the basic reports
- cdf, computed document format (developed by Wolfram Research) for the advanced reports.

The core of the reports look like this:



The left part is called the **Daisy tree**. It is the display of the project tree as a daisy chart.



The **Daisy tree** acts as a navigator for the project's S-curves: on the web page, clicking on an item will display its S-curve. You can already have a “hands-on” experience here.
➜ The Daisy tree can be zoomed and panned[2][3].

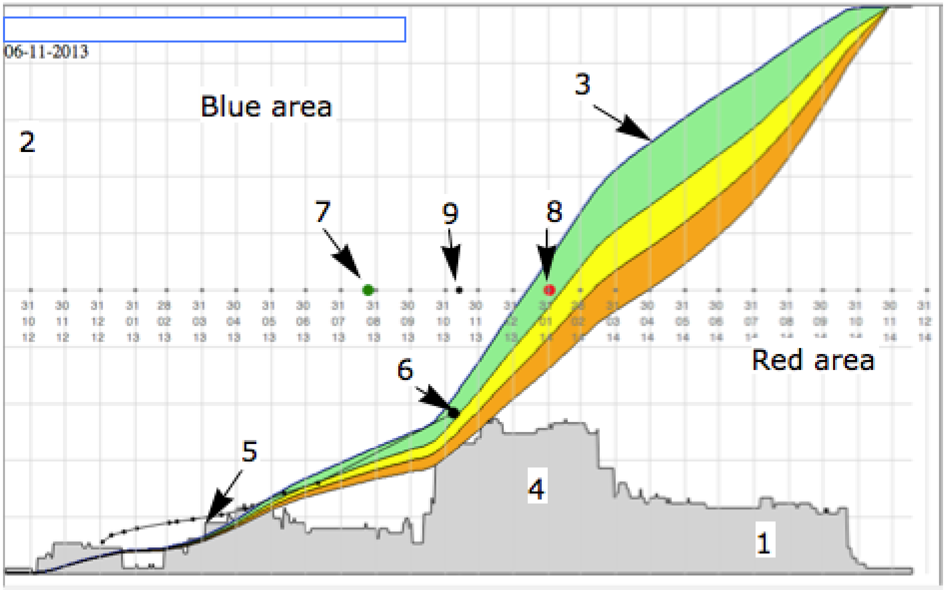
- Every segment of the Daisy tree corresponds to a specific part of the project.

[2] Best with these browsers: Chrome - Safari - FireFox - IE10 supporting SVG formats
[3] With recent versions of Safari, the MC.html page needs to be re-loaded for the zoom and pan to work: open MC.html, then “reload the same page”.

- The central disk corresponds to the complete project.
- The items of the first ring correspond to the first level items of the project tree, the second ring items to the second level of the project tree, etc.
- The color of any item corresponds to the "color" of the present project status: see below.

➜ *Important remark.*
This style of reporting not only displays Information on the global project, but also, and more importantly, on the all sub-sections of the projects.
This allows for early detection of parts of the project that are developing problems (generally they are then "red").
This in turn, acts as an early warning allowing for timely correction, so that problem propagation is averted.

This is an S-curve. It has been displayed in the right part of the report by clicking on an item in the Daisy tree.



1	Horizontal axis	days elapsed
2	Vertical axis	% complete value (0-100)
3	Blue line	the progress line as scheduled
4	Gray area	the activity profile as scheduled
5	Black dotted line	the observed progress line
6	Fat black dot	the latest status point: where we stand now
7	Green dot	a marker at 50% progress and 40% duration

8	Red dot	a marker at 50% progress and 60% duration
9	Black dot	midpoint, 50%, 50% duration

The color areas are related to different degrees of safety.
Safety in terms of "safe position" regarding the likelihood of finishing in time.

- Blue area: ahead of schedule
- Green area: safest area
- Yellow area: less safe area
- Orange area: lesser safe area
- Red area: problems must be taken care of

➜ By simply looking at the area where the latest status point (6) lays we already know how safe we are.
- The color of the item in the Daisy tree is the same as that of the area of the last status point.
- So the color of the Daisy tree item already tells us where the problems are: the "Red" ones and to a lesser extend the "Orange" ones.

