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This article presents reasons how and why a stage gated approach to capital project approval is efficient in terms of both time and money. It also dispels some of the common misconceptions about such an approach.

Stage Gated Approval Processes – A Practical Way to Develop and Filter Capital Investment Ideas

by Gordon R. Lawrence

Introduction

A key step in deciding to proceed with any new capital investment project is the development of the cost estimate. Typical questions include how much will it cost? Can we justify the cost of the project against the business case? How much time and effort are we willing to spend to find out whether the project cost can be justified?

In the pharmaceutical industry, there is often pressure to provide accurate cost estimates at short notice and there is confusion over the amount of effort required in order to develop a certain level of estimate accuracy. This can lead to unreasonable expectations of what is possible when preparing a cost estimate.

Ultimately, it can lead to inefficient expenditures in one of three ways: (1) expenditure of large quantities of funds on a project idea that ultimately proves to be unjustifiable; (2) a project being approved on the basis of an optimistically inaccurate estimate that would not have been approved, if the true costs been known; (3) a project being approved on the basis of a very rough estimate, leading to lack of strong budgetary control and ultimately a project that is built for an uncompetitive (and possibly unpredictable) cost and schedule.

This article will examine how much effort is required to produce an estimate of a given level of accuracy. It will then go on to examine a stage gated approach as the best way to balance the two conflicting concerns of (a) spending money to get a better estimate against (b) avoiding wasting money on estimating a non-viable project. Next, it will look at the situation where the business idea is of such value that the project capital cost is only a small proportion of the business case, and the key issue is getting the product to market quickly. It will examine how a balanced, structured, stage gated approach to project scope and estimate development is of benefit even in such extreme "schedule driven" situations. Finally, the article will examine the negative effects of two common actions taken by business management: (1) the desire to "force" an estimate to be more accurate than the scope development can justify and (2) an overly optimistic view of early estimates.

The article is intended for senior managers whose role includes making decisions on whether to proceed with a project idea, but who may have not previously received any engineering or cost estimating training. By the end of the article, readers should have a better appreciation of the amount of effort required to

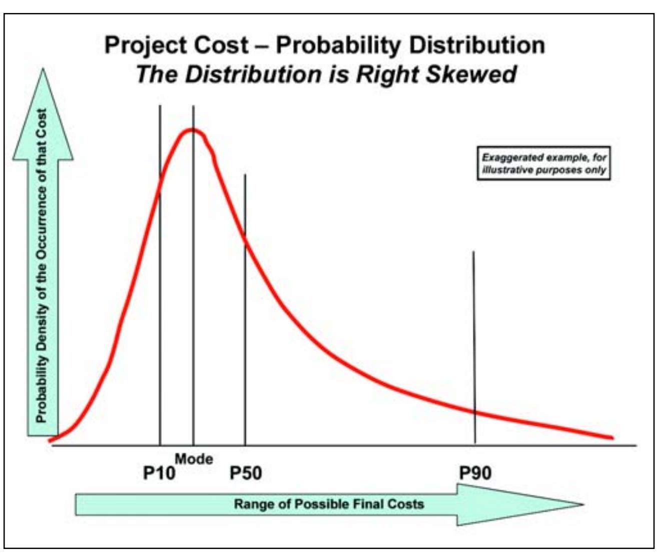

Figure 1. Probability distribution of possible cost outcomes.

achieve a certain level of estimate accuracy and an appreciation of how to balance the desire for greater estimate accuracy before making a final decision against a desire not to "throw good money after bad" on a project idea that won't come to fruition. They also should have a better appreciation of the need for a structured approach to project scope development and estimating, even for a schedule driven project with a solid business case.

How Much Effort is Required?

Problem Number One – I need a number!

Someone has come up with an idea for a project. The business case says that if it could be built for an investment of less than X, then it would meet the company payback criteria.

But can it be built for less than X?

You call the Project Engineering Department and ask them to quickly tell you how much it would cost to build this facility. They ask a few questions and hang up. They call you back the next day with the answer that the 50/50 cost is X with a range of 0.8X to 1.5X, or -20% and +50% at the 80% confidence level.

Should you go ahead?

Your immediate questions to the Project Engineering Department are:

a. Why can't you just give me one number? Why are you giving me a range and what does this range mean?
b. How do I narrow the estimate range to find out if the true project cost is closer to 1.5X or closer to 0.8X? (This is important since the answer will decide whether the project is viable or not).
c. How do I narrow that range without wasting a lot of time and money?

Estimates are Ranges, not Points

Any cost estimate for a capital investment project is exactly what it says: an estimate. It is a prediction of what the final cost will be at some time in the future. Since no one has yet invented a foolproof crystal ball, no-one can predict the future with absolute certainty. Consequently, any estimate will have a range of possible outcomes. That range of outcomes can be expressed as a probability distribution. Because the minimum cost is fairly certain, but the maximum is less certain, the probability distribution curve is generally not normally distributed, but is right skewed, as shown in Figure 1.

