The Amoebic Growth of Project Costs

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ABSTRACT

In the public arena, we often hear about projects that have suffered massive cost overruns. Often they are related to large public construction projects such as airports, bridges, or public buildings. Large overruns also exist in private industry. However, often these do not appear in the newspapers, so the public is not as aware of them. Of course, not all projects go badly wrong, but quite a few do, and frequently we find ourselves uncertain of the causes for such overruns. In this paper, industrial projects that overrun and overrun in a surprising manner are considered. In other words, the paper considers those many projects where the extent of the overrun is well beyond what might ever have been anticipated, even though what was going wrong within the projects was, for the most part, understood.

The basis for the content of the paper (that is, the structure and lessons), are drawn from a *postmortem* analysis of many large projects as part of claims analysis, particularly "delay and disruption" claims for projects whose total spend appeared at first look inexplicable or surprising. The aim of the paper is to contribute to an understanding of how projects go badly wrong, when they do, and in particular to draw some lessons from this exploration which are likely to help all managers. The reasons for cost escalation are not just the responsibility of project managers.

KEYWORDS: disruption and delay, project costs, complex projects

The Amoebic Growth of Project Costs

In the public arena, we hear about projects that have suffered massive cost overruns. Often, they are related to large public construction projects, such as airports, bridges, and public buildings. Some poignant examples include Denver's $5 billion airport that was 200% overspent (Szyliowicz & Goetz, 1995), the DKK $800 million Oresund bridge that was 68% overspent, (Flyvberg, Bruzelius, & Rothengatter, 2003), and the UK's Scottish Parliament, which is expected to be 10 times the original budget (Scottish Parliament, 2003). The Major Projects Association (1994) talks of "the calamitous history of previous cost overruns of very large projects in the public sector."

Large overruns also exist in private industry, although often the public is not as aware of them. Morris and Hough (1987), list 33 databases of project outcomes, concluding "the track record of projects is fundamentally poor, particularly for the larger and more difficult ones.… Projects are often completed late or over budget, do not perform in the way expected, involve severe strain on participating institutions or are cancelled prior to their completion after the expenditure of considerable sums of money." More recent studies have reached similar conclusions For example, Flyvberg, Holm, and Buhl, (2002) describe 258 major transportation infrastructure projects showing 90% of projects overspent.

This paper considers projects where the extent of the overrun is well beyond what might have ever been anticipated, even though what was going wrong within the projects was generally understood. The aim of the paper is to contribute to an understanding of how projects go badly wrong, when they do, and in particular to draw some lessons from this exploration.

The structure and lessons are drawn from the authors' postmortem in-depth analysis of many large projects as part of claims analysis, particularly "delay and Disruption" claims for projects whose total expenditures appeared at first inexplicable or surprising alongside the authors' involvement in risk analysis of major projects.

The paper addresses "projects" as defined by the Project Management Institute: "a temporary endeavor undertaken to create a unique product or service" (Project Management Institute, 2000). Projects are a unique undertaking, which implies that they are "one-shot," non-repetitive, time-limited, bring about revolutionary (rather than evolutionary) improvements, start (to some extent) without precedent, and are risky. In our definition of projects, if physical products are being produced, then the product is in some way significantly new, or there exists so many differences between this and previous occasions of manufacturing (for example, in its engineering principles, or the expected operating conditions of the product, etc) that there is a need to take a project orientation.

We are particularly interested in "complex" projects, ones in which project outcomes are difficult to predict, and even difficult to explain post-hoc. We also presume that there is a customer and a contractor, there is a bidding process, and the project has a clear beginning and an end—that is, when the customer (internal or external) signs off a contract. Finally, we are not looking at the whole project business life cycle, but that part where major cost overruns occur: thus, we will start our consideration when a bid is to be prepared, consider development and manufacturing or construction, but then stop when the product of the project is handed over to the customer.

Illustrating the Growth in Projects

The primary way in which the nature of project overexpenditures is explored is through a series of figures. These figures demonstrate in a graphical manner that the growth in cost is “amoebic” in nature. In other words, at the end of a project, it is not easy to pin down what drove the total cost overrun—it tends to have spread in an amoebic manner.

Developing this graphical representation starts with the notion that a well-behaved “tidy” project is a circle. In this circle, each of the radii reflects the cost of a different aspect or arena of the project in some sense. This represents graphically the idea that there are different aspects, dimensions or arenas of the project that need to be considered, and that the diagram’s radii are essentially representations of those costs, with the area bounded by the circle representing the total cost. This use of radii is for the purposes of illustration and should not be treated as indicative of a formal or precise decomposition or division of the project. Also, for the sake of discussion, it is assumed that “cost” is measured in labor-hours. Generally, labor costs overrun significantly more than can satisfactorily or easily be explained. Non-labor costs can more usually be tied to specific causes.

As will be explained, the radii at different parts of the circle will grow and grow until the original circle begins to look like an amoeba. It is what happens when the cost of the different arenas grow (and why they grow) that is the focus of attention. The discussion, illustrations, and figures seek to explain "why project costs escalate in an exponential manner, and in ways that seem surprising." This runs contrary to the general assumptions of linearity in project cost build-ups, as demonstrated in C/SCSC (United States Department of Energy, 1992) and, similarly, in its replacement Earned Value methodology (United States Department of Defense, 1996). In addition, it runs contrary to the assumptions of additivity underlying much project risk work. This paper will explore the reasons behind this.

The paper is structured by discussing stages of the project expenditures, from the first estimate to the final total. These stages are:

- Estimating for the bid
- The planning or "control" estimate
- Unexpected growth: external changes
- Growing further: "naughty customer, silly contractor"
- Customer behavior: dealing with interference beyond what's anticipated
- Systemicity: how it all links together
- Accelerating to compensate.

As each "stage" is reviewed, it will comprise a textual description of the stage, figures that ultimately reflect the amoebic growth of the project, a case study taken from the authors' experience of analyzing real projects, and lessons for management.

Estimating for the Bid

Description

Before a bid has been submitted, estimators come together to try and get a sense of what is involved and, therefore, how much the project is going to cost. This stage seems so obvious, and has been discussed many times before, that it hardly seems to warrant another presentation. However, as the surprising growth in costs that unfolds later in the project is discussed, it will become clear that the implications of this stage can impact cost escalation in a significant and unexpected manner. Consider Figure 1.

Figure 1: Estimators' estimate for bid (ABOUT HERE)

Even when a manager asks an estimating team to estimate a familiar project, it is implicitly appreciated that there is some degree of uncertainty about the likely cost involved—which may be quite a high degree of uncertainty at this stage. Most often, estimators are not explicitly asked to express that uncertainty, although they will informally tend to express it amongst themselves. Sometimes, estimators will give some sort of judgment of what the possible or probable maximum costs might be for a specific arena. As the "maximum" could be very large, often estimators are expected to express this as a "surprise limit" to indicate the level above which the estimator thinks it is very unlikely to go. Likewise they can indicate the minimum cost that an arena is likely to be. Thus, in the figure, there is an expected cost, a virtually certain minimum cost, and a probable maximum cost for each arena.

A careful inspection of the way in which the circles (representing the estimation) have been drawn shows that the centers of the circles are not quite matching. This is to reflect the fact that the uncertainty is likely to be more or less depending on what part of what arena is being considered.

There is an uncertainty in both directions. Estimators are more likely to be certain about what the minimum might be on the basis of experience, so they can usually pin this down much more accurately in their mind than they can the maximum cost. The bold dashed, dotted line in Figure 1 is referred to as an expected total cost—that is, what it is expected to be, or the estimators' best estimate at this stage.

In principle, if three different arenas (or different parts) of the project are considered—call them "A," "B" and "C"—they will have different levels of uncertainties. So, the arrow marked "A" in Figure 2 is a double-headed arrow reflecting the extent of uncertainty around that part of the project (and similarly for "B" and "C"). They give a sense of the extent of the uncertainty at this state of the project. It is usually presumed that the uncertainty at this stage is likely to be much higher than it is ever going to be later in the project, as knowledge is much lower.