5.2.2. This is what one does with the report

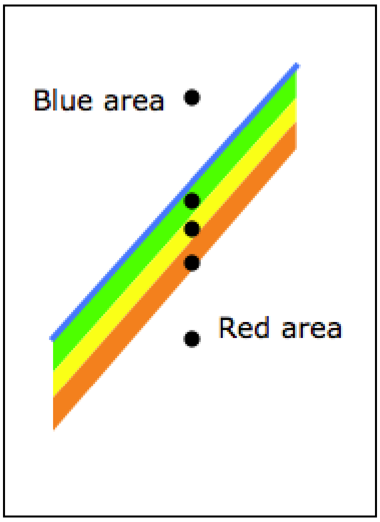
5.2.2.1. Inspect the Daisy tree

⚒
- Spot the red items: these are the ones having troubles.
- By clicking on the item, display the corresponding S-curve.

➜ In this one simple step, we already know where the problems are

5.2.2.2. Inspect the S-curves

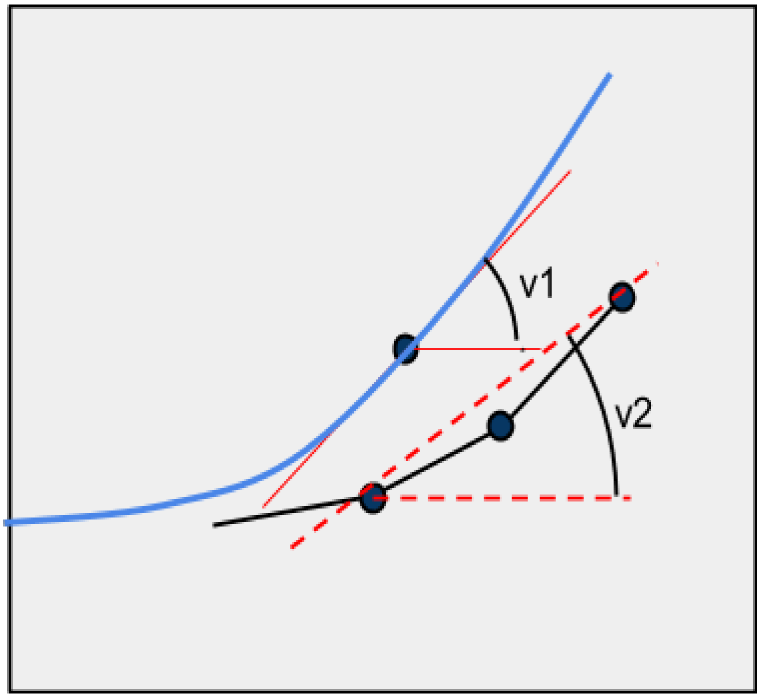
5.2.2.3. Identify the area in which the last point lays



- In Blue: ahead of schedule
- In Green: safe
- In Yellow: less safe
- In Orange: should get worried
- In Red: problems to take care of

5.2.2.4. Check the trend line

The trend line is the average progress line of the observed track (the black dotted line). Its slope is the actual average progress speed (in % complete per day)
Compare this slope to the average slope of the schedule progress line (the blue line) for the same period.



Rules

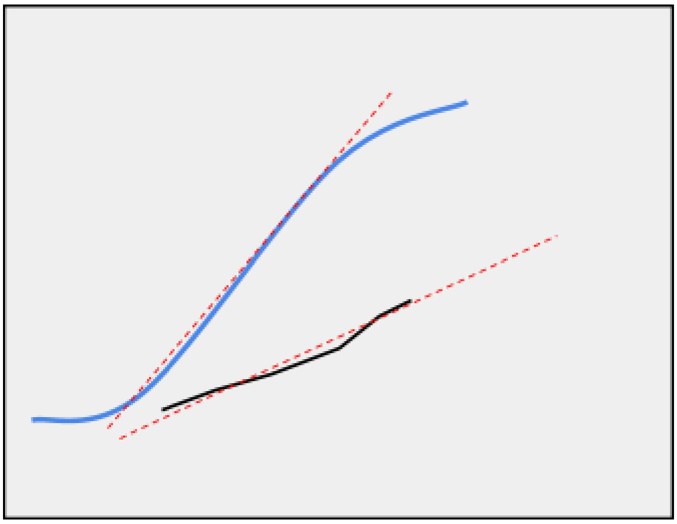
1. V1 is the progress rate of the scheduled S-curve
2. V2 is the average progress rate of the track

3. If V2<V1, then delay will increase
4. If V2=V1, then delay will remain stable
5. If V2>V1, then delay will decrease

5.2.2.5. Diverging track

This picture displays a diverging track. We are in the condition V2 < V1 (see above). Delays will continue to increase.

