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Continuous Adjustments and the Reality Test in Managing Complex Projects

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Abstract: The state-of-the-art in the practice of probabilistic network planning for complex construction projects PERT (Program Evaluation Review Technique) is evaluated along the lines of thought of the reality test that was introduced in the workshop “Error in the Sciences”, Lorentz Center, Leiden University, 2011. The conclusion is that the application of the PERT-methodology during project execution can be improved by including in the planning software the actual durations of the activities as soon as these are finished; monitoring progress by keeping the probability of timely completion just over 50%; and adopting risk ranking for prioritizing managerial attention.

Keywords: Project Management; Project Execution; PERT; Complex Construction Projects

1 Introduction

Complex construction projects tend to be completed with substantial overruns in time and money, and sometimes also poor functionality. One of the causes of this state of affairs could be that the planning methods as currently in use by practitioners do not sufficiently satisfy their needs.

The current state-of-the-art of mathematical modeling to support progress control of complex projects is probabilistic network planning known as PERT (Program Evaluation Review Technique). Practitioners, however, do not embrace this technique. They prefer to stick to the familiar Gantt chart for the weekly scheduling of their activities and use PERT only for communication with their stakeholders.

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Could it be that the PERT-methodology contains flaws that justify this reluctance from the part of practitioners?

We address this question by an analysis along the lines of thought of the article ” Economic Theory and the Reality Test” [5], which will be discussed in the next two sections as an introduction to our review of the PERT-methodology.

Finally, the conclusion is drawn that the PERT-methodology, as currently used in practice, contains three flaws, all pertaining to decision making during execution. Removing these flaws could improve the incorporation of the PERT-methodology in the day-to-day decision making of a project.

2 Mathematical Modelling in Engineering Sciences

Mathematical modeling in engineering sciences involves three steps:

1. We make simplifying assumptions when mapping the empirical system, the reality, into the mathematical system, the model. For instance, the assumption of an ideal (incompressible, frictionless) fluid in Potential Theory and Finite Element Theory in Fluid Dynamics.
2. Computations are carried out in the mathematical system to provide useful insights into the behavior and interaction of various components of the empirical system. For instance, the occurrence of resonance in a vibration problem or the stresses in the materials of a construction.
3. We map back from the mathematical system, the model, the results of the computations into the empirical system, the reality, to test if the mathematical model reflects reality to a satisfactory degree. We call this test *the reality test*.

In the engineering sciences, a reality test is always possible. In hydrodynamics of ship propeller design, a test in the cavitation tunnel or an open water test in the towing tank. In aerodynamics of aircraft design, a test in the wind tunnel. In construction design, full-scale testing on stresses in the materials of the construction.

As an example, consider the performance calculation of heavily loaded ducted propellers. See Chapter 5, pages 81-98 of Ref. [6].

The dots in Figure 1 (Figures 43, 44, and 45 of Ref. [6]) indicate the results of mathematical calculations carried out with the non-linearized theory, in which slipstream deformation, contraction as well as the downstream increase of the pitch of the slipstream vortices, is accounted for. These results pertain to the mathematical system, the model.