Figure 2: Estimators' estimate for bid showing extent of uncertainty for different aspects

(ABOUT HERE)

At this point, the bid for the project is submitted.

Case Study: From an aerospace project

For manufacturing projects, a key element of the estimate is the anticipated learning from one unit to the next—the “learning curve.” Two important factors usually influence learning: the anticipated rate of learning and the time required to produce either the first unit or a unit when the time to build is expected to stabilize. In this illustrative case, the estimate of both these factors was particularly problematic, due to two circumstances. First, similar units had been made several years earlier to almost the same specification, and it was expected that some learning would be transferred to this new project—but how much? Second, the units were to be manufactured by a subcontractor in a different country (as demanded by the customer to boost the local economy), so it was difficult to know the nature of the labor force or the manufacturing plant.

After considerable debate, the estimating team decided to assume that transferred learning would mean that the time taken for stabilization would be significantly less than for a new project—50 units rather than the usual 100 units. They also reckoned they could estimate with reasonable accuracy the time it would take to manufacture the first 50 units. In addition, they expected the rate of learning would be fast, because supervision by the main contractor would mean learning could be transferred.

During these debates, there were many different views about the figures that should be used for each of the above estimating parameters. In the end, the manufacturing vice-president imposed a sort of consensus.

Small variations in each of the figures created significant variation in the predicted total labor hours. Under pressure to agree an estimate, no calculations were undertaken to express the extent of uncertainty reflected in the debates. The contractor won the contract at a price of $72 million.

Later in the project, and as costs were soaring against estimate, the notes from the estimating debates were used to calculate the level of uncertainty in the estimates of learning. These revealed "surprise limits" of +70% and –40%. The outcome was 58% above estimate.

The organization, although a multinational manufacturing organization with considerable project experience, had no history of explicitly recognizing uncertainty in their bid estimates.

Lessons

The main lesson to be drawn from the preceding example is that when projects are being estimated, it is important to acknowledge uncertainty from the outset. A first step in reducing cost overrun is to acknowledge that a substantial risk for overrun exists and cannot be completely eliminated, but it can be moderated (Flyvberg et al., 2003). If the uncertainty is not acknowledged, the risk cannot be analyzed and managed. The reality can sometimes mean that uncertainty is so high that it discourages an organization from bidding for contracts, in which case they would go out of business!

So why do experienced organizations not do this? They are worried that acknowledging uncertainty will make bids less aggressive than they need to be to win contracts, and that their staff will be complacent about continuous improvement and innovation. These are sensible concerns, but trying to pin down uncertainty is about managing uncertainty out, rather than simply acknowledging it. Also, there are minimum costs as well as maximum costs, so there is a need to recognize and capitalize upon the upside risks, as well as the downside risks (Hillson, 2003).

The Planning or "Control" Estimate

Description

Let us assume that the bidding organization has been able to manage the uncertainty well enough to be satisfied with its bid, and has put in the bid, and been awarded the contract.

The extent of uncertainty is likely to have been reduced from what it was at the bid stage. There will be a clearer view of what is involved in the project, more information will have been gained, some uncertainties will have been managed out, and other uncertainties will have disappeared because there is now accurate information available. However, while new knowledge or research to manage the uncertainty may reduce it in some arenas of the project, it may not in others, giving rise to further uncertainty.

Management at this stage has to give the project a clear planning estimate. That estimate could be less than the original expected costs, particularly if the organization has been very effective in managing uncertainty. However, in practice, this tends to not be the case, and projects usually end up with a planning estimate a little higher than the original expected total costs. This planning estimate is given an official status as a baseline for the project and usually has some title such as “control estimate.” Conventional project management practice, as espoused in the *PMBOK® Guide* (Project Management Institute, 2000) puts heavy emphasis on maintaining the baseline control estimate, with strong encouragement to check on variances, and manage the project back to the plan. Some, such as Koskela and Howell (2002) say too heavy an emphasis.

Figure 3: Planning estimate—post-contract award (ABOUT HERE)

Figure 3 illustrates the planning, or control, estimate. Again, “A,” “B” and “C” symbolically represent different arenas of risk of the project, where different uncertainties pertain. The area contained by the bold solid line represents the expected total cost in hours of labor, including the contingency (hence, the solid circle is bigger than the dashed circle). Some of this contingency may be retained as project manager’s contingency rather than allocated to particular project arenas.

It may be important to acknowledge that there might be different contingencies required for different arenas of the project. However, establishing a range of contingencies can require a considerable of the amount of work by estimators. Typically estimators simply add on (say) 10% contingency across the board in order to acknowledge that it is very difficult to pin down uncertainty with respect to any specific arena. In Figure 3, variable contingencies are shown.

The organization might have decided to put in a bid that is actually less than the expected cost of the project. This might be for strategic reasons because it wants to enter a new market. With this strategic aim, the organization acknowledges that it needs to write off part of the cost for strategic development. This does not change the expected cost of the contract, although setting targets does influence the performance of a workforce (Parkinson, 1957).

Figure 4 depicts the bid estimate (shown in Figure 2) grayed out, with the planning estimate, post-contract award (shown in Figure 3), superimposed. It can be seen that the extent of uncertainty has changed, and now the estimate also includes contingency.

Figure 4: Comparison of bid estimate and planning estimate (ABOUT HERE)

Figure 5 shows the ideal circumstance of uncertainty, where everything is known about the project, leaving only random events. That is, knowing what each of the different tasks involved in the project requires, as well as individual work rates and structured tasks, still leaves some variability in actual turnout. Figure 5 would represent a planning estimate in an ideal situation where all “epistemic” (lack of knowledge) uncertainty has been resolved with only “aleatoric” (probabilistic) uncertainty remaining (Oakes, 1986).

Figure 5: Ideal pre-project estimate—planning estimate remains the same (ABOUT HERE)

Case Study: Ensuring the train arrives on time! Resolving some of the uncertainty

Having successfully won the contract to build the rolling stock for an airport transport system (moving passengers both between terminals and to major connecting points to the city), the contractor began the process of reviewing their bid estimate. The customer had just provided details regarding forecast airline flight schedules (which had to be met), along with further specifics on other service requirements—for example: accurate station stopping, extremely flexible operating modes, etc. While some of this information had been available in the invitation to tender, it had been fairly superficial—more details were now forthcoming that needed to be taken account of in the planning estimate. A review of the original budget was conducted, and reallocation (particularly from the contingency fund) was undertaken. In addition to this information, feedback from earlier inquiries to the customer had just been received—suggesting that certain areas of the project might prove more problematic than anticipated. However, to counteract this news, there was information gained from surveys that had been carried out amongst those living beside a major expressway, along which the transport system would run. When putting the estimate together, the contractor had built in a significant allocation for managing the noise and disruption effects; it now appeared that some of this money might be freed up, if necessary, to deal with the other issues. Some careful reallocation would be necessary.

Ensuring that the project (and the transport system) followed the project plan

The project manager, who had taken over responsibility from the bid team, began examining each specific work area (for example structural design of the carriages, electro-magnification of the power system, wiring, etc.). Along with the different discipline heads, she reviewed what needed to be done—breaking the tasks down to a greater level of detail so as to be able to manage responsibilities, and taking into account the new information received. This review, put into the form of a computer-based schedule, would allow them to keep track of progress (both in terms of timing and hours) and meet the contractual deadlines. In addition, the schedule would monitor potentially critical points, for example, ensuring that the construction partners were also on time (both were responsible for the incurrence of liquidated damages).

Managing remaining uncertainties

The final part of completing the planning estimate concentrated on the areas where there were unresolved uncertainties. Actions were identified as means for reducing the uncertainty—for example, as the train was to use new power technology, they needed to learn as much as possible from a similar project carried out 12 months earlier. Also, they had become aware of the customer's use of consultants to advise them about contractor design proposals, so mechanisms were put in place to continue to "monitor" the customer's use of consultants.