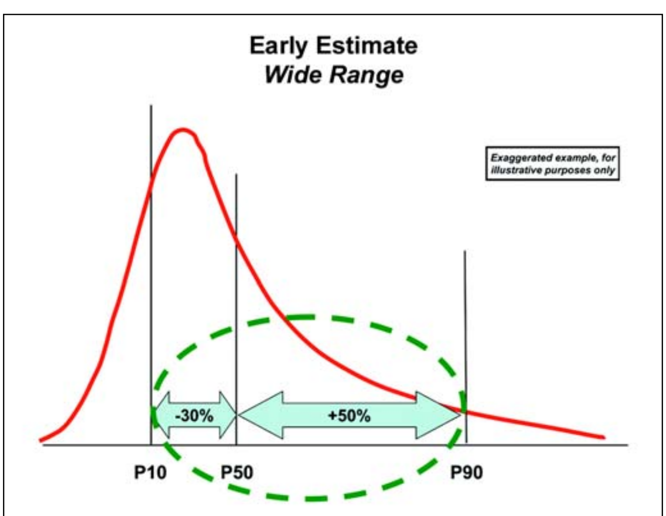

Figure 2. An early estimate with the correct, wide range.

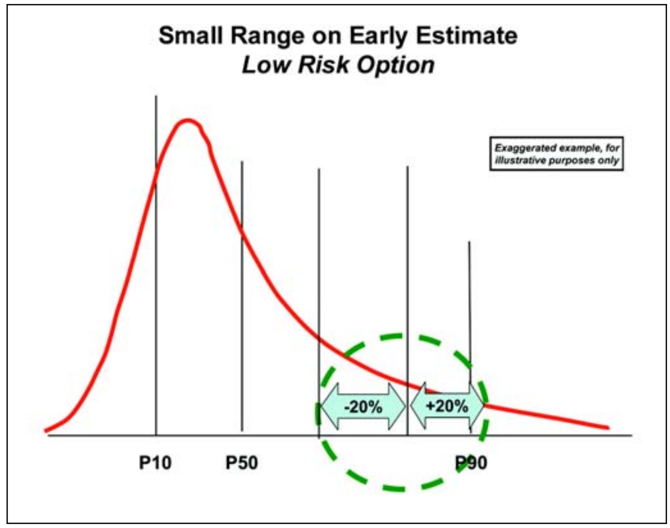

Figure 3. An early estimate with a low risk attempt at a narrow range.

A cost estimate is usually quoted as a point number with a range around it. For example, "the cost is $X million, ±50%." The fact that the ± percentage is even (the same on the plus and the minus side) is a reflection of the common tendency to simplify and assume that the distribution curve is normal. A more accurate percentage might be something like -20%, +50%. The percentage range is usually quoted as a confidence range (typically the 80% confidence range). So, if we return to our probability distribution in Figure 1 we can see that:

- The base cost calculated by the estimator (without contingency) is the **mode** (i.e., the "most likely" outcome – but note that the final cost has a less than 50% probability of being this value or less – that point is denoted by the median). This discussion of mode, median, and range is taken from Lawrence.[1]
- The point number for the estimate (i.e., base cost plus contingency) is the **P50** (i.e., the median or the point at which there is a 50/50 likelihood of the actual cost being greater or smaller than this value).
- The percentage range limits are (assuming we used an 80% confidence interval) the **P10** and **P90** values. (That is, there is a 10% probability of achieving a lower cost than the bottom percentage value and a 10% probability of achieving a higher cost than the top percentage value. Note that this means the percentage range cost is NOT a guarantee of being within that range, it merely expresses an 80% probability of being within that range.)

So, now that we know why estimates are quoted as ranges and what those ranges signify, how do we go about reducing the range and hence improving the estimate accuracy?

Narrowing the Range – Developing Increasingly Accurate Estimates

It is clear that the less risk and uncertainty there is around a project, the more the range of possible outcomes can be reduced. Ultimately, when the project is built, all final costs are known; therefore, there is no more risk and uncertainty about the cost and hence no range is needed at all.

Therefore, greater estimate accuracy is achieved by reducing the level of risk and uncertainty surrounding the project. As discussed in numerous studies, such as Merrow,[2] the sources of project risk and uncertainty can be broadly characterized as:

- The **project type** – for example, a project that is using new technology carries greater design and execution risks than a project to build a facility that contains no new process technology and that uses processes and equipment that are tried and tested.
- The level of completeness of **project front-end definition** – a cost estimator prepares an estimate based on the scope of work documents supplied to him/her. Therefore, any items omitted from that scope of work will not be picked up by the estimator and will remain as potential risks to the project cost outcome. Similarly, any ill-defined items will carry greater risk than clearly defined items.
- Risks arising from the **project environment** – for example, risks from extreme weather or from labor shortages in a remote environment.