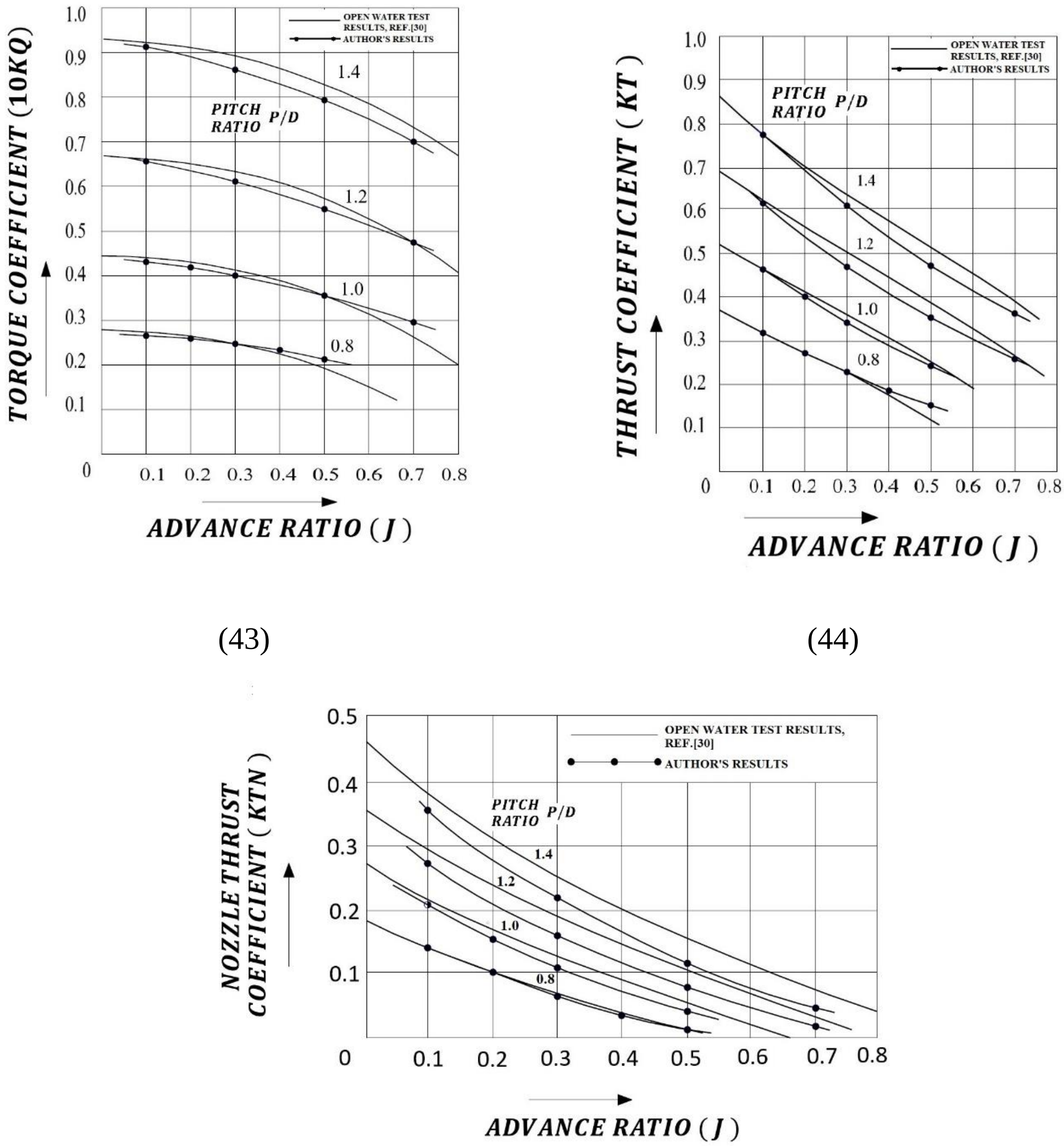

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Figure 1: Figures 43, 44, and 45 of Ref. [6].

The lines in Figure 1 (Figures 43, 44, and 45 of Ref. [6]) represent open water test results. These results pertain to the empirical system, the reality.

In spite of the simplifications that still remain in the mathematical model, the agreement between the two can be regarded as satisfactory. The theory successfully passes the reality test.

If we do not account for slipstream deformation, that means we assume the diameter and pitch of the slipstream vortices to be constant downstream, then the agreement becomes very poor at low advance ratios, more or less, as depicted in Figure 2.