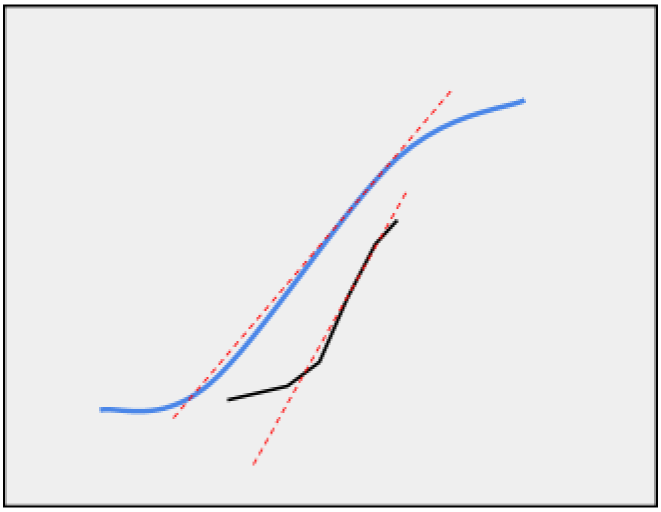
If you see this: the process is out of control.



5.2.2.6. Converging track

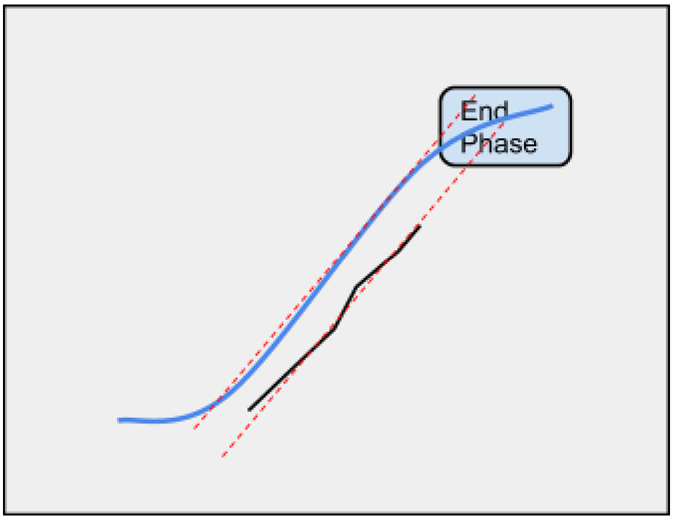
This picture displays a converging track. We are in the condition V2 > V1 (see above). Delays will decrease.

If you see this: control over the process has been regained.



5.2.2.7. Parallel track

When the process track runs parallel to the scheduled S-curve, then one can conclude that the process is well under control. We are in the condition V2 = V1 (see above).The delay can be recovered during the end phase (see in diagram); eventually a limited acceleration might be needed.



5.2.3. Action!

➞ S-curves are not for contemplating but for defining actions.

As soon as we detect problems - remember that this goes for any part of the project, any sub-process as we call it - we should consider to act upon the process in order to correct the course.

The domains upon which one can act (more or less) are a.o.:
resources quantity - resources quality - information flows - logistics - worked hours - scope

➞ When and only when no room for improvement is left, then rescheduling can be considered.

⇏ Never contemplate re-scheduling every time a delay is incurred: you will only fool yourself and the whole project organisation.

This "strength of action" matrix can give some guidance

Trend / Color	Blue	Green	Yellow	Orange	Red
Divergent	Monitor	Monitor	Monitor closely	Prepare for action	Act strongly
Parallel	Consider slowing down a little	Do nothing	Do nothing	Consider accelerating a little	Act
Convergent	Do nothing	Do nothing	Monitor	Monitor	Monitor closely

5.3. Forecasting

Two forecasting methods have been developed:

- linear extrapolation: the end date of a process is estimated from the current linearized progress line
- affine transformation: the originally scheduled progress line is transformed to match the observed progress line, using affine transforms. From here an estimate of the end date, under steady conditions, can be obtained.