Lessons: Underestimating at the planning stage is one of most common triggers for cost escalation

It is important to establish a realistic baseline for the project (in cost and schedule) as part of the project plan. The organization should clearly acknowledge at this stage the difference between the role that a project manager has in managing a project with respect to original expected costs, as compared with any commercial consideration that was made in bidding for the contract. It is common for commercial considerations to lead to "doctoring" of the estimate in order to drive estimated costs down—particularly where there are strategic reasons for wanting to win that particular bid. Later, at the planning stage, this "doctoring" is forgotten and unrealistic plans are made. As the project unfolds, this lack of realism is very likely to play one of the most significant and unattributed roles in increased costs. Underestimating at the planning stage is one of the most common triggers for cost escalation, as we see later.

Consider whether it may be important to acknowledge that there might be different contingencies required for different arenas of the project and that these might change differently as the project develops.

Recognize the difference between planning estimates and control figures released as targets.

Where we end up…before we work out "why"

Having explored the process of bid-estimating and planning the project, the discussion now moves on to consider the final outcome, before considering what occurs as an estimate unfolds into the completed project.

Figure 6 shows the nature of projects' growth—even taking into account maximum uncertainty limits. While the dashed dotted line is still there (the probable maximum cost in hours), the "amoebic" outline-type cost of the actual outcome is shown. In the three example project arenas "A," "B" and "C," all have exceeded that which was expected, and there are different excesses: the excess of "C" is considerably larger than those of "A" or "B." In the next five sections, the discussion seeks to unravel what caused the total cost overrun and why it results in the amoeba shape.

While the next sections imply “stages,” this is not, in fact, an orderly progression—the stages do not happen chronologically, but, rather, the influencing factors appear at different points of time, impact upon one another over time, and repeat themselves. Nevertheless, in order to demonstrate the influences and factors that contribute towards project cost overruns, they are broken here into sections and dealt with step by step. Thus, the stages refer to stages of analysis rather than chronology.

Figure 6: Post hoc—what actually happened: “amoebic growth…” (ABOUT HERE)

In Figures 5 and 6, the bold solid line represents the planning or “control” estimate—the planned total cost in hours including contingency. This solid line is an ideal, a “hoped for” outcome. In this scenario, there are no customer disruptions beyond what could be reasonably expected, and the product and project remain within the bounds of expectations. However, there is still, in practice, a mix of some bad and good luck. Where there is good luck, the project costs will be under those anticipated. In Figure 7, the actual costs in arenas “A” and “B” are under, whereas in arena “C” the actual cost is over (but not far off from that expected). Figure 7 reflects the actual work assuming nothing untoward happens. It suggests that the project is within the bounds of expectations, the estimating is not that far out, and while some arenas’ contingency are exceeded, that of others is freed up so that there is an expectation that the overall contingency is not used.

Figure 7: Actual cost build-up (post-hoc view): Stage 1 (based on Figure 5) (ABOUT HERE)

Overall, it is rare for a project not to experience some problems.

Unexpected Growth: External Changes

First, consider the impact of external risks—these might be classified as *force majeure* in a contract. These are where the extent of uncertainty can be greatest. For example, as a result of changing safety regulations due to new legislation, the product is now required to be different from what was originally conceived, as in the nuclear industry (Morris & Hough, 1987; Kharbanda & Pinto, 1996). The actual cost of the project has now changed because the product has changed (in this example, in order to meet the new safety requirements).

Had it been known that the product was going to be different at the beginning of the process (at the bid stage) then, in turn, the original planning estimate would have been different. Bidding would have been for a different (and possibly larger) job!

Figure 8 shows that while "B" is still less than the contingency, "C" and "A" are now exceeding the contingency. Therefore, we might now presume that a substantial amount of the changes of the product are around arenas "A" and "C." However, at this stage, no account is taken of the additional impact of these changes because they occurred after the project had started (which is likely to have a number of consequential effects). This particular consideration is addressed later in this paper.

Figure 8: Actual cost build-up (post-hoc view): Stage 2 (ABOUT HERE)

Case Study: Channel Tunnel—How safe is our estimate?!

Approximately six months into the project, designing and constructing a transport system for conveying passengers in their cars through the Channel Tunnel, two major transport disasters occurred (the sinking of a ferry and a fire in a London subway). In both cases, there was significant loss of life; as a result of various inquiries into the causes of the disaster, new legislation was introduced to prevent such circumstances from reoccurring. The project was expected to adhere to these requirements and appropriate safety certifications would be needed.

A review exploring the impact of these new safety requirements on the project revealed that both engineering and manufacturing would be affected. For example, a more sophisticated fire and smoke detection facility had to be introduced. This had an impact on the wiring and ducting arenas. In addition, improvements to the door systems (to ensure better sealing against smoke) had to be designed. All of these requirements absorbed extra design and manufacturing hours, particularly since a number of the proposed design options posed complicated fitting procedures.

Had the safety requirements been known in advance, the organization would have been able to consider what this new product would cost and provide an appropriate estimate. However, as they were already into the project and had carried out most of the design work, the changes not only increased the amount of hours required, but also impacted the design schedule as designs were revisited. As designs were revisited, they impacted other designs.

Lessons

Estimating the labor cost of changes to a product once the project is into execution is a difficult task. New requirements imposed by external risks are very likely to have impacts on the product and reveal changes to particular arenas (see Figure 8), particularly in relation to contingencies required. Estimating is difficult partly because the estimating team (who originally assessed the potential costs) usually are no longer with the project or engrossed in it. Under these circumstances, the project manager often is forced to consider the impact without use of the estimating team's prior knowledge. Providing processes for using expertise from the original estimating team late in the project is useful.

The contingency applied to the estimates for additional work, both the cost in work-hours and impact on the schedule, will need to be considerably greater than that used for the planning estimate. When it is agreed that the customer should pay for the extra work, negotiating a realistic, but large, contingency is very difficult. Contractors typically lose. Negotiating the contract to permit different estimating procedures for change orders will assist with this process.

Growing Further: The Impact of the "Naughty Customer and Silly Contractor"

Many of the changes that occur in a project are not due to unanticipated, force majeure circumstances. Consider where one or both of the main parties (customer and contractor) cause changes to the product, and thus to the project.

Our analysis of many projects has identified that a significant part of cost overruns occurs when the contract has changed because there have been what might be called "giveaways." Giveaways occur when the contractor or customer engineers find a new and exciting engineering solution. The engineers believe that a better product will be produced as a result. Often, there are assertions that this new way of doing things will also turn out to be cheaper to build.

But, what happens in practice? Frequently, changes are not properly recorded, and responsibility for the cost of those changes is not recorded either. The changes are "state of the art," and although they are sometimes excellent solutions, they can turn out to be both expensive and disruptive, by diverting the attention of key engineers from their routine concerns. Responsibility for the extra costs is disputed and often results in the contractor having to give away the extra work. In Figure 9 arena "A" has suffered from giveaways and the cost has increased.

Figure 9: Actual cost build-up (post-hoc view): Stage 3 with contractor/customer-induced changes to the product (ABOUT HERE)

Another similar trigger occurs when the contractor and customer have different interpretations of the contract requirements. So, when the contract calls for a door to open and let out 50 passengers in 20 minutes, and the contractor designs it accordingly, the customer might insist on this being so for larger, slower passengers than assumed by the contractor's design considerations. This effect is often known as "preferential engineering". Another example is given in the case study below.

In Figure 9, arena “D” (a further arena) can be seen to have had such changes and the cost has increased. Here, there have been contractor and/or customer-induced changes to the product, so that the product is more than was originally conceived, perhaps because of lack of “commercial and technical fit” (see Kumar, Persuad, & Kumar, 1996). More engineer hours will be required, as well as more manufacturing.