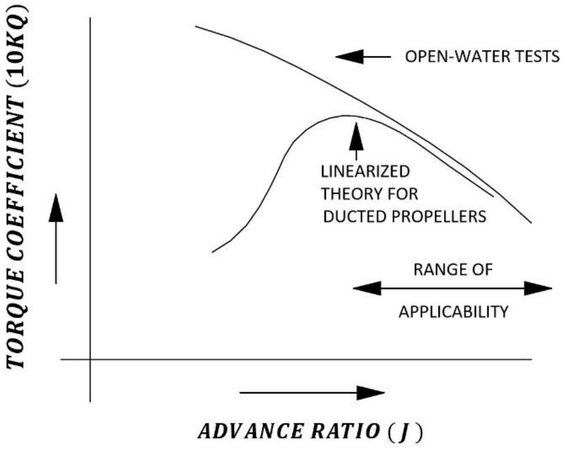

Figure 2: The reality test of linearized theory for ducted propellers

In the area of heavy propeller loadings - i.e., towing conditions (tugs, fishing boats) - linearized theories, which do not account for slipstream deformation, fail the reality test.

Another example (pages 87-88 of Ref. [6]) concerns the way nozzle-induced velocities can be incorporated in the performance calculation for open propellers:

1. Adding the nozzle-induced axial velocities to the speed of advance as a virtual wake pattern in which the propeller is operated, or
2. Adding them to the axial velocities induced by the propeller in the screw disk.

Both procedures were programmed, but the latter yielded far better agreement with experimental results and was therefore adopted in all further calculations. The former, by contrast, fails the reality test.

3 Mathematical modeling in economics and social sciences

In economics and social sciences, a reality test is not readily available. As a result, improper use of scales that are ill-defined, as is commonplace in those fields, remains unpunished.

If a direct reality test is not possible, one has to resort to meticulously scrutinizing each step in the process of shaping the theory concerned. Therefore, every fundamental error that is discovered has to be regarded as a step forward, as progress, not as criticism on the scientists who produced the error (Ref. [1]).

A reality test on decision support methods used in the scheduling of complex projects is not available. Like in economics and the social sciences, one has to resort to scrutinizing the various steps involved in these methods.

We will do so for the planning methodology of the so-called Mitigation Planner, published in 2009 and 2011 (Ref. [2] and [4]), and describe the improvements that have been attained since then.

Scrutinizing steps is considered to belong to the reality test whenever direct testing, as in the engineering sciences, is not possible.

4 The state-of-the-art in the practice of probabilistic network planning

As mentioned before, the state-of-the-art in the practice of probabilistic network planning for complex projects is PERT (Program Evaluation Review Technique), which we will first review for the preparatory phases of a project.

The PERT-procedure for scheduling the activities needed for the completion of a project involves the following steps:

1. Creating the Work Breakdown Structure (WBS); decomposing the work to be done into manageable units: *activities.*
2. Determining the *durations* and *timing* of the activities in a GANTT chart.
3. Determining the *interrelationships (start-finish relations)* of the activities in a *network.*
4. Estimating the *range* of the durations of the activities by specifying the best guess, a pessimistic, and an optimistic estimate.
5. Making a deterministic computer run with the best guesses only; the resulting Critical Path enables us to set a realistic *target completion time* of the entire project.
6. Calculating the bell-shaped probability curve and the associated S-shaped accumulated probability curve of the *throughput time* of the project.
7. Establishing a Monte Carlo based *risk ranking of paths* through the network according to the probability of a path becoming ultimately the Critical Path. The risk ranking of paths provides a basis for prioritizing management attention during execution.

Like in economics and social sciences, a reality test is not available for this kind of modeling. To establish the reality gap between model and reality, we have to scrutinize these seven steps.

Since no flaws were to be found in any of them, we conclude that, as far as the preparatory phases, i.e., before starting execution, are concerned, the mathematical model of the PERT-methodology reflects reality to a satisfactory degree.
This is not the case, however, for the execution phases of a project.

5 Decision making during execution

The implicit, but unavoidable, assumption in all current planning methods is that execution will take place as indicated by the planning software, which obviously is never true. When things do not evolve as planned, the project manager takes all kinds of measures - mitigations - to ensure that the target completion date is attained in spite of all the things that do not develop according to plan. In short, planning software that does not account for mitigations on-the-run is not of any use for the practitioner who is responsible for the ongoing scheduling of activities.