6. Educational project with a school for industrial engineers.

6.1. Introduction

As said before, there is to our opinion, a lack of exposure of future engineers to the concepts and techniques related to project management.
Sometimes there is some exposure, but it then often limits itself to trivialities and eventually some basic training in the usage of a scheduling software. As we all know, learning to use a scheduling software has nothing to do with mastering CE driven projects.

So the idea was to set up an environment in which the Master students would be exposed to all the ingredients of CE driven projects. We chose to have them run their master thesis as a full fledged project.
Doing this they would have to go through all the steps of the real world projects:

- Understanding the processes
- Understanding the interactions
- Coordinating the activities
- Deterministic planning
- Sequentially deterministic planning
- Process monitoring

This would all happen on a small scale. But more importantly: the complete picture would be revealed to them in this process.

6.2. Description

The Master students in industrial engineering of the KU Leuven Campus De Nayer must produce a Master thesis by the end of their academic year (June 2014). They have to present their work in front of a jury who then decides on what grade to grant them. It happens that the presented work is found insufficient and that complementary work is requested. It also happens (on rare occasions) that the work is rejected and that the student leaves the school without a diploma.
For the second time, the last years Master students will run their Master thesis work as a project. They will use Smartsheet and DPC to schedule and track the progress of their work. The first experiment was ran in 2012-2013 and involved about 45 students and 35 projects. This year, the academic year 2013-2014, about 70 students are involved in 50 projects. Some Master projects are ran by a single student, some are ran by a pair of students.

A Master work has a standardized structure:

- literature study
- theoretical part
- designing an experiment or prototype
- building the test or demo device
- run experiments

- report the results
- write up the final book
- present the work to the jury.

Such Master thesis work is a textbook example of a project. All aspects of project controls can be applied, be it on a miniature scale. The duration of the Master work is almost a full academic year. So, this environment is ideal for students to learn by discovering.

6.3. Organisation

The college signed up for a Team 3 plan with Smartsheet. This grants them 3 sheet creators and 150 sheets. One assistant has been appointed as key-user. The key-user creates all Gantt sheets and shares them with

- the student(s): one sheet one student or pair of students
- the head of department
- the promoter(s) of the master thesis
- the DPC admin

At the start, the Gantt sheets are empty copies of a template. The students must construct their schedule in these sheet instances.
There is one "job list" created by the DPC admin. This "job list" lists all projects, their Gantt sheet id's, and some other admin data. This list is shared with the key-user; it drives the DPC engine.

The students attended two introductory lessons of 1.5 hrs. The first lesson was on the project environment and general context. The second lesson was on detailed technical aspects of project scheduling, the use of Smartsheet, and how to read the reports. One introduction of 1.5 hours was also given to the promoters involved in the monitoring of the students.

6.4. Educational value

Unfortunately, it often happens that Masters in industrial engineering, not to speak of the M SC's in engineering, finish their studies with little if any insight in project scheduling and control techniques.
Though, in many cases, their first and last job during their career may well be running part or the whole of a project.
And so we witness, time and again, young engineers starting from scratch and repeating the same mistakes all over, eventually getting stuck in the standard set of bad habits.
So we think that it is a necessity to offer engineering students a thorough exposure to modern project scheduling and control techniques.
We think that the Smartsheet-DPC couple offer an ideal environment for students in order to become aware of the concepts related to project scheduling and controls, and to acquire

experience in these matters. These are the major reasons:

- the system is very accessible
- no time is lost on learning to master a zillion buttons or key-strokes
- from day one focus can be put on the project scheduling and control techniques
- the scope of the project is, by its nature, limited in volume, still displays the same structure as the most complicated projects.
- the techniques used may be a reduced set of what is currently used in the professional world, still all the basics are covered and combined into a coherent system

6.5. Learning by discovering

The exercise in se is one of self-control. The student only schedules and controls his own work. He must track, analyse and report on his own progress.
When corrective actions will have to be taken in order to recover incurred delays, he will talk to himself.
This experience will make him discover the difficulties of being objective, the common pitfalls when reporting progress, and many things of the same order. Later, when he will manage people in a project context, he will know

- what can be asked to do in terms of scheduling and control
- what can be expected as reaction, as problems
- what pitfalls are to be avoided and how

If project supported teaching has to be introduced, this is the ideal path.

