45th International Conference on Environmental Systems
12-16 July 2015, Bellevue, Washington

ICES-2015-046

Underestimation of Project Costs

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Large projects almost always exceed their budgets. Estimating cost is difficult and estimated costs are usually too low. Three different reasons are suggested: bad luck, over-optimism, and deliberate underestimation. Project management can usually point to project difficulty and complexity, technical uncertainty, stakeholder conflicts, scope changes, unforeseen events, and other not really unpredictable bad luck. Project planning is usually over-optimistic, so the likelihood and impact of bad luck is systematically underestimated. Project plans reflect optimism and hope for success in a supposedly unique new effort rather than rational expectations based on historical data. Past project problems are claimed to be irrelevant because "This time it's different." Some bad luck is inevitable and reasonable optimism is understandable, but deliberate deception must be condemned. In a competitive environment, project planners and advocates often deliberately underestimate costs to help gain project approval and funding. Project benefits, cost savings, and probability of success are exaggerated and key risks ignored. Project advocates have incentives to distort information and conceal difficulties from project approvers. One naively suggested cure is more openness, honesty, and group adherence to shared overall goals. A more realistic alternative is threatening overrun projects with cancellation. Neither approach seems to solve the problem. A better method to avoid the delusions of over-optimism and the deceptions of biased advocacy is to base the project cost estimate on the actual costs of a large group of similar projects. Over optimism and deception can continue beyond the planning phase and into project execution. Hard milestones based on verified tests and demonstrations can provide a reality check.

Nomenclature

AMCM	=	Advanced Missions Cost Model
CEH	=	Cost Estimating Handbook
CER	=	Cost Estimating Relationship
LCC	=	Life Cycle Cost
MOCM	=	Mission Operations Cost Model
MSFC	=	Marshall Space Flight Center
NAFCOM	=	NASA-Air Force Cost Model
PCEC	=	Project Cost Estimating Capability
PRICE	=	Parametric Review of Information for Costing and Evaluation
WBS	=	Work Breakdown Structure

I. Introduction

THIS paper considers the very common, apparently unavoidable problem that project costs are significantly underestimated and that therefore projects usually overrun their budgets. Developing accurate cost estimates would be better than threatening that project managers must stay within their budgets or face cancellation. It is simply silly to pretend that the initial project cost estimate must be correct and can be set in stone forever by management. A project's final cost is just one result of a continuing dynamic project process involving multiple conflicting stakeholders.

It is often emphatically stated that a project must deliver its product within specification, on time, and in budget. However, the final project cost seems to be more an indirect and unpredictable result of the project process than a

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controlling major goal. Project value and customer satisfaction do depend partly on the final project cost compared to budget, but very few successful projects stay within the original budget.

How should project cost be estimated? The paper considers different cost estimation approaches, the well known reasons that cost estimates are too low, and a strongly suggested way to get better estimates.

II. Different cost estimation approaches

Sometimes cost estimates are based on a close analogy with a previous project or they are generated by expert judgment and group consensus without bothering with too much data and methodology. However, the two most frequently used cost estimation methods are parametric top-down and engineering bottom-up.

Parametric top-down cost estimating methods include the Advanced Missions Cost Model (AMCM), the commercial PRICE-H space hardware cost model, and the NASA-Air Force Cost Model (NAFCOM), which is being replaced by the Project Cost Estimating Capability (PCEC). They are based on one or several mathematical relationships called cost estimating relationships (CER's) that are derived from the costs of similar hardware. The most important cost estimation parameter is system mass, followed by production quantity and the design heritage or number of previously developed similar systems. (Jones 2015-41) (Trivailo et al. 2012) (Guerra and Shishko 2000)

Parametric top-down methods can be used early in project planning when only the top-level system requirements are available. The AMCM is especially easy to use, requiring only the estimation of a half dozen parameters that can be entered into a spreadsheet or online calculator to produce a cost estimate. The AMCM seems the best cost estimator for use during early broad system trade-offs and initial technology assessments. The Price-H cost model, NAFCOM, and the PCEC that is replacing it all require complex software, a trained cost estimator, and extensive interaction between the cost estimator and project management. They can be subjective and are strongly influenced by management expectations and strategy. Price-H, NAFCOM, and PCEC are more suitable for planning the final budget that project management will present and be held accountable for. (Jones 2015-041)