The planning methodology published in Refs. [2] and [4] emphasizes mitigations on-the-run: corrective measures that are necessary to cope with unforeseen unpleasant surprises during execution. The methodology is, therefore, referred to as the *Mitigation Planner*.

The Mitigation Planner constitutes an improvement over the current practice of the PERT-methodology in various aspects, as will be discussed in the sections that follow.

6 The reality gap

When the project progresses after starting execution, the gap between model and reality, the reality gap, widens whenever activities are completed. Their durations and costs are then exactly known, but this information is not incorporated in the PERT-planning software. When the planner who is responsible for the scheduling of activities feels that the reality gap has become too big, an update of the planning is conducted as if a new project would be started at that point in time, and the completed activities would not exist. The reality gap is thereby reset at its original level. When such updates are conducted at times t_1, t_2, t_3…, the reality gap as a function of time gets a saw-shaped form with peaks at t_1, t_2, t_3 (Figure 3).

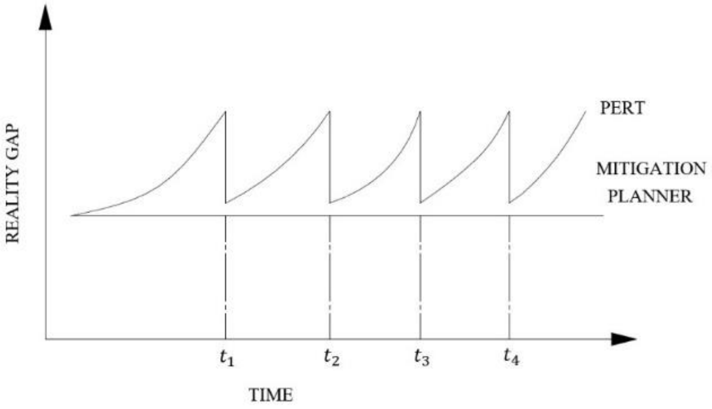

Figure 3: Reality gap as a function of time

In the Mitigation Planner methodology, activities that are completed are set in the planning software at their actual values as soon as these become available. In this way, the reality gap stays at its original level (horizontal line in Figure 3).

The continuous updating of completed activities results in a better reflection of the reality in the model.

At the end of the project, when all activities are completed, a database of costs and durations of the activities becomes automatically available. This feature of the Mitigation Planner is of great value for the planning of future projects.

7 The 50% threshold

Unexpected delays are unavoidable in complex projects. When they emerge, the common way to cope with their consequences is to simply extend the target completion time and accept that the benefits of the project will materialize later than initially planned.

In many cases, however, extending the target completion time is not possible, like in construction work for the Olympic games, offshore projects that have to be executed during a fine weather window, and infrastructure works where the availability date is fixed as a contractual condition *sine qua non*.

In such cases, the common way to cope with this problem is to require a high probability, in the order of 85 %, of timely completion. This approach not only brings along unnecessary costs but also does not guarantee that the target completion date is indeed attained.
The Mitigation Planner methodology includes the 50 % threshold, which reads:

Maintaining the probability of finishing the project within the target completion time just above 50% at all times during the execution, is enough to attain an almost certain timely completion.

The underlying reasoning is the following.

Let us consider the hypothetical case of a project with almost certain activity durations. For instance, the pessimistic estimate is 1% above the best guess, and the optimistic estimate is 1% under the best guess. Then the project will be finished at almost exactly the target completion time. This will also be the case for wider ranges, +/-5%, +/-10%, etc. as long as the distribution remains symmetrical. When the distribution is skewed to the pessimistic side, completion will be slightly over the target completion time. How much depends on the skewness of the distribution.

Mitigations that are implemented to keep the probability of timely completion above 50% at all times do not increase that probability to exactly 50% but slightly over it.