Of these three, project type is out of the control of the project team, but the other two are within the control of the project team and are relevant to our current discussion. We shall focus on front-end definition since by doing this correctly, risks arising from the project environment also should be mitigated.

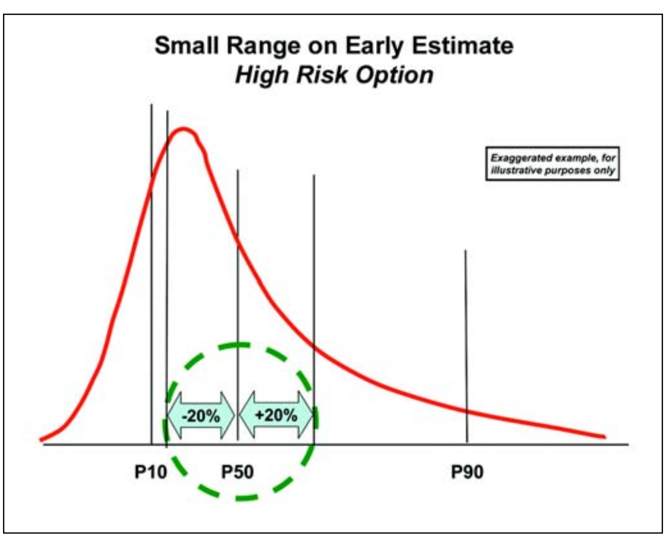

Figure 4. An early estimate with a high risk attempt at a narrow range.

Cost Estimate Classification

If completing more front-end definition can mitigate risk and uncertainty, how much front-end definition is required in order to achieve a cost estimate of a particular accuracy?

The Three Main Estimate Categories

The following will focus on three key estimate accuracy levels:

- Rough, Order of Magnitude (ROM) Estimate
- ±30% Accuracy Estimate
- Control Estimate

Sources of Scope Definition Classification

Several organizations, including the Association for the Advancement of Cost Engineering-International (AACE-I), have produced documents classifying estimate types, and describing in a **qualitative** way, the approximate estimate accuracy level to expect, based on the amount of front-end development of the design package that has been done.[3]

Two **quantitative** methods of measuring the level of front-end definition achieved that are becoming industry standards include the Construction Industry Institute (CII) Project Definition Rating Index (PDRI)[4] and the Independent Project Analysis (IPA) Front-End Loading (FEL) Index.[5] All three sources generally give a similar description of what level of front-end definition is required in order to achieve a cost estimate of a particular level of accuracy.

Level of Front-End Definition Required for a Particular Estimate Accuracy Level

Stochastic or Deterministic?

As a general rule, project estimates develop from very rough estimates that use a "Stochastic" method of calculation (i.e., they are "top-down" estimates, based on rough cost capacity benchmarks – cost per m^2 for a laboratory or cost per ton of production for a bulk chemical plant, etc.) to get an estimate when very little is known about the detail of the project to a "Deterministic" method of calculation when the scope is defined in more detail (i.e., a "bottom-up" estimate, based on material take-offs of estimated material quantities). A useful overview of stochastic versus deterministic estimates is given in Dysert.[6]

Rough Order of Magnitude Estimate

This is a stochastic estimate, typically used when very little is known about the project scope. (Table A provides an example of the level of deliverables required). This Table is adapted from the AACE-I[7a] and Griffith and Yarossi.[7b] Such an estimate uses simple benchmarks, based on historical data. For a (highly simplified) example, *"The last five facilities built had an average cost of $X per 1000 tablets/day of production capacity. Therefore, since our facility will produce 5,000 tablets/day, it will cost in the region of five times $X."*[8]

Assuming a database of benchmarks is available,[9] this type of estimate can be produced very quickly, and with very little expenditure, typically less than 0.5%[10] of the Total Installed Cost (TIC) of the project.[11] However, one can only expect an accuracy of -50 to -100% up to + 50 to +100% with a typical range being in the order of -20 to +50%.

30% Accuracy Estimate

At this stage, one begins to move between the stochastic and the deterministic approach. Such an estimate is very often developed using factors based on one key element of the scope. For example, in a bulk API plant, if the major equipment list is known, one can factor the cost of the entire facility from the equipment cost (a Lang factor approach[12]).

This type of estimate requires more work and would typically cost around 1.5% of the TIC of the project to produce. The level of front-end definition required is reflected in the example deliverables shown in Table A. By the time this amount of scope definition is completed, the project estimate accuracy should be in the region of -20% to + 30% (with the proviso that some projects, with unusual characteristics, may have a wider estimate range).