The engineering bottom-up approach requires detailed estimates for the costs of hardware design, development, and test. Engineering cost estimating can only be done during the project design phase when the subsystem requirements are known. Detailed cost estimates require that the project deliverable be broken down into subsystems and the project tasks organized into work packages usually defined by a Work Breakdown Structure (WBS). The bottom level cost estimates are provided by the subsystem engineers doing the design and planning to spend the budget. A major advantage of bottom-up detailed cost estimates is that they allow detailed cost monitoring later during the project. A major disadvantage is that they are complicated, inflexible, and expensive, so that they cannot adapt quickly to changes in requirements or designs. Changes are discouraged but seem inevitable. (Trivailo et al. 2012)

An engineering bottom-up estimate is much more convincing to managers and engineers than a parametric top-down estimate because it can be broken down and checked in detail. Professional cost estimators strongly defend their top-down approach, claiming that the engineers' bottom-up approach is usually more subjective and less accurate. Engineering cost estimates often assume the best case design process and tend to ignore administrative and program overhead, possible requirements changes, possible design errors and rework, etc., etc. Probably the best way to do cost estimation during the project life cycle would be to use the AMCM for quick early trade-offs, Price-H or PCEC to develop the proposed project budget and monitor it at the top level during the project, and a modular updateable engineering bottom-up estimate for detailed project management and cost control.

III. Why are initial cost estimates almost always too low?

This section considers the project, psychological, political, and economic perspectives on cost underestimation and budget overruns.

A. The project perspective

All project based industries have the problem of cost overruns. The highway transportation industry identifies two fundamental causes of increasing cost estimates. First, the project scope is not understood at the time of planning and expands as new stakeholders add requirements. Second,

> "There is sometimes speculation that, to secure funding for projects, items may be purposefully excluded from initial project scopes and costs with the intention of adding them later. Questions about honesty or competence can threaten the credibility of the planning and programming process and that of the transportation agency." (NCHRP, 2007)

An engineering project text observes that cost overruns are the norm and mentions the same two problems, poor scope definition leading to requirements creep and low ball estimates to gain approval. It adds that project cost estimators can be too optimistic, assuming all will go well and no problems will occur. If unanticipated technical difficulties arise due to poor design or bad test results, the result is higher than expected costs. (Venkataraman and Pinto 2008)

The three reasons for overruns so far are: scope misunderstood or changed, deliberate low bid, and excessive optimism. A software researcher notes that inaccurate cost estimation is a major cause of software project failure, and identifies the same scope definition error and deliberate underbidding problems. Cost estimates are required before requirements are defined. New requirements are added but the original estimate cannot be changed. Management may simply reject a realistic conservative cost estimate and dictate a lower more aggressive one. The project may fail to use the best available cost estimating methods that use good historical cost calibration data. To limit scope problems, early estimates should include contingencies for requirements changes. To discourage the arbitrary downward adjustment of accurate estimates, cite historical data from similar projects that is harder to discount. (Jones, C. 2006)

From the project perspective, the suggested reasons that initial cost estimates are too low are:

1. Scope undefined, misunderstood, or changed
2. Deliberate low bidding
3. Excessive optimism
4. Poor cost estimating methods and calibration data

B. The psychological perspective

The Nobel laureate, Daniel Kahneman, explored the idea that humans think in two different ways in his best selling 2011 book, Thinking, Fast and Slow. Fast thinking is intuitive, subconscious, using rules of thumb and common sense models. Slow thinking is logical, rational, deliberative, systematic. The lesson of Kahneman's interesting, intelligent, and original 499 pages can be summed up in five words, "Not so fast! Think slow." (Kahneman 2011)

Kahneman spends ten pages to describe "one of the most instructive experiences of his professional life." He was leading a group developing a textbook on rational decision making. While they were considering group decision making, he decided to collect individual estimates on how long their textbook project would take. Estimates varied from one and a half to two and a half years. But then he remembered that one group member, a textbook development expert, had been involved in many similar projects, so he asked him, "How long do similar projects usually take?" The surprising answer, "Seven to ten years, those that finish. 40% don't." Yet the expert stuck to his original roughly two year estimate for their current project, and so did all the group, and they pushed on. The project took eight years and the textbook deliverable was too late and never used.