6.6. Value for academic personnel

There are two levels on which valuable content is created.

- The short term: how are the individual project teams performing
- The long term: how is the project-related behaviour of students evolving.

In the short term, the monitoring of the students is done by inspecting their progress reports, and by matching these against observed progress, as is normally done by the thesis promoters.
This leads to evaluations and classifications based on verified facts.
In the long term, as experience and project histories pile up, a wealth of statistical information can be extracted. Patterns can be detected, eg. what type of subject lead to better results than others, etc.

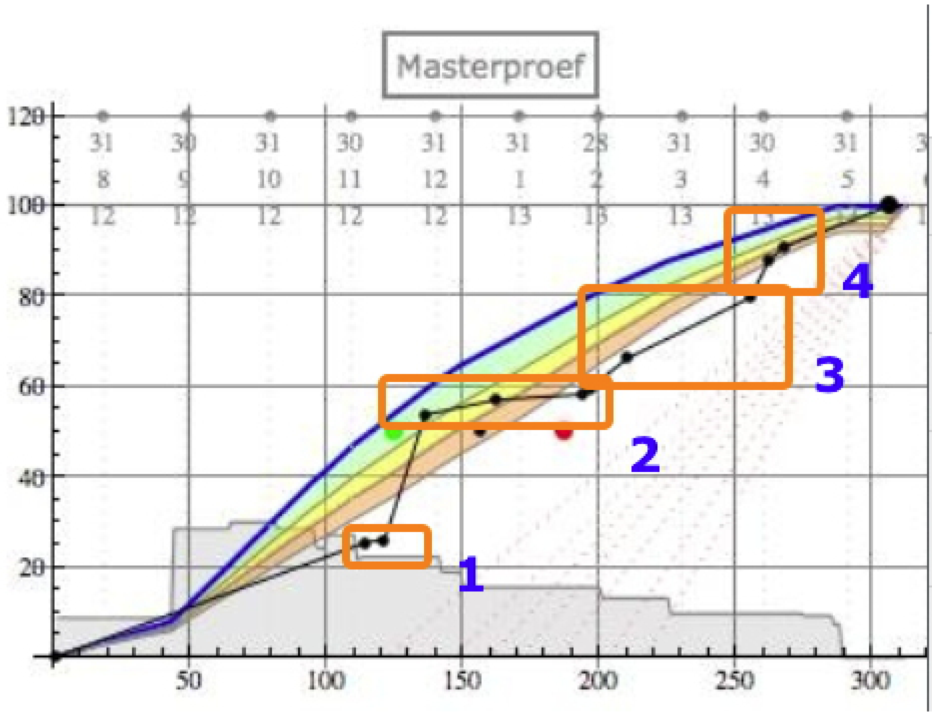
6.7. Lessons learned from first experiment

The first experiment involved some 45 students and 35 projects. The exercise was completely free: no grades, no points no credits were to be earned (there was no EVM for the student :)). Only the personal satisfaction of learning something extra was put forward. At the end of the road we saw this:

- 15 % didn't bother to start with scheduling
- 85% did set up a schedule and started tracking progress
- 20% did so till the very end of their project, the balance stopped somewhere "en route".

We noticed that those students that started to show substantial delays, stopped tracking progress. In doing so, they confirmed that this behaviour, also called "negationism", is widespread and probably deeply human. Indeed, this phenomenon is also frequent in the professional world: when things go really bad, some people choose to ignore the facts and start to operated in panic mode.

Of the 20% that went all the way, all produced a high quality end work. A few displayed a quasi professional project related behaviour. One of the best performances is displayed hereafter.



example student

These are the specific lessons drawn from this example:

- Area 1: tracking was started a bit late, so there was a bad surprise as a substantial delay appeared → Start tracking at an early stage so to avoid surprises
- Area 2: after a recovery effort was done with good results, the progress stagnated. This can be traced back to the concurrent exams period → Do not overload your resources, progress targets will not be met
- Area 3: period of good progress rate, with a little delay → When the progress track is

parallel to the scheduled track, the progress rate is OK.
- Area 4: a recovery effort was initiated well in time (about a month before the end date) → Do not wait until the last moment to start extra efforts: it pays in quality of the end product.