Control Estimate

For an estimate of this accuracy, one moves to a detailed level of scope definition and a deterministic approach.

At this stage, the major equipment (and possibly the building in a laboratory project or pharmaceutical finishing project) and possibly the detailed engineering office work will be based on firm quotations. Other equipment may be based on budget quotations. Material costs will be based on material take-offs either priced using historical data or via budget quotations.

This type of estimate requires the expenditure of a further 3-5% of TIC, over and above that spent to develop the 30% estimate. As shown in Table A, the level of definition required is quite detailed, but the accuracy achieved can be expected to be in the range of -5% to +15% or better.

How to Balance Effort Against Results

It is now clear that developing greater definition of the project scope during the front-end phase of a project takes time and money. It takes very little effort to produce a rough estimate, but it takes a cumulative expenditure of upward of 4 to 7% of TIC to produce an estimate with an accuracy in the region of -5 to +15% or better.

Problem Number Two – I need a number, but I don't want to waste time and money!

It is clear that we have two opposing concerns:

- On the one hand, management would like as accurate an estimate as possible of what a project idea will cost and how long it will take so that they can decide whether the project is worth pursuing.
- On the other hand, management does not want to waste money on projects that will prove to be not worth pursuing, once the true costs are known.

Management needs a system that balances the advantages of having a more accurate estimate of costs against the disadvantages of having to expend time and effort to achieve that better accuracy on an idea that might then be dropped as being uneconomic.

A Parallel with Drug Discovery

The issue can be viewed in some ways as a parallel with the research function in the pharmaceutical industry. Manage-

	ROM Estimate	30% Estimate	Control Estimate
General Project Data			
Project Scope Description	General	Defined	Defined
Facility Capacity	Assumed	Defined	Defined
Facility Location	General	Specific	Specific
Ground Surveys	None	Defined	Defined
Project Execution Plan	None	Defined	Defined
Contract Strategy	Assumed	Preliminary	Defined
Project Schedule	Rough milestone benchmark	Preliminary	Detailed, resource loaded schedule
Cost Estimating Plan(Code of accounts, escalation philosophy, work breakdown structure)	None	Defined	Defined
Engineering Deliverables			
Block Flow Diagrams	Outline	Complete	Complete
Plot Plans	None	Preliminary	Complete
Process Flow Diagrams	None	Complete	Complete
Utility Flow Diagrams	None	Preliminary	Complete
Piping and Instrumentation Diagrams	None	Preliminary	Complete
Heat and Material Balances	None	Preliminary	Complete
Process Equipment List	None	Preliminary	Complete
Utility Equipment List	None	Preliminary	Complete
Electrical Single Line Diagram	None	Preliminary	Complete
Process Engineers Equipment Datasheets and specifications	None	Preliminary	Complete
Mechanical Engineers equipment datasheets	None	Preliminary	Complete
Equipment General Arrangement	None	Preliminary	Complete

Table A. Outline of deliverables required for a given level of estimate accuracy.

ment receives thousands of "promising" drug ideas. It then wants to know which ones will be successful, but it can't know that without spending at least some money to develop each idea. The trick is to spend the minimum on each idea to get a sufficiently accurate idea of whether it should be abandoned or not.

The Solution

The system that has been worked out over the years across the process industries is a "stage gated approval" system, whereby an investment idea is developed from a ROM estimate through a ±30% estimate to a control estimate. At each stage, the idea goes through a "gate" where it can be challenged and a decision made on whether to proceed further. This system has now been adopted across most of the pharmaceutical, chemical, oil and gas, metallurgical, and many other industries as being "best practice."

The advantages of this system are that not only does it provide the best compromise between expenditure and estimate accuracy that has been found to date; but it also provides a controlling framework to ensure that project teams develop the design in the most cost and schedule efficient way. As discussed earlier in this article, developing a "rough order of magnitude" estimate requires very little capital expenditure; developing a ±30% estimate requires a little more expenditure; and developing a control estimate a little more.

The stage gate process requires a project team to develop the project estimate through each of those three estimate stages, but it also requires the team to pass through an approval gate after each estimate at which management reviews the project and decides whether it is worth expending the next portion of funds to develop the project further. The gates are intended to provide a set of information to allow decisions to be made in alignment with business needs. The objective of the process is to spend the minimum to provide the right level of information to allow a decision to be made on whether to proceed. The process also provides a structured framework for developing a good front-end design package.