Kahneman learned three lessons. First, there are two different approaches to forecasting, which he calls the inside or project view and the outside or global view. Second, estimates are usually optimistic, too close to best case, which he calls the planning fallacy. And third, people push on when cancelling a project is the better choice.

The textbook development expert first took an inside view when he estimated the project would take two years. He was completely immersed in the project and the group's hopes and plans. When asked about similar projects, he then stepped back and took an outside view. But he did not apply the baseline statistics of the reference class to his current prediction, and neither did the rest of the group. In project cost estimation, engineering bottom-up estimates take an inside view and parametric top-down estimates take an outside global-historical view.

Considering the forecast and the actual outcome, the textbook group's and many other estimates appear delusional. The planning fallacy describes forecasts that are optimistic, unrealistically close to the best case, and do not consider the statistics of similar cases.

1. The additional scope, underbidding, and cost data problems

Kahneman in an aside also notes the familiar problems of scope changes and deliberate underbidding,

> "The optimism of planners and decision makers is not the only cause of overruns. Contractors of kitchen renovations and of weapon systems readily admit (though not to their clients) that they routinely make most of their profit on addition to the original plan. The failures of forecasting in these cases reflect the customers' inability to imagine how much their wishes will escalate over time. They end up paying much more than they would if they had made a realistic plan and stuck to it.
>
> Errors in the initial budget are not always innocent. The authors of unrealistic plans are often driven by a desire to get the plan approved – either by their superiors or a client – supported by the knowledge that projects are rarely abandoned unfinished merely because of overruns in cost." (Kahneman 2011, pp. 250-1)

The psychological perspective emphasizes the cost underestimates are caused by optimism due to the inside view and the planning fallacy, but it also notes the importance of scope changes, deliberate underbidding, and the need for good cost reference data. The psychological and project perspectives produce the same four causes of project cost underestimation.

2. Persistent and incorrigible over-optimism

Over-optimism usually persists beyond the planning phase of a project and into the execution phase. Psychological optimism produces two effects, low estimates and overconfidence that the low estimates will be met. Over-optimism is not only <u>not</u> cured by good cost models and data, it is encouraged!

A simulation was conducted to investigate the persistence of the psychological optimism bias during a project by essentially eliminating technical problems and strategic underbidding. Competing project teams were provided with good planning models and techniques and accurate on-going project data. They were asked only to prepare, revise, and meet their estimates during the project. There was no need to bid for initial approval. Optimistic estimates not only persisted without the motivation of underbidding to gain project approval, they were actually encouraged by having good cost models and data. Good models and accurate data helped produce the illusion of certainty, predictability, and controllability. "Paradoxically, instead of providing realism and planning accuracy, the perceived ease of use and usefulness of planning tools reinforced a false sense of certainty." (Kutsch et al. 2011)

3. Reference class forecasting

Kahneman mentions that the planning expert Bent (not Bert) Flyvbjerg endorsed the idea of using the outside view to cure the planning fallacy as "the single most important piece of advice regarding how to increase accuracy in forecasting." The outside view can be implemented by using the statistics of similar cases in a method called reference class forecasting. (Kahneman 2011)

C. The political-strategic-economic perspective

The political-strategic-economic perspective of Bent Flyvbjerg emphasizes the self-serving calculations driving deliberate cost underestimation, but also acknowledges the importance of natural over-optimism and simple ignorance of actual past project costs. Reference class forecasting can mitigate ignorance, delusion, and deception in cost estimating. (Flyvbjerg 2006) (Flyvbjerg et al. 2009)

Flyvbjerg's analysis is briefly summarized. Budget overruns are often blamed on poor scope definition, project complexity, technical surprises, and the political conflicts of opposing stakeholders. These do increase costs, but why do project planners and cost estimators not anticipate them? Cost under estimation errors are due to three factors, technical errors, over-optimistic delusions, and deception by strategic manipulation of the cost estimate.