Again at this stage, no account is taken of the impact of these changes coming during the project rather than at the start. Had the contractor known about all of the effects of external changes and customer/contractor changes in advance of the project, then he could have produced a planning estimate such as that shown in Figure 5.

As will be seen later, the ramified consequences of these types of disputes—it may be appropriate to describe them as “naughty customer and silly contractor”—lead to a “lose/lose” outcome.

Case Study: An open and shut case?…but how watertight?

A state of the art train was well into construction. Using well-established design principles adopted from similar train systems, the contractor was carrying out initial tests of the first few units. One of the tests involved watertightness. The passenger doors were not sufficiently watertight to satisfy the customer. Under extreme test conditions, a small (tiny puddle) amount of water appeared. The customer demanded that there was no ingress of water, despite acknowledging that passengers experiencing such weather would bring in more water than the leakage.

The contractor argued that no train had ever met these demands, citing that most manufacturers and operators recognized that a small amount of water would ingress. Nevertheless, the customer interpreted the contract such that new methods and materials be considered for sealing the openings. The contractor was forced to go back to design. An option was presented to the client for his approval, one that would have ramifications for the production process. After many tests and after the verdict of many independent experts in the field, the customer finally agreed to the solution. Not only were many designs revisited and changed, with an impact on other designs, but the delays in resolution impacted the schedule.

As a result of becoming engrossed with the watertightness of passenger doors, the customer also reexamined the watertightness of windows and locomotive doors. Further demands were made, and, to make matters worse, the customer admitted no allowances for schedule slippage or extra costs beyond the estimate.

Lessons

Having a specification for the product to be designed, particularly a functional specification, does not necessarily mean that the scope is known and contained, as both the customer and the contractors' designers usually have different interpretations of the specification.

Acknowledging that designers are often attracted professionally to new and alternative design options is important. This can increase morale and motivation, and sometimes provide both less costly and more effective solutions. However, the increase in uncertainty must also be acknowledged through increasing contingencies. Educating engineers of the potential ramified consequences of these changes (in cost and time) is important—whether or not such proposals are encouraged. The impact of changes and change orders is almost always more than expected. Finding systems for logging all changes and their rationale is essential.

Developing and agreeing systems for managing issues regarding alternative interpretations of specifications is a crucial part of a "change management system." Anticipating how tightly, or not, detailed specifications are to be adhered to requires more understanding about the customer's knowledge and stakeholder position. When customers are very knowledgeable and up-to-date about the product, they are more likely to take a practical view of contract interpretation; however, where there is relatively little knowledge, the customer team is more likely to stick to a possibly unreasonable interpretation of the contract. When a customer team is not the ultimate user, they typically have less concern for practicality and more concern for the written contract. These considerations need to become a part of estimating and risk management; and there should be involvement by legal personnel in the drawing up and interpretation of specifications.

Customer Behavior: Dealing With Interference Beyond What's Anticipated

Consider when, for example, customers do not behave the way the contractor expects them to behave (beyond bending specifications, as previously explained). Also consider where the contractor does not perform in the manner anticipated (in addition to giveaways). The unexpected behavior in this stage changes the project, but does not change the product.

These circumstances give rise to a variety of different possibilities. Figure 10 shows arena "E," illustrating the example of a customer not behaving as might have been expected. This might be where the customer changes its mind—in some cases frequently, but on apparently minor aspects; in other cases only once or twice, but with significant changes. It might also be due to the customer interfering with the work by demanding extra benchmarking; demanding more meetings than expected; not providing equipment, parts or information in a timely manner; not making decisions when contractors might expect them to be made; or simply getting in the way and slowing the contractor (for example, when contractor's and customer's engineers are co-located).

Figure 10: Actual cost build-up (post-hoc view): Stage 4, but neither customer nor contractor behave as expected (ABOUT HERE)

Each of these interferences and interruptions means that progress will not be as fast as expected. There is a range of unanticipated consequences. Typically, the customer action itself is not obviously significant—for example, a customer is late supplying some "customer-furnished information." However, this means that the design team, rather than do nothing, must now focus on another part of the design until the information is available. By the time the information becomes available and team members return to that part of the design, they have lost the "flow of design" and need time to get themselves back up to speed. Because the designs were done out of order, other drawings now have to be modified to account for the ramifications of the late information. When multiple units are being built and learning gains are expected, any late changes can mean lost learning opportunities, since going back up the learning curve significantly increases cost (Eden, Williams, & Ackermann, 1998).

This is the sort of behavior often not anticipated when considering customers, although it might be regarded as part of a risk assessment exercise—sometimes, in fact, customers have a reputation for poor delivery of information.

Also, a contractor may not be as productive as expected. The contractor might have finished up with a less productive labor force than expected because labor was attracted to a competitor during the project; in such an event, new labor has to be acquired and needs to be trained in the use of company systems, and there are learning inefficiencies when new labor comes into a project late and starts work at the top of the learning curve. This is illustrated in Figure 10, where new labor is used on arena "F."

Case Study: When you only estimate the "mill standard"!

A large paper mill was to be extended and modernized. The extension was given extra urgency by new anti-pollution laws imposing a limit on emissions with a strict deadline. The mill currently could not meet these limits.

Prior to awarding of the contract, the contractor and mill owners had worked jointly, many uncertainties were significantly reduced, and the contractor felt it had come to know the customer. Also, during this time, the scope of work was reduced in line with the owner's budget. Good estimating techniques were used—the contractor was a leading-edge engineer in the field.

However, there was little opportunity to inspect the existing mill with which the new work would need to interface. Nor had there been much interaction between the owner's prospective project manager and the bidding consortium.

The contractor was very surprised when the client began to cause a number of unexpected disruptions, which did not affect the product but had grave consequences for the smooth running of the project. The customer and contractor engineers were co-located, and there was "endless" talking and meetings—slowing the rate of both design and, later, commissioning. Documents issued to the customer for information only were changed late in the process. The customer insisted on benchmarking proven systems, involving visits to sites working with experimental installations or installations operating under different conditions in various countries—all considered unnecessary by the design team and which brought further delays to the project.

Lessons

When bidding for a contract, as well as the scope of work and contractual issues, research is needed into the nature of the customer's management style and, if possible, the management style of the project manager. It is also important to reevaluate the assumptions about project management style—and indeed the underlying strategic direction of the customer—each time the project manager changes.

Do not presume that an apparently comfortable relationship between customer and contractor will continue throughout the project. Although mutual trust is crucial to the good running of a project, proper and full records and timely confirmation is also absolutely important. It is important to immediately alert the other party to any problems that arise and deal with them then, rather than taking a more accommodating stance in order to keep good relationships, and thereby implicitly condoning problems.

Systemicity: How it All Links Together

Up to now, each of the preceding aspects of the project cost increases has been considered individually. However, as intimated in many of the case studies, each aspect not only has multiple ramifications cascading throughout the project, but also impacts the others. For example, the typical consequences of continuous changes of mind and late customer-furnished information together may cause a far greater impact than either of the two interferences individually; this produces a portfolio type effect. When combined with force majeure events, differing interpretations of the project specification, and implementation of exciting (i.e., novel) engineering ideas, the project is likely to grow in an escalating manner and in unexpected arenas. Like the amoeba, it is not only the arenas that extend, but also other arenas between and around them, thus causing unexpectedly massive overruns as shown in Figure 11.

Figure 11: Actual cost build-up (post-hoc view): Stage 5 “systemicity” (ABOUT HERE)

To complicate matters further, these interacting implications are often not visible to any one manager on the project. One part of the design team could be experiencing delays while waiting for information. This change to the schedule, however, is not known to another part of the design team that is trying to deal with the customer changing its mind frequently. As a result, the team (while working out of schedule) does not know about a change to the product and ends up producing something that no longer meets requirements—an apparent mistake!