The Three Gates

So what are these three phases with gates at the end of them,

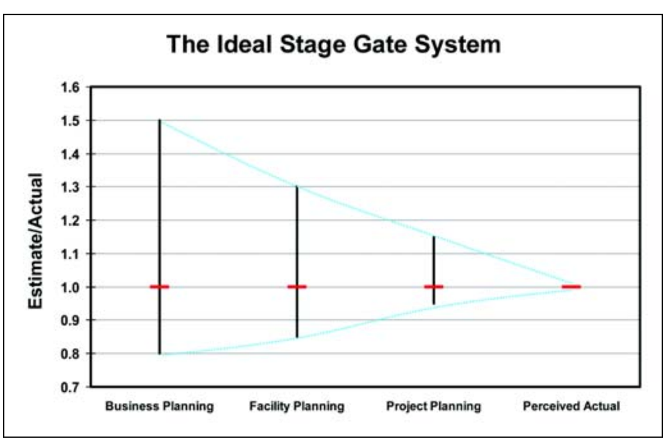

Figure 5. Estimate progression in an idealized stage gate system.

and what are the criteria for passing the gate and moving to the next phase?

Business Planning – Initiation Phase

- **Focus**
  This phase focuses on the development of the idea for the investment. (i.e., is this an idea worth pursuing?)
- **Cost Estimate Accuracy**
  Estimates are developed only to the "rough order of magnitude" level. (±50-100%)
- **Object**
  The object of this phase is to invest the minimum amount necessary to decide whether the business opportunity is a viable idea.
- **Leadership**
  Business representatives usually lead this phase, not project engineering staff (although project engineering staff may provide support).
- **Deliverables**
  The key deliverables of this phase are a clear description of the "business opportunity" and business objectives and a clear list of possible alternatives that will be examined in the next phase.
- **Decision**
  The decision to be made in the gate at the end of this phase is "Is this business idea viable? Do I want to spend money costing it out?"

Facility Planning – Conceptual Design Phase

- **Focus**
  This phase focuses on evaluating the possible alternative project solutions to meet the business objectives. (e.g., do I want process A, process B, or outsourcing? – Do I want to build in the USA, Europe, India, or China? – Do I want to expand plant X or build a new plant at site Y? – etc.)
- **Cost Estimate Accuracy**
  Estimates are developed to the ±20 or 30% level.
- **Object**
  The object of this phase is to invest the minimum amount necessary to decide which SINGLE option gives the best fit with the business objectives and then whether the business opportunity is still a viable idea.
- **Leadership**
  In this phase, project engineering staff typically take over control from the business representatives, as the work to develop conceptual design studies becomes more technical.
- **Deliverables**
  The key deliverables of this phase are a clear differentiation between options in order that one option can be chosen, and a ±30% estimate of that option.
- **Decision**
  The decision to be made in the gate at the end of this phase is three-fold "Are we agreed on a single option? – Does this option still meet the business objectives – Is the business idea still sufficiently viable that I want to spend money to go to the next stage?"

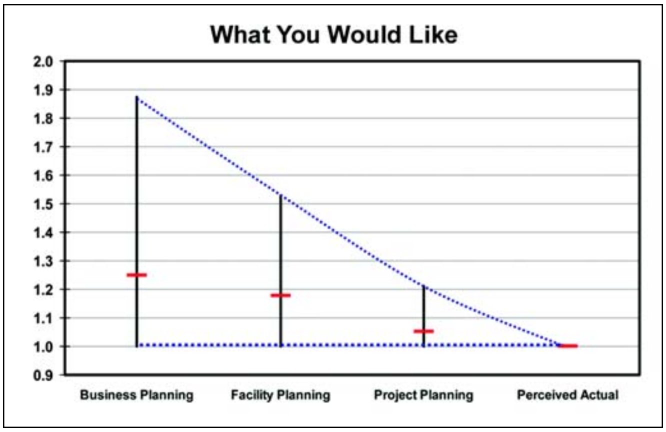

Figure 6. An optimistic view of estimate progression.

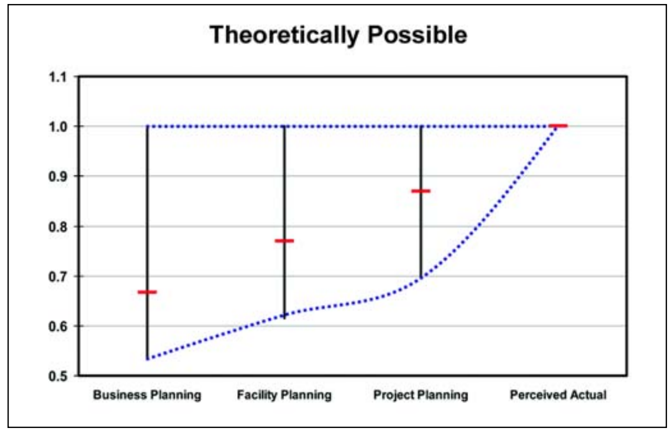

Figure 7. A pessimistic view of estimate progression.