1. Delusion and deception

Kahneman's planning fallacy is the tendency to make optimistic underestimates of cost, even while knowing that similar projects usually cost more. The risks of scope change, complexity, surprises, and conflicts are discounted or ignored during planning. Bottom-up planning, taking an inside view, and emphasizing the project's uniqueness all contribute to the planning fallacy. Over-optimistic delusions can be reduced by a good learning environment, where similar problems are frequently solved and the proposed solutions quickly checked against reality.

Deception occurs when the participants and stakeholders have different and conflicting interests and engage in political and strategic behavior, usually for economic advantage. Project advocates deliberately underestimate costs to increase the chance that their project will be chosen over its competitors. This defeats the project selection process, since the most deceptive rather than the most cost-beneficial projects can be selected. Strategic deception is encouraged by conflicting goals, asymmetric information, different risk preferences and time horizons, and unclear accountability. Deception can be reduced by openness, sharing information, and aligning incentives so that all stakeholders succeed or fail together.

Delusion is personal and psychological while deception is organizational and political. Although delusion and deception have different causes, they are often intermingled and can be difficult to distinguish. Delusion and deception can combine in a negative synergism to create even lower cost underestimates. Large unique projects are especially prone to delusion and deception. (Flyvbjerg et al. 2009)

2. Reference class forecasting

When delusion and deception both occur, both can be mitigated by reference class forecasting, which implements the outside view. Reference class forecasting deliberately avoids the complex details of the inside view and simply focuses on the historical costs of similar projects. It is both much easier and much more accurate than detailed bottom-up cost estimation. (Flyvbjerg et al. 2009) Using past project cost data for cost prediction is used in engineering parametric cost estimation models such as AMCM, Price-H, NAFCOM, and PCEC.

D. Summary: Why are initial cost estimates too low?

The project, psychological, and political perspectives each emphasize one particular cause of project cost underestimates but they acknowledge the other possibilities. Together they provide a clear, comprehensive, and compelling view of why project cost estimates are usually too low.

1. Project: Scope unclear or changed, poor cost models and data, etc., etc.
2. Psychological: Over-optimism, inside view, and planning fallacy (Kahneman)
3. Political-strategic-economic: Deliberate underbidding (Flyvbjerg)

Project problems, psychological over-optimism, and political strategic underbidding all cause cost estimates to be too low. Political underbidding is an intentional strategy; the cost estimate is reduced to increase the probability of gaining funding. In contrast, psychological optimism is subconscious. Project problems may be cited as excuses for a cost overrun actually due to over-optimism or deliberate underbidding.

1. Project: Scope unclear or changed, poor cost models and data, etc., etc.

Project organizations propose and conduct projects with a defined deliverable, schedule, and cost. If the project falls short, as most do, it seems obvious that the project is somehow at fault. And yet, when asked to explain an overrun, project management can usually plausibly blame external factors including scope change, poor cost estimating, project difficulty and complexity, technical uncertainty, stakeholder conflicts, unforeseen events, and unpredictable bad luck. With so many plausible, handy excuses, a project really has no compelling need to meet its estimated final cost.

Project scope does often change, but it does not always increase. Scope is often cut if costs rise. Cost estimating methods tend to be industry specific and subjectively influenced. Good historical cost data may be unavailable for the particular field and type of project being estimated. For instance, human space projects are few, significantly different from past efforts, have an unpredictable political and funding environment, and have a high degree of technical uncertainty. However, if cost estimates were inaccurate only due to estimating error, then overestimates should be as common as underestimates. However, unanticipated project problems such as difficulty, complexity, uncertainty, conflicts, unfavorable events, and bad luck all tend to increase cost over estimates.

2. Psychological: Over-optimism, the inside view, and the planning fallacy (Kahneman)

When project planning is over-optimistic, the probability and the negative impact of all the potential project problems are systematically underestimated. Best cast cost estimates are provided and they have nowhere to go but up. Over-optimism is a fundamental, subconscious, ineradicable, human perceptual error. It is especially infectious as a form of group-think. Over-optimism may be a necessary cognitive error for project advocates and innovators. Few radically new things would come into being if only low risk incremental developments were attempted. But do we want to fund the most over-optimistic project advocates or the most promising projects? A realistic assessment of project costs would be helpful.