Moreover, while there has been consideration of how the project ceases to unfold as expected, there has still been no accounting for another important aspect of these disruptions—that of time. So far, there has been an assumption that these interruptions are just absorbed, and the extra time it takes to complete all of the hours encompassed by the amoebic shape is offset by a significant saving somewhere (a very unlikely scenario) or, otherwise, delivery is late. Even if allowed the extra time to deliver, the project will incur significant increases in cost—as reflected in the amoebic shape. No attempts to accelerate the contract to deliver on time have yet been considered.

Interactions among disruptions is one reason why quantifying claims for cost overruns is so difficult. While the individual effects that trigger cost overruns might be discernable, and the direct consequences of these can be computed, the effects combine with a portfolio-type impact that is greater than the sum of the parts. This points to one reason why the current Project Risk Management prescription (Project Management Institute, 2000) is inadequate; it treats risks as individual entities to be managed separately, even though risks combine in systemic relationships that endanger a project significantly more than the accumulation of individual risks.

Case Study: The mill (continued): the problems come together

Continuing the story of the mill project: The contractor was now in despair. Although the project had started well, the project costs seemed to be growing beyond anything that made sense, given the apparent minor nature of the disruptions. Relations with the customer, who was continually interfering with progress of the project, were steadily deteriorating. Interference included constant requests to do further benchmarking exercises, many changes of mind about where equipment should be positioned and how certain systems should work, and preferential engineering requiring rework.

As a result, the project was behind schedule. As it involved a considerable amount of external construction work, it was vulnerable to being affected by the weather. In the original project plan (as used for the estimate), the outer shell (walls and roof) was due to be completed by mid-autumn, ensuring that during the winter months work could take place indoors. However, the project manager now found himself undertaking the initial construction of the walls and roofing in the middle of winter! As chance would have it, the coldest winter in decades resulted in many days being lost while it was too cold to work. The combination of the particularly vicious winter and much interference resulted in an unexpectedly huge increase in both labor hours and overall delay.

Lessons

Recognize that interference and other effects on a project can impact one another in surprising ways. Therefore, do not compute project forecasts, including demands for labor, on a piecemeal basis. Rather, take a more systemic view that encompasses the impact of portfolios of disruptions and the interaction between the consequences of events. Often long and ramified causal chains need to be elaborated.

In order to evaluate impacts, communication between different parts of the project needs to be enhanced, even though time to do so is tight. Often there is less, rather than more, communication when a project is under stress.

Accelerating to Compensate

When projects go wrong, mitigation for expected delays occurs. Some mitigation has been mentioned—working on designs in the "wrong" order. Nevertheless, the above sections generally assume that the project plan stays constant and management has accepted the delays and interruptions and rescheduled accordingly. But, typically, a project manager chooses to accelerate a project because of the forecast delay to project delivery. For example, when customer-furnished equipment or information is late, then acceleration occurs when labor is asked to "work-around" (i.e., alternatively work on other tasks out of order and return to the original task later).

The direct effects discussed in the sections above can be relatively straightforward to estimate, but once management takes steps to accelerate a project, the relationship between an event triggering the delay, and overspend, is much more difficult to understand. This, of course, assumes that the manager decides to continue the project rather than abandon it—but by the time management needs to accelerate a project, generally there is a high investment in work done, and the “sunk cost” effect comes into play, unjustifiably increasing managers’ subjective probabilities of project success (Arkes & Hutzel, 2000).

Typical actions taken to accelerate projects include starting activities out of order, increasing manpower beyond efficient levels, increasing parallelism between activities, and so on. These actions are taken to bring the project “under control.” However, such actions can result in unhelpful dynamic behavior characterized by self-sustaining “feedback” effects. When effect “A” causes or exacerbates or promotes effect “B”, which causes or exacerbates or promotes effect “C”, and so on, the causal chain can be captured by traditional project management methods. However, under conditions of acceleration, it is usual for effect “C” to feed back and impact effect “A”. Under these circumstances, the loops may be “vicious cycles”, or “virtuous cycles” (depending on whether the result magnified is desirable or not), with often massive and unexpected escalatory impacts.

Humans are particularly poor at anticipating the impact of feedback. It is well known that managers make decisions particularly poorly for problems involving feedback mechanisms (Sterman, 1989), and these loops often produce counterintuitive behavior within projects. Eden, Williams, Ackermann, and Howick (2000) describe some of these effects, showing how feedback structures can be set up and how they can highly magnify small effects (see also Williams, Eden, & Ackermann, 1995).

One of the most frequent vicious cycles is what has become known as the “rework cycle” (see Figure 12 below). For example, as a result of a customer being late in the delivery of information, there is an interruption to the work. However, the contractor carries on, knowing that it will have to later take some of that work apart before the customer supplies information. However, the effect of doing such rework means that labor is not employed on its proper task, causing further delays to the project, and more work completed out of order, leading to a “domino effect.”

Figure 12: Vicious cycles causing rework (ABOUT HERE)

The sort of actions that set up vicious cycles (e.g., “throwing manpower” at a project [see Cooper, 1994], increasing parallelism in design, moving forward to manufacturing with incomplete designs) will often be the cause of projects’ overspending by very large amounts that are difficult retrospectively to understand (Williams, Ackermann, Eden, & Howick, 2004).

Underestimation at the very beginning of the project will cause the project to fall significantly behind the original planned schedule. The acceleration actions required in attempting to return to an unrealistic schedule exacerbate the situation because of the vicious cycles caused by these actions.

All of the effects discussed in previous sections can cause delays that demand acceleration. Because of delays, management will accelerate the project, thus avoiding extensive liquidated damage. This will set up the feedback effects described above and, because of this, the total expenditures will increase in all directions, as shown in Figure 13.

It is generally impossible to tie down the cost increase to individual causes. Rather, the effects are in a systemic relationship even more complicated than the portfolio effect. This is one reason why it is often difficult to decide whether the additional cost resulting from the acceleration is self-imposed or caused by the client (Howick & Eden, 2001). For example, two very significant areas for claiming compensation are reduced productivity and rework—both of which can rarely be allocated to particular original causes but arise from the systemic interaction of causes, secondary effects and management actions such as acceleration. Looking back on a project in retrospect, “hindsight” effects mean that post-mortem evaluation of management decision-making “tends to be biased in an unflattering direction. If the world is predictable, failure to act effectively must reflect poorly on the competence of the managers involved” (Bukszar & Connolly, 1988). However, the types of decisions discussed in the previous paragraphs are the natural decisions a good project manager would make in the middle of a disrupted project. Indeed, the commonly used project management methods, based around simply decomposing the project into additive parts, would imply these decisions (Koskela & Howell, 2002).

Figure 13: Actual cost build-up (post-hoc view): Stage 5 with acceleration (ABOUT HERE)

Case Study: The mill (continued): spiralling out of control!

Continuing the story of the mill: The project started well but, due to all the effects described, the project was increasingly projected to be very late in delivery. And there was the strict deadline caused by the new anti-pollution laws. The project manager took the sort of actions any reasonable project manager would in these circumstances. As a result of the ongoing delays to the basic conceptual design of the mill (for example, customer changes of mind, delays, and so on), design work on many systems moved to detailed design before the conceptual design was agreed upon. This meant that detailed design was often more difficult, and had to be reworked, but “it was necessary to keep the project moving.” In addition, and in order to keep the construction work going, drawings were released to construction before being fully agreed upon. This meant that construction was done in a piecemeal fashion, often inefficiently (for example, scaffolding would be put up for a job, then taken down so work could proceed, then put up in the same place to do another task for which drawings subsequently had been produced). As the construction time scale got tighter and tighter, much more labor was put on the site than was efficient (considerable overcrowding ensued), so each task took longer than estimated. Overtime payments (for design and construction workers) escalated. The final overspend was over 40% more than the original budget!