Project Planning – Basic Design Phase

- **Focus**
  This phase focuses on developing a control estimate of the chosen option.
- **Cost Estimate Accuracy**
  Estimates are developed to the ±5 to 15% level.
- **Object**
  The object of this phase is to invest the minimum amount necessary to develop a control estimate of the chosen option and to check that the business opportunity is still a viable idea.
- **Leadership**
  In this phase, project engineering staff control the development of the basic design.
- **Deliverables**
  The key deliverables of this phase are a control budget, coupled with an estimate of an accuracy in the region of -5+15% or better.
- **Decision**
  The decision to be made in the gate at the end of this phase is "Do we want to build this?" (i.e., does the business case still make sense?)

The Advantages of a Stage Gated Approach

The advantages of this system are that it allows controlled expenditure of funds up to a maximum of only around 4-7% of TIC, while gradually improving the level of knowledge about the likely final cost; and within the system, management receives three clear opportunities to review whether it wishes to proceed or not.

The Role of the Gatekeeper

For such a gate system to work, it is vital that no project is allowed to pass through a gate until it has fulfilled all the necessary criteria. Therefore, a gatekeeper either needs a good knowledge of the scope definition criteria for a ROM estimate, a ±30% estimate and a control estimate; or he/she needs a proxy way of measuring the scope definition.[13]

In addition, it is important to recognize that as well as not allowing a project to pass through a gate until it is ready, the gatekeeper has a duty to stop any project that no longer meets the business criteria. This "stop" decision should not be viewed as a failure. Rather it should be viewed as the gate process doing its job – that is, encouraging business ideas, but canceling those that prove not to be viable.

Fast Track Projects and the Use of Stage Gates

A common complaint about stage gated systems is that they appear to be just extra bureaucracy; therefore, hindering the achievement of fast projects. However, this assertion can be challenged.

Several studies have shown that a pharmaceutical industry project using best practices (i.e., following a rigorous stage gate process to develop a good front-end package) compared to a pharmaceutical industry project using poor practices (i.e., bypassing the rigorous process) achieves an execution schedule[14] advantage. Two examples drawn on for this discussion are Merrow[15a] and Lawrence.[15b]

The question then becomes: Does that advantage during execution outweigh any perceived additional time needed during the front-end phase?

The studies show that projects performing with very good front-end definition by following a rigorous stage gated process achieve an execution schedule advantage of anything up to 32% over the industry typical project and up to 43% over those projects that do not achieve a good level of front-end definition.

Therefore, a strong case can be made that any extra time spent in developing a good front-end package would be more than recovered during execution ("more haste, less speed"). In addition, an argument can be made that if proper planning is performed there is no reason why preparing a good front-end package should take much longer than inefficiently preparing a weak front-end package.

High Risk Methods of Fast Tracking Projects

There are other methods that can be used to fast track projects. However, since they carry risks and costs, they should only be considered if after implementing a strong stage gate process and achieving best practical front-end definition, further acceleration is seen to be required. If they are used, it should be on the understanding that they come with risks and costs attached. Examples of such methods are discussed below.

Early Ordering of Long Lead Items

Many firms order long lead equipment during Basic Design with the proviso that if the project does not go ahead, the equipment will be cancelled. This carries some risks, depending on how early in Basic Design one orders the equipment – the wrong equipment specification may be given or even the wrong item may be ordered. The risk is slightly less for a Bulk API facility than for a pharmaceutical facility or for a facility in other process industries because much of the large equipment is of very standard designs.

Starting Construction Early

Starting construction early carries a risk of inefficient working. The construction team may outstrip the supply of engineering drawings or the supply of material, or they may have built an item that then undergoes a late change. All of these risks will have a cost effect and also may have a schedule effect, thus negating the very purpose of starting construction early.

Use of Overtime and Shift Work

The use of overtime and shift work is a highly expensive and generally inefficient way to try to accelerate a project. If used too early in construction, these methods can result in the same problems as starting construction early. Overtime work is paid at a premium rate. In addition, several studies have shown that although paid at a higher rate, the productivity of the workers is less, their susceptibility to accidents increases, and if it continues for more than a couple of months, overtime can actually cause a project to take more time, not less. The most famous study is probably the 1974 Business Round Table Report.[16a] Other examples include Hanna[16b] and also CII Report SD-98.[16c]

Some Points to Ponder

The previous sections have explained why the project department will quote an estimate as a range, how the range can be reduced, and how to develop a good, control estimate in a controlled manner.

However, what if you insist on a greater level of accuracy than the level of front-end development can justify, and/or you take an overly optimistic or aggressive view of early estimates. These points are discussed below.