3. Political-strategic-economic: Deliberate underbidding (Flyvbjerg)

Underestimating costs is a usual strategy to gain project approval and funding. Project advocates and managers, pushing to get their projects funded, over-promise what the project will do and understate how much it will cost.

Strategic cost underestimation seems inevitable, a requirement of circumstances.

> "(T)he persistent existence over time, location, and project type of significant and widespread cost under-estimation is a sign that an equilibrium has been reached: Strong incentives and weak disincentives for underestimation may have taught project promoters what there is to learn, namely that cost underestimation pays off." (Flyvbjerg et al. 2002, p. 286)

The main reason that project advocates deliberately underestimate cost is simply to gain approval of a project they think is so necessary and beneficial that it would be worth its probably much higher ultimate cost. This defeats the project selection process, since the most deceptive rather than the most cost-beneficial projects could be selected. The project funders may not agree that the project would be worth its actual cost. If the project fails and is cancelled, the project advocates will be blamed for the cost underestimation as well as other faults.

IV. More accurate cost estimates through reference class forecasting

The best approach to avoid the delusions of optimism and the misrepresentations of strong advocacy is to use reference class forecasting. The cost of a large group of similar projects is used to estimate the cost of the current project. Reference class forecasting uses past project experience, measures of similarity, and cost estimator intuition in a structured process. The outside view taken by reference class forecasting is more objective, less manipulable, and less challengeable than the inside view of bottom up estimation.

Flyvbjerg and others discussed the inaccuracy of forecasts and explained reference class forecasting in 2005. (Flyvbjerg et al. 2005) Based on this work, the American Planning Association officially endorsed reference class forecasting. It made strong recommendation to use it combined with traditional methods as a way to improve accuracy, especially for non-routine projects. (Flyvbjerg 2006) The Association for the Advancement of Cost Engineering has recommended using reference class forecasting since 2006, and it is being used effectively. (Bordley 2014)

Flyvbjerg emphasized that, "Reference class forecasting is based on theories of decision-making under uncertainty that won Princeton psychologist Daniel Kahneman the Nobel prize in economics in 2002." (Flyvbjerg

2006) Errors in judgment are often systematic and predictable due to the decision-maker's bias rather than random mistakes. Most surprisingly, these errors persist and are very difficult to correct, even when they are explained and the explanation is grasped and accepted. Understanding our own bias and cognitive illusions does not free us from them. (Flyvbjerg 2006)

Reference class forecasting is an outside view method to help avoid both delusion and deception in cost estimation. The three basic steps are to identify the reference class of past projects, organize the data on the cost and other attributes of the projects, and predict the new project's cost based on its similarity to the past projects. (Flyvbjerg 2006) (Flyvbjerg et al. 2009) (Bordley 2014) These steps are described in more detail.

1. Define the reference class. The reference class should include all similar projects, unsuccessful as well as successful past projects, to reflect the actual distribution of possible outcomes. The reference class should be numerous enough to provide convincing data but narrow enough to be sufficiently similar to the projects to be estimated. Obtaining similar projects with relevant data can be difficult and time-consuming.

2. Compile and analyze the cost and other relevant data on the reference class projects. Project data should include the major attributes related to cost, such as system mass, design generation, etc. The quality of the final cost estimates depends on the accuracy of the data used. The usual project issues that affect costs - scope changes, redesigns, uncertainty - may affect data validity. For each cost driver attribute, the numerical difference between the new project to be estimated and each past project is calculated. Relative weights are assigned to each attribute. A measure of similarity between the new project and each past project is then computed.

3. The cost outcomes of each past project and its similarity measure with the new project are used to produce the new project cost estimate.

Reference class forecasting is most helpful for non-routine projects, those different from recent local experience. The biases toward optimism and strategic misrepresentation tend to be large in planning new efforts. Getting data on a reference class of relevant past projects can be difficult, requiring search beyond the here and now, but is likely to be very beneficial.

If forecasters are honestly trying to accurately predict the future, they should appreciate the need for the outside view and the potential of reference class forecasting. In this case, no one would to be against improved methodology.

In many cases, cost underestimates are deliberate, the result of organizational responses to political-strategic-economic pressures. Projects compete fiercely for approval and funds. There is no incentive for the individual project to provide higher, more realistic forecasts, but rather the opposite. Projects claim as low costs as possible to beat the competition. Reference class forecasting would still improve accuracy but as things are, no one is interested because the inaccuracy is deliberate. Practical organizational pressures prevent seeking a true and accurate view of the expected future.