Lessons

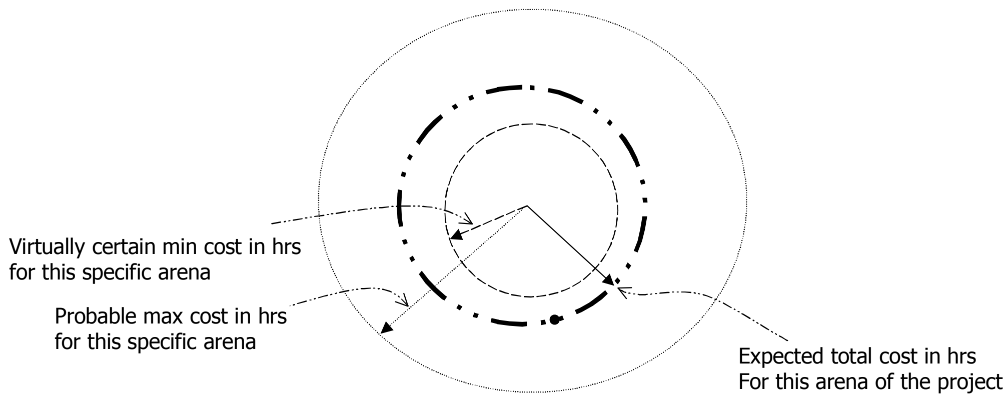
A major cause of feedback, and thus of badly failed projects, is management action taken to accelerate a time-constrained project when late completion is projected. Project managers usually have to respond to disruption by taking decisions that seek to retain planned delivery and planned quality. The consequence of such actions designed to bring the project back on schedule (negative or controlling feedback) will be to increase the power of the vicious cycles (positive feedback), because these actions are also disruptions that, in turn, must be contained within a shorter time scale.

Usually, there can be a trade-off: extending delivery may reduce some of the power of the feedback loops compared with reducing delivery delays by accelerating, implying more disruption costs of extra man-hours. Managers of both contractors and customers need to be educated about the likely lose/lose feedback consequences of actions taken in the heat of a disrupted project (Williams, Ackermann, Eden, & Howick, 2004).

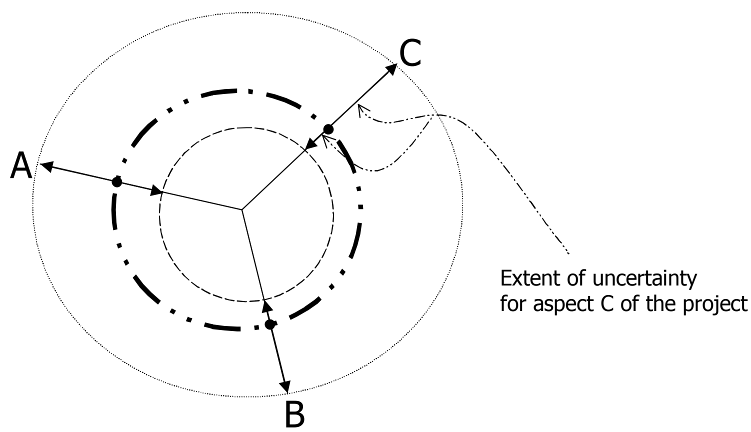
Final Comments

This paper has illustrated diagrammatically how projects often overrun and do so beyond any reasonable expectations. The figures are intended to be used as prompts for everyone involved in projects, helping them explore the possible reasons for anticipated late delivery and cost overruns. Costs combine together in non-linear ways, and accelerating projects can set up vicious cycles that increase costs many more times than expected.

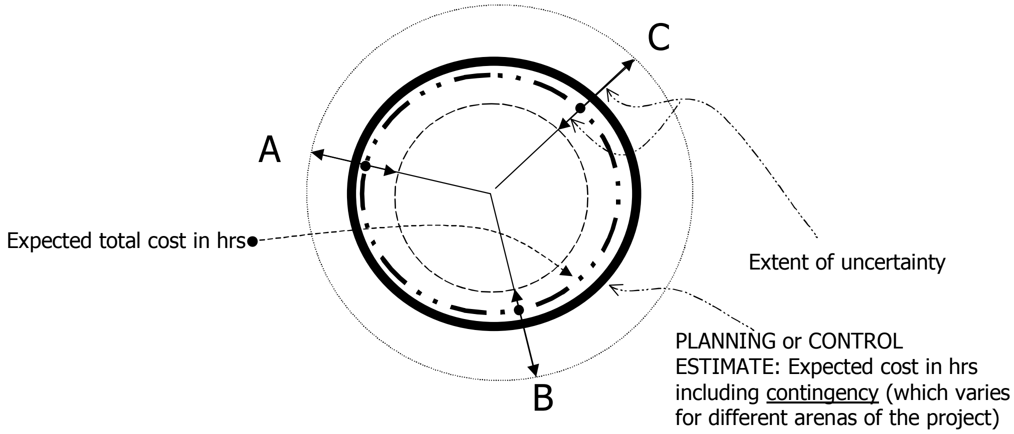
As the examples show, most projects that significantly overrun are a lose/lose situation for both contractors and customers (and subcontractors who might go out of business); simple procedures for allocating costs between the parties are generally inadequate and can be misleading. Better estimating procedures at different stages in a project that account for uncertainties, the “portfolio effect,” and the dynamics of acceleration, are important. But these must be provided through fast “rough and ready” procedures; otherwise, they will not be used. Many overrun projects “feel like chaos” that cannot be managed sensibly. Most significantly, the realism of the planning (or control) estimate is crucial in avoiding project acceleration—which could otherwise result from underestimation, thereby permitting cost escalation.



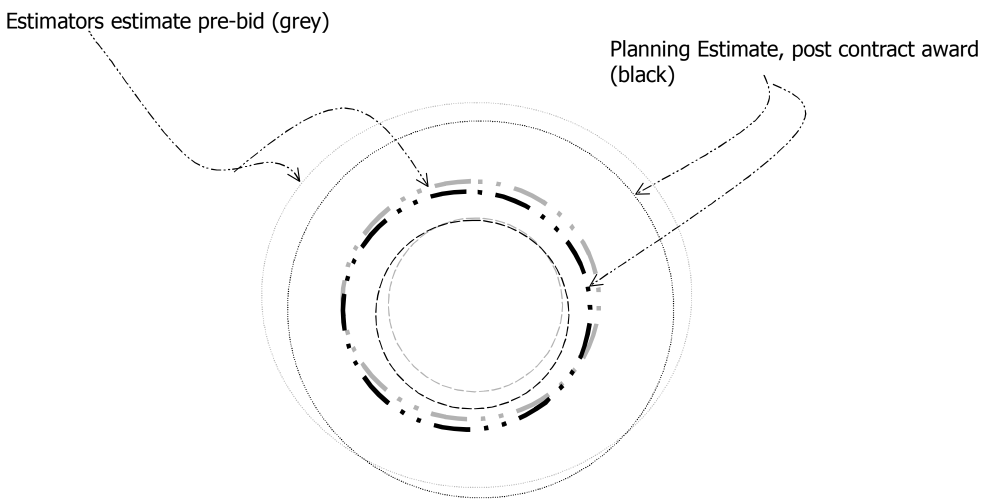
Picture 1: Estimators Estimate for Bid



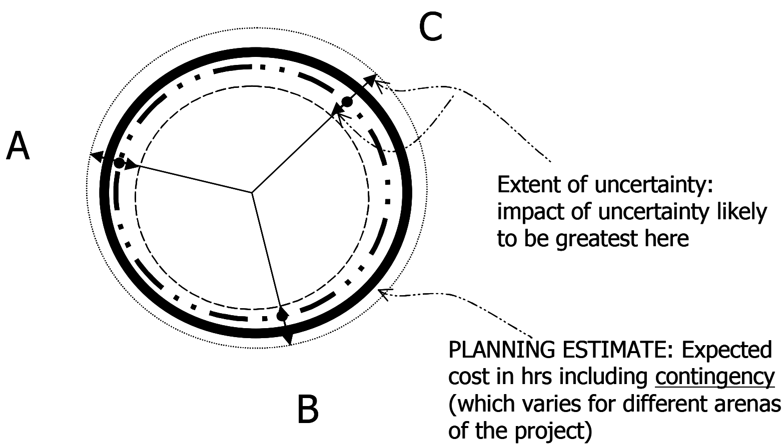
Picture 2: Estimators Estimate for Bid Showing Extent of Uncertainty for Different Aspects