Asking for Greater Accuracy than the Scope Can Justify

One situation that may arise is when a team is asked to provide a cost estimate to a high degree of accuracy, but is not given the time or resources to develop an estimate to that level of accuracy. Thus, we have an estimate range that may look like that in Figure 2. But the team is asked to present the estimate as being of greater accuracy. The team has effectively two choices if it is to comply. It can take the lower risk option, as shown in Figure 3. But in doing this, the team is offering a price that is above the 50/50 point and hence is headed toward achieving predictability at the expense of competitiveness. Alternatively, it can take a high-risk option, as shown in Figure 4. In that case, the probability of having an unpredictable, cost overrun outcome is greatly increased.

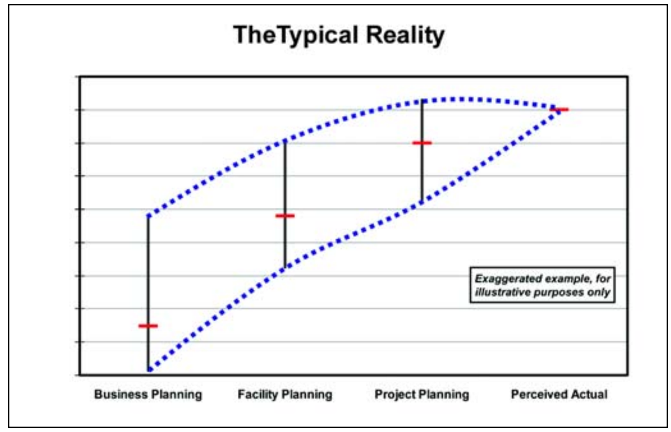

Figure 8. The reality of estimate progression.

Optimism Skews Cost Estimate Progression

In developing a gradually improving level of accuracy of a project cost, the ideal and the common perception is that the 50/50 point will stay the same, as the accuracy improves, as shown in Figure 5. Many people may even take an optimistic outlook and choose to perceive the likely outcome as being gradually converging on the bottom end of the estimate range, as shown in Figure 6. People also tend to forget that theoretically, the cost could converge on the top end of the range, as shown in Figure 7.

In fact, numerous studies have shown that, human nature being what it is, what typically happens is that projects are underestimated in the early stages and reality looks like the example in Figure 8. Some of those studies, such as Merrow,[17] attribute this to wishful thinking on the part of the project sponsors in the early phases, or to weak front-end development, thus failing to recognize the full potential costs. Others have studied the phenomenon and see it as a deliberate political act by the business sponsors and project champions, designed to increase the probability that a project is approved.[18]

Conclusions

This article has shown why estimates are quoted as ranges and how to reduce those ranges, improving estimate accuracy. The article also has shown that the level of accuracy achieved is a function of the time and effort spent on developing the front-end package. Furthermore, the article outlined a stage-gated process, giving an efficient way to balance the need for greater estimate accuracy against the desire not to waste money on projects that may not get authorized. The discussion also demonstrated that following a stage gated approach can help, not hinder a fast track project. Finally, an indication has been given that taking an optimistic view of early estimates is usually a mistake.

In summary, the advice for finance managers, business sponsors, project champions, and end users is:

- understand what level of front-end development is required for a given accuracy level
- expect to have to spend in the region of 6% of TIC if you want a good control estimate of what the project will cost
- follow a rigorous stage gated process, even if you're in a hurry; it will give you a faster project in the end
- Remember that historical evidence shows that optimism about the final cost, based on early estimates, is usually misplaced.

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2. Merrow, E.W. and Yarossi, M.E., Assessing Project Cost and Schedule Risk. *Association for the Advancement of Cost Engineering (AACE) Transactions*, Boston Massachusetts, USA H.6.1. (1990).
3. *AACE-I Recommended Practice No. 18R-97* (2005) Cost Estimate Classification System – As Applied in Engineering, Procurement, and Construction for the Process Industries.
4. The Project Definition Rating Index (PDRI) is a weighted checklist of project scope definition elements developed by the Construction Industry Institute (CII). It is a self-assessment tool, designed to facilitate assessment of a project during pre-project planning. Two different versions of the tool exist - one for industrial (process) facilities and one for building facilities. See the Web site http://www.construction-institute.org/pdri/pdri-is.cfm for more information.
5. The Front-End Loading (FEL) Index is a weighted checklist of project scope definition and project planning elements developed by Independent Project Analysis (IPA). It is an independent assessment tool, designed to facilitate assessment of a project during pre-project planning. Several different versions of the tool exist – including versions for different types of industrial (process) facilities, offshore oil and gas exploration, and production facilities, buildings and laboratories, pipeline projects, and Information Technology (IT) projects. See the Web site http://www.ipaglobal.com/index.asp for more information.
6. Dysert, Larry R.; Sharpen Your Cost Estimating Skills, *Chemical Engineering*, Vol. 108, No. 11, Oct 2001 – reprinted in *Cost Engineering*, Vol. 45, No. 6, June 2003.