6.8. Lessons learned from the current experiment

At the time of editing this document, the current experiment is still ongoing. A few general status reports have been issued. The final results will be available by the end of June 2014, and will be included in the final version of the paper.

This time we produced a “portfolio” report: this is a report over all projects.
Here are some rough data as per 15-03-2014

Project Count	41	
In good shape	18 (44%)	These are project that are well under control
In the Red	21 51%)	These are project that display a substantial delay
Improving	24 (59%)	These are project that display improving levels of control
Deteriorating	16 (39%)	These are project that display worsening control levels.
Red and deteriorating	7 (17%)	These are the real bad ones

The present experiment is ran under other conditions:
- participating is mandatory
- the goodness of project control will contribute to the final grade.

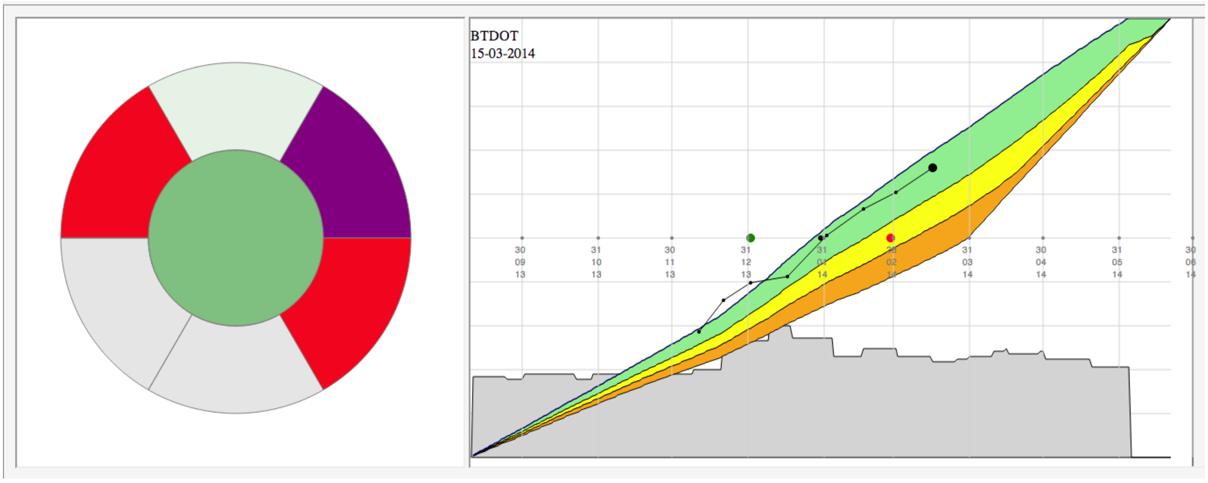
From these figures we can see that only 17% of the projects don’t really care. Now there can be some reasons for that beyond the student’s responsibility; it is too early to know.

The overall picture is quite good, taking into account that at the start of the experiment the students had no knowledge about project planning, monitoring etc.
Mind that to be “in the red” is not a disaster provided that the status is “improving”.