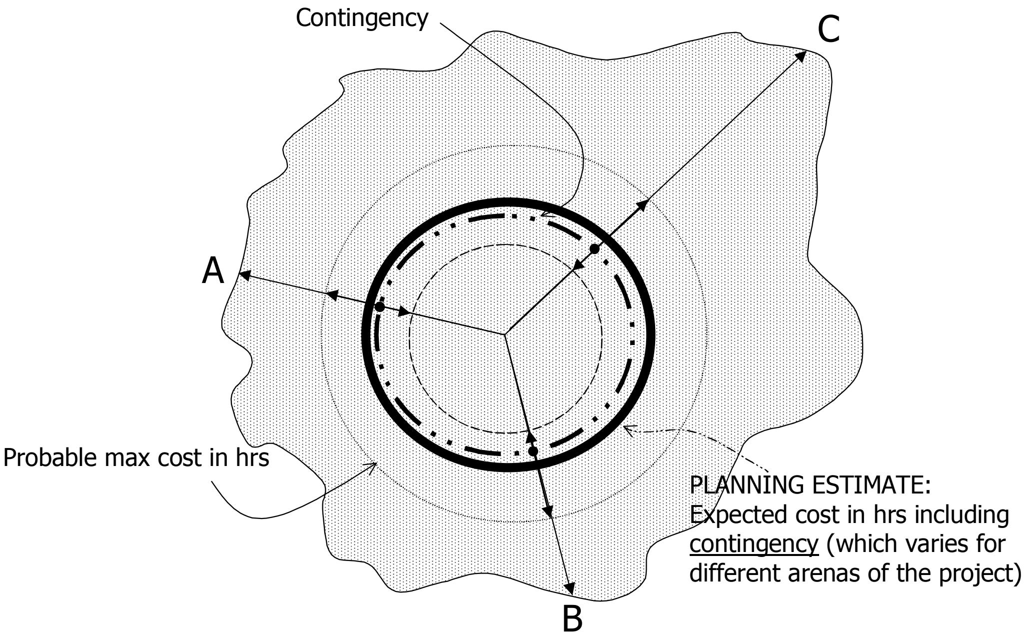
Picture 3: Planning Estimate - post contract award



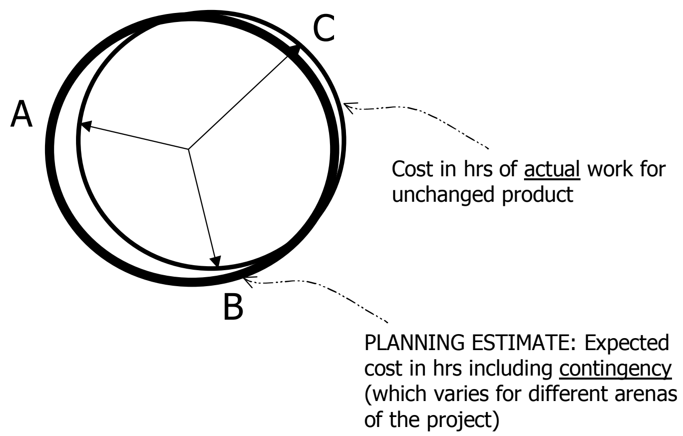
Picture 4: Comparison of Bid Estimate and Planning Estimate



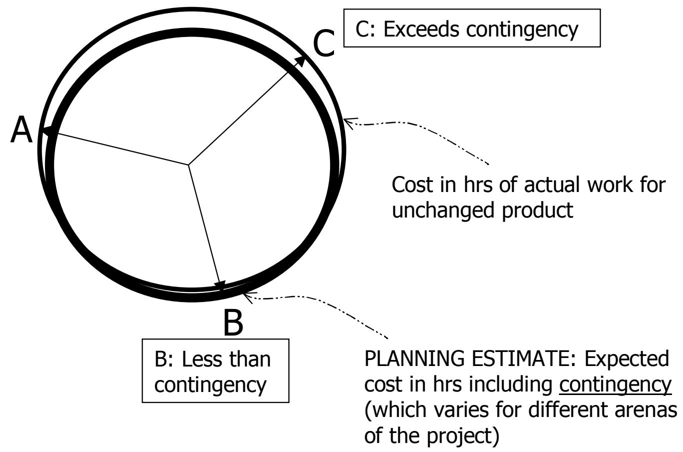
Picture 5: Ideal Pre-project Estimate – planning estimate remains the same



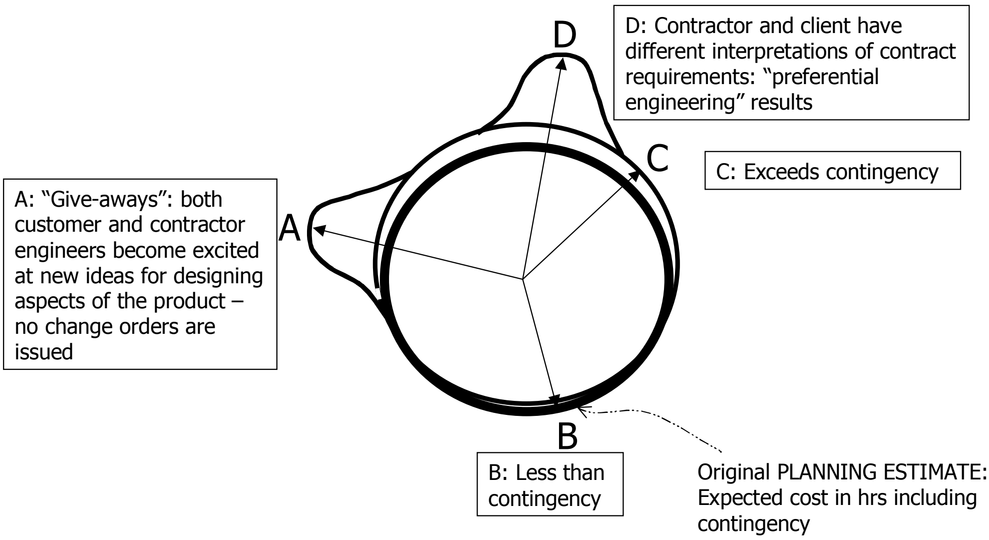
Picture 6: Post Hoc – What Actually Happened: 'Amoebic growth…'