For all practical purposes, we may assume that these two effects cancel out. Real-life cases indicate that this is a conservative assumption.

If the mitigations could be split up into a large set of mini-mitigations, the probability of timely completion could be kept at almost exactly 50%. In practice, however, mitigations are discrete and have, as a corollary, a stepwise effect on the completion time. For instance, when a mitigation is implemented because the probability of timely completion has dropped to 48%, the probability of timely completion will not increase to exactly 50% but to, say, 53%.

The 50% threshold is of particular interest for projects with a fixed availability date, like construction projects for the Olympics, because it provides the earliest possible warning signal that managerial action is required. Simulations with the Mitigation Planner on construction projects for the Olympic village of the Rio Olympic games in 2016 show that spending only a few percents of the total cost on mitigations in early project phases could have prevented the chaotic mess that actually has taken place in the late project phases (Ref. [3]).

The selection of mitigations for keeping the probability of timely completion of just over 50% is facilitated by the distinction between *tentative* and *permanent* mitigations. Tentative mitigations that could decrease activity durations are defined and stored in the planning software in the early phases of execution.

This entails for each tentative mitigation: it’s gain in activity duration, it’s cost, and its expected expiring date beyond which making the mitigation permanent is no longer possible. Mitigations that are beyond their expiring date are removed from the set.

Whenever needed for implementation of the 50% threshold, tentative mitigations can be made permanent. The decision on which ones to select can be based on various criteria.

Since the criteria *costs* and *availability of resources* always play a role, optimization procedures on these two criteria have been included in the Mitigation Planner.

8 A thought experiment on the threshold for timely completion

Let us consider two hypothetical projects, A and B, that are identical except for how progress is monitored during execution: In project A by adhering to the 50% threshold and in project B by requiring the probability of timely completion to be kept over 85% (Figure 4).

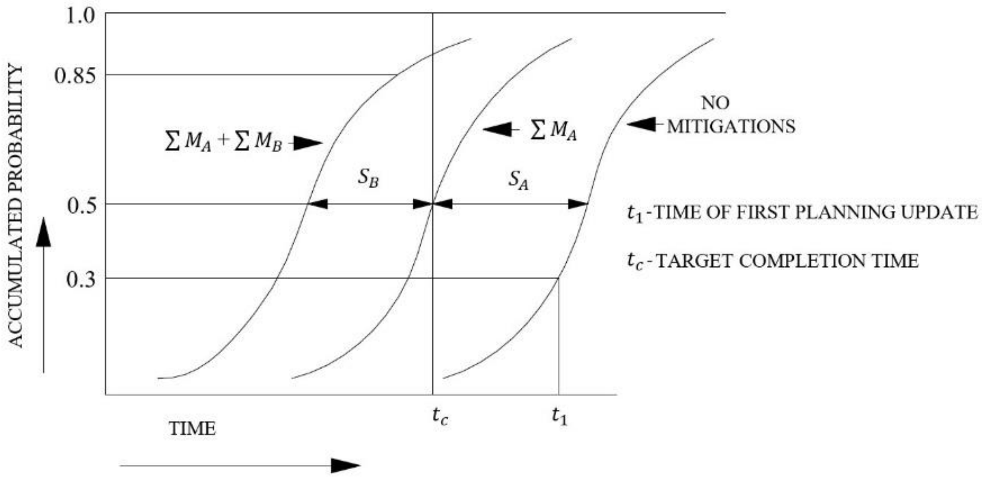

Figure 4: Two hypothetical cases

In both cases, a target completion time is adopted according to step 5 of the planning procedure mentioned before (Critical Path computation on best guesses only).

At the first planning update at time t_1, it appears that the probability of timely completion had been decreased to 30%. To restore that probability to 50%, a set $\sum M_A$ tentative mitigations is made permanent, which moves the accumulated probability to the left by a shift S_A. In case B, an additional set $\sum M_B$ tentative mitigations is made permanent, which moves the accumulated probability curve further to the left by a shift S_B.