7a. *AACE-I Recommended Practice No. 18R-97* (2005) Cost Estimate Classification System – As Applied in Engineering, Procurement, and Construction for the Process Industries (estimate classifications 5, 3, and 2).

7b. Griffith, Andrew F. and Yarossi, Mary-Ellen; Stage Gated Process for Project Definition of Capital Projects; *19th IPMA World Congress*, New Delhi, India 13-16 November 2005.

8. This example is highly simplified. In fact, the relationship is rarely linear, a fact first discussed by Williams and particularly Chilton in the late 1940s and early 1950s. The relationship of cost to capacity usually has a capacity ratio exponent in the range of 0.5 to 0.85 and the methodology is often referred to as the "six tenths rule" in recognition of the fact that 0.6 is the typical exponent value. An example would be (cost of new facility/cost of old facility)=(capacity of new facility/capacity of old facility)$^{0.6}$.
9. Sources of cost benchmarks and cost ratios include the CII (through their pharmaceutical benchmarking forum), IPA (through the pharmaceutical section of their cost engineering committee), Compass directories, Richardsons Means publications, and many others.
10. This and the percentage expenditures given for the other two estimate types are taken from - Griffith, Andrew F. and Yarossi, Mary-Ellen; Stage Gated Process for Project Definition of Capital Projects; *19th IPMA World Congress*, New Delhi, India 13-16 November 2005 – However, similar benchmark values are very common and can be found in numerous other publications.
11. Total Installed Cost (TIC) includes Conceptual Design, Basic Design, Detailed Engineering, Procurement, and Construction up to mechanical completion. It does not include Initiation, Commissioning, IQ, OQ, or PQ.
12. Lang factors (ratios of total project cost to the cost of the major equipment) were first proposed by H.J. Lang in 1947. They have subsequently been updated by others, such as Chilton in the 1950's and Guthrie in the late 1960s and early 1970s. They have since been widely adopted as a common stochastic estimating method across the process industries.
13. One solution used by some process industry firms is to use the PDRI or FEL quantitative measures as a proxy check on whether a project is sufficiently well defined.
14. Execution phase – the phase from end of Basic Design up to mechanical completion.

15. a.Merrow, E.W., It's time for Capital Excellence in Pharma Projects, presented at *The Pharma Summit on Aseptic Technologies*, June 1-3 2005, Cork, Ireland.

15. b.Lawrence, G.R., Achieving Faster Project Delivery – More Haste, Less Speed. *Pharmaceutical Engineering*, May/June 2006, Vol. 26 No. 3.

16. a.The 1974 Business Roundtable report, revised in 1980: "Scheduled Overtime Effect on Construction Projects – A Construction Industry Cost Effectiveness Task Force Report" – Report C-2, November 1980, pub. *The Business Roundtable.*

16. b.Hanna, A.S., Taylor, C.S., and Sullivan, K.T., "Impact of Extended Overtime on Construction Labor Productivity," *Journal of Construction Engineering and Management*, Volume 131, Issue 6, pp. 734-739 (June 2005).

16. c."Effects of Scheduled Overtime on Labor Productivity: A Quantitative Analysis" – Report SD-98, pub. *Construc-*

tion Industry Institute.

17. Merrow, E.W., Phillips, K.E., and Myers, C.; "Understanding Cost Growth and Performance Shortfalls in Pioneer Process Plants," pub. *Rand Corp*., 1981.
18. Flyvbjerg, Bent, and Bruzelius, Nils and Rothengatter, Werner; Megaprojects and Risk: An Anatomy of Ambition*; Cambridge University Press*, 2003.

About the Author

Gordon Lawrence has more than 20 years of experience in project management, having worked for several pharmaceutical owner firms, as well as Jacobs Engineering, the international contractor, and Independent Project Analysis, one of the leading management consultancies in the field of project management best practice. He currently works as a Senior Project Manager for a major pharmaceutical firm and is based in Basel, Switzerland. Lawrence has a degree in chemical engineering and advanced degrees in biochemical engineering and business administration. He is a chartered engineer, registered in the United Kingdom and Europe. He is a fellow of the UK Institution of Chemical Engineers, a member of the American Institute of Chemical Engineers, a member of the Project Management Institute, and a member of the Association for the Advancement of Cost Engineering – International. He is a member of the ISPE French Affiliate, a member of the Project Management Community of Practice, and is Vice-Chair of the ISPE Membership Services Committee. He can be contacted by telephone at +41-79-618-7391 or by e-mail at gordon_r_lawrence@hotmail.com.