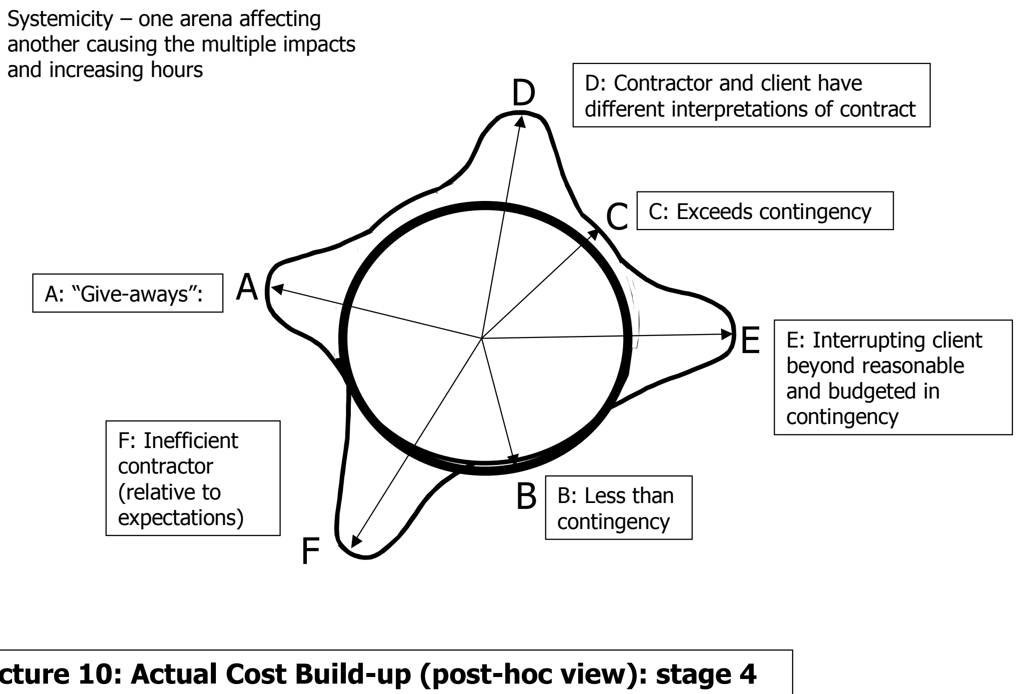
Picture 7: Actual Cost Build-up (post-hoc view): stage 1 (based on Figure 5)



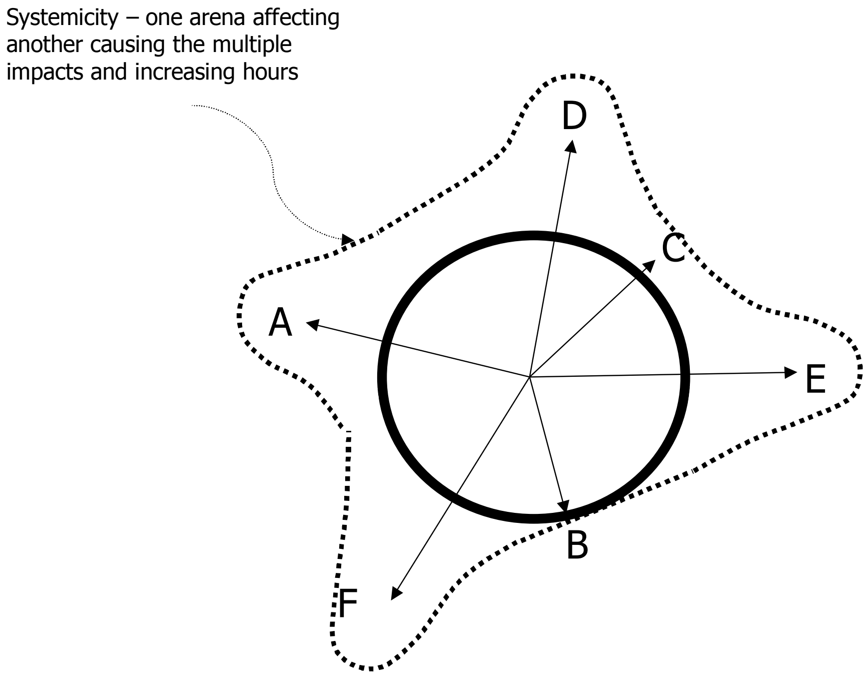
Picture 8: Actual Cost Build-up (post-hoc view): stage 2



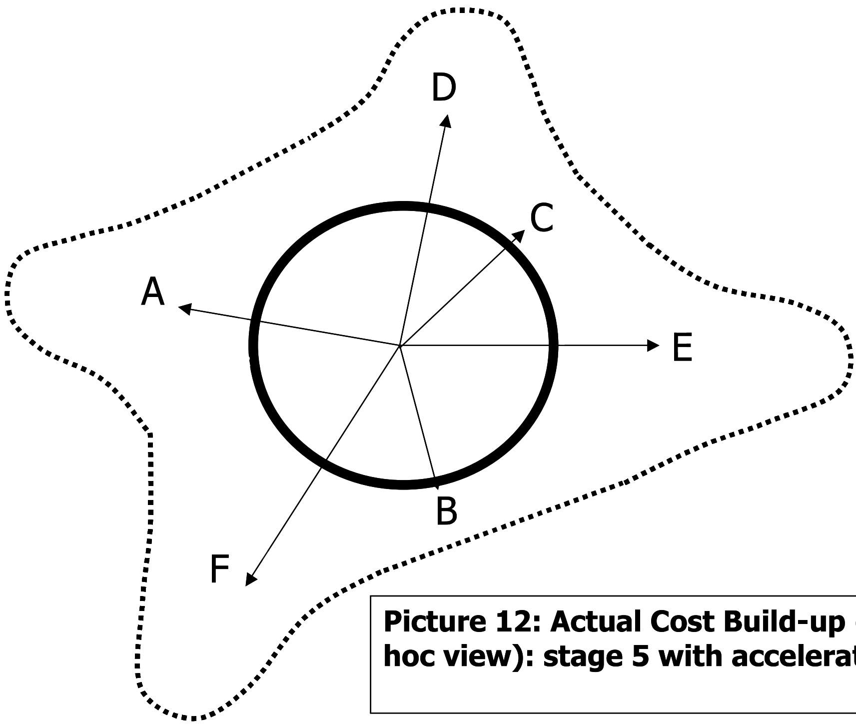
Picture 9: Actual Cost build-up (post-hoc view): stage 3 with contractor/customer induced changes to the product.



Picture 10: Actual Cost Build-up (post-hoc view): stage 4 but neither customer or contractor behave as expected

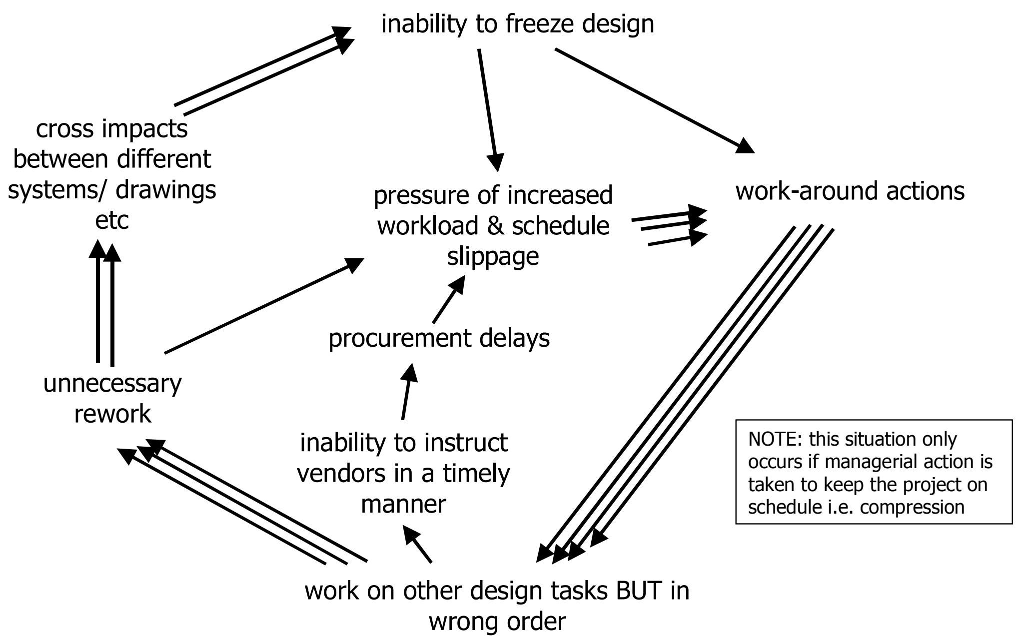


Picture 11: Actual Cost Build-up (post-hoc view): stage 5 systemicity



Picture 12: Actual Cost Build-up (post-hoc view): stage 5 with acceleration

Figure 1: Vicious Cycles Causing Rework



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