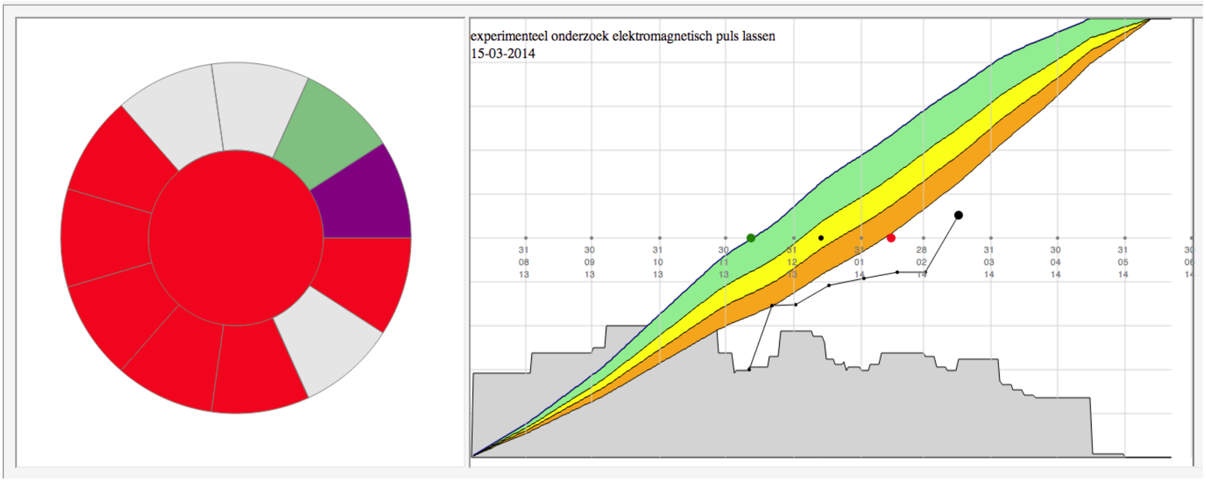
These results show that the method, tools and techniques chosen are obviously absorbed quite quickly and to a satisfactory degree.

Now let’s look at a few typical S-curves

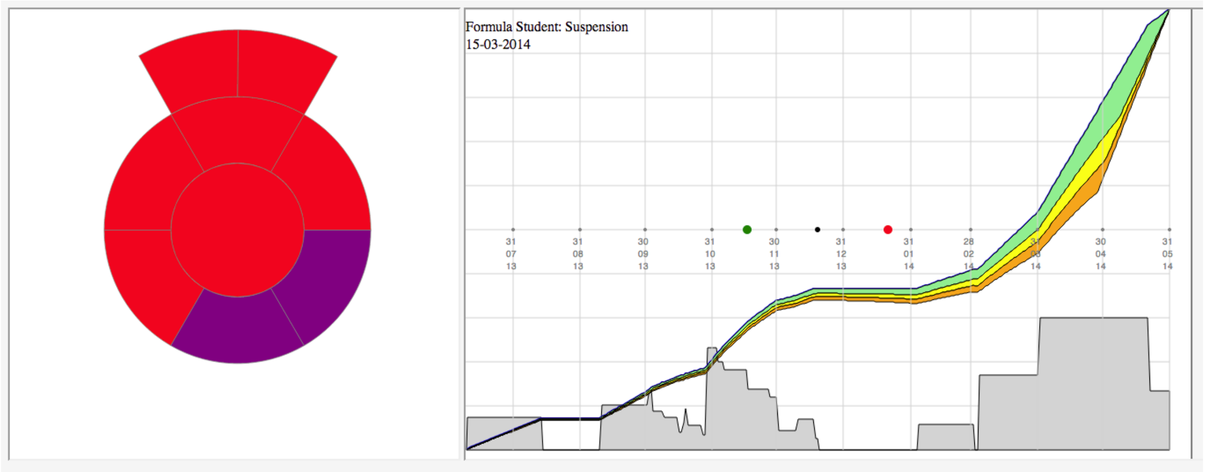
This is an example of excellent project control.
We already can forecast that this master thesis will be ok in terms of content and quality.



This is an example of a project in difficulties. Might finish in time, but at the cost of extra and hurried work at the end of the project. We may expect lesser quality.



This is an example of a project that is apparently brain dead: no progress at all. The cause may lay beyond the student's responsibility.



The preliminary results of the second experiment are quite encouraging. We also already note that including project scheduling and monitoring performance in the final grade, has produced a higher "motivation" than the first time.

6.9. Overall conclusions

We think that we may conclude that we found a good technique to expose engineering students to most if not all aspects of modern CE driven projects.
We show that this can be realised with a minimum of "ex cathedra " teaching, and lots of learning by discovering.
We do foresee a debriefing type of session some time in April. During this session every project will be reviewed in relation to the scheduling and monitoring.

We also show that the effect of the exercise on the students, the degree of comprehension, the degree of mastership of the proposed techniques, can also be monitored as such by the educators.
This come with an extra bonus: when it becomes clear that a student runs into problems, this can then be discussed on a fact based basis.

We are now convinced that our approach opens the path to a simple though effective method to teach modern project scheduling and monitoring techniques to engineering students.

ir JP Tollenboom
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