To establish use of reference class forecasting, cost estimators and project advocates should be held accountable for accurate forecasts and penalized for inaccurate ones. Cost estimates should be reviewed by independent analysts who would probably apply reference class forecasting to check estimates.

V. Conclusion

Correctly estimating project cost is apparently very difficult. Cost estimates are usually too low and there are frequent cost overruns. The final project cost is the result of a complex and somewhat unpredictable process, which can provide many excuses for the failure of a project to meet its budget. Inaccurate cost estimates are often blamed on bad cost models and inadequate cost data. If true, this should have led to serious work to improve the models, data, and resulting estimates, but the problem persists unabated. Clearly, cost estimators and project managers are not actively seeking more accurate cost estimates.

The two most significant reasons that project cost is underestimated are delusion and deception. Project insiders are optimistic and provide best case cost estimates. Project advocates deliberately underestimate cost to secure project funding, knowing they won't be held to their original estimates.

Reference class forecasting uses past project cost data to counter honest optimism and manipulative underbidding. Cost models such as the AMCM that use past project costs and cost driver attributes to estimate new project cost work in a similar way.

References

Bordley, R. F., “Reference Class Forecasting: Resolving Its Challenge to Statistical Modeling,” The American Statistician, 68:4, 221-229, 2014. Online at http://dx.doi.org/10.1080/00031305.2014.937544

Flyvbjerg, B., “From Nobel Prize to Project Management: Getting Risks Right,” Project Management Journal, vol. 37, no. 3, August 2006, pp. 5-15. Online at http://flyvbjerg.plan.aau.dk/Publications2006/Nobel-PMJ2006.pdf

Flyvbjerg, B., Garbuio, M., and Lovallo, D., "Delusion and Deception in Large Infrastructure Projects: Two Models for Explaining and Preventing Executive Disaster," California Management Review, vol. 51, no. 2, Winter 2009, pp. 170-193.

Flyvbjerg, B., Holm, M. K. S., and Buhl, S. L., “How (in)accurate are demand forecasts in public works projects? The case of transportation.” Journal of the American Planning Association, 71(2), 131-146, Spring 2005.

Flyvbjerg, B., Holm, M. S., and Bulh, S., “Underestimating Costs in Public Works Projects: Error or Lie? Journal of the American Planning Association, 68, 279, 2002. Cited in (Kutsch et al. 2011)

Guerra, L., and Shishko, R., “Estimating the Cost of Crewed Space Systems,” in Larson, W. K., and Pranke, L. K., eds., Human Spaceflight: Mission Analysis and Design, McGraw-Hill, New York, 2000.

Jones, C., “Social and Technical Reasons for Software Project Failures,” Crosstalk: The Journal of Defense Software Engineering, June 2006.

Jones, H. W., “Estimating the Life Cycle Cost of Space Systems,” submitted as ICES-2015-041, 45th International Conference on Environmental Systems, 12-16 July 2015, Bellevue, Washington.

Kahneman, D., Thinking, Fast and Slow, Farrar, Straus, and Giroux, New York, 2011.

Kutsch, E., Maylor, H., Weyer, B., and Lupson, J., "Performers, trackers, lemmings and the lost: Sustained false optimism in forecasting project outcomes—Evidence from a quasi-experiment." International Journal of Project Management 29, no. 8 (2011): 1070-1081. Also IEEE Engineering Management Review, vol. 42, no. 3, September 2014.

NCHRP, National Cooperative Highway Research Program, Report 574, Guidance for Cost Estimation and Management for Highway Projects During Planning, Programming, and Preconstruction, Transportation Research Board of the National Academies, Washington, D.C., 2007.

Trivailo, O., Sippel, M., and Sekercioglu, Y. A., “Review of hardware cost estimation methods, models and tools applied to early phases of space mission planning,” Progress in Aerospace Sciences, Volume 53, August 2012, pages 1–17.

Venkataraman, R. R., and Pinto, J. K., Cost and Value Management in Projects, Wiley, Hoboken, 2008.