If everything evolves from then onwards exactly as planned, progress will converge to the same final throughput time. The target completion time will be attained in both cases—the costs of the set mitigations $\sum M_B$ constitute an unnecessary waste.

If an unexpected delay would occur in late project phases, mitigations cannot prevent overruns in delivery time, because all tentative mitigation expiring dates are exceeded. The basket of tentative mitigations is empty when the project approaches its end. Having implemented the set $\sum M_B$ only decreases the overrun in delivering time by a margin S_B.

What the project manager can and should do, is trying to prevent such an unexpected delay to occur by paying particular managerial attention to activities on the paths in the network that rank high in the risk ranking,

In short, the practice of requiring during execution a probability of timely completion substantially above 50% in view of a fixed availability date brings along unnecessary costs and is by no means a guaranty for the timely delivery. It fails, therefore, our scrutiny on this element of the PERT-methodology as currently in use.

9 The Critical Path

The Critical Path is the path of the network in which any delay of activity causes an equal increase in the throughput time of the entire project.

The general recommendation is to pay extra managerial attention to activities on the Critical Path.

When an audience is asked if they agree with this recommendation, the outcome is invariably an almost complete agreement. Actually, there is no such thing as “The” Critical Path. The widely prevailing focus on the Critical Path is unwarranted and misleading. When a path close to the Critical Path incurs a small delay in the late phases of a project, these paths change places in the slack ranking, but it is then too late to do anything about it. For this reason, risk ranking should be the basis for prioritizing managerial attention, not slack ranking.

In short, the usual preoccupation with the Critical Path fails our scrutiny on this element of the PERT-methodology as currently in use.

10 Mitigation Planner features

The relevant features of the Mitigation Planner and their consequences are summarised in the table below.

Feature:	**Consequence:**
Setting durations of completed activities at their actual values	Mathematical model remains a good reflection of reality when the project progresses
Historical database of time and cost estimates automatically becoming available	Enables fine-tuning of time and cost estimates in future projects
Risk ranking instead of slack ranking	Avoids unpleasant surprises at late project stages and the misleading emphasis on the Critical Path
Optimization of mitigations on the criteria time and cost	Facilitates decision making on the selection of tentative mitigations that have to be made permanent
Allowing for non-availability of resources	Enables ease of implementation to be considered

11 Conclusion

Application of the PERT-mathematical model during project execution can be improved by:

1. Including in the planning software, the actual durations of activities as soon as these are finished.
2. Monitoring progress on the basis of the 50% threshold, i.e., keeping the probability of timely completion just over 50% at all times.
3. Adopting risk ranking for prioritizing managerial attention, i.e., ranking the paths through the network according to their probability of ultimately becoming the Critical Path.

About Author

Lex A, van Gunsteren is a business consultant, lecturer and innovator in marine propulsion. He graduated as a naval architect and received his PhD from Delft University of Technology, where in 1981 he was also appointed as Professor in Management of Technology. He was one of the pioneers of the Rotterdam School of Management where he taught R&D management and crisis management.

After his military service as an officer in the ship design unit of the Royal Netherlands Navy, Lips Propeller Works employed him, initially as an industrial scientist and later in various managerial positions. In the shipbuilding group IHC Holland, he was managing director of their shipyard Gusto, specialised in off shore equipment. In the Royal Boskalis Westminster Group he served as director of corporate planning and R&D.

In the late eighties, he founded the innovation company Van Gunsteren & Gelling Marine Propulsion Development for the further development of his invention of the slotted nozzle (duct with a slot at the front), which ultimately led to the successful application of the wing nozzle (duct with a slot at the rear).

He served on various boards for monitoring R&D subsidies, among others as vice chairman of the board of the Dutch Foundation for Technical Sciences 'STW'. Since 1997, he lectures, at Delft University, computer aided support in architecture, urban planning and project management.

His publications include eight patents and ten books.

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