‘Left Shift’ vs The Time Value of Money:

Unravelling the business case for systems engineering

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Abstract

The principle of left shift – increasing project expenditure in the early part of a project in order to reduce unanticipated costs later in the project – is advocated as a cornerstone of good systems engineering practice. In fact, the expenditure profile of a project, and in particular the proportion of the total spend attributed to early stage activities such as project definition, is often used as a proxy for the overall level of systems engineering effort expended in a project. In order to establish the business case for systems engineering, this level of systems engineering effort can be compared to the project performance relative to cost and schedule targets. A common premise is that projects that spend more early in the project achieve better outcomes than those that defer expenditure until later. This proactive approach to the management of risk seems sensible as it reduces the probability of unanticipated problems plaguing the project midway through, and recognises the lower cost of rectifying problems identified early on. To assume that such an expenditure profile will be attractive to non systems engineers, however, ignores three crucial factors. Firstly, project managers are judged on measurable progress. Often, these definition activities, whilst possibly preventing costs from being incurred, deliver little visible output. Secondly, in a competitive market, almost all successful project bids are under-costed and underestimate the time required to complete (otherwise they would not win the contract). This puts extreme pressure on choosing risky cost-cutting and time-saving measures. Thirdly, and most importantly, money available now is worth more than money available in the future, since this money could be invested in other projects in the meantime, generating returns typically in the range 10-25%. It is therefore rational for financial managers to insist on minimising early project expenditure. Worse still, the riskier the project, the more rational it is in financial terms to try to defer spending until later in the project.

We have developed a model that takes into account financial and engineering risks to predict the optimum resource allocation profile for a given project. This generates some interesting conclusions on the level of up front systems engineering effort that can really be justified under different conditions.

Introduction: Understanding Project Failure

Most projects fail, whether by disappointing in terms of delivered product quality or service, or by exceeding cost or schedule estimates. There is significant evidence to support this assertion in a range of industries. According to the Standish Group [1994], only 16% of IT projects are completed successfully – on time, on budget and with the features and functions as initially specified (or better). Figure 1 highlights the rarity of major MOD projects being completed on time and on schedule [National Audit Office, 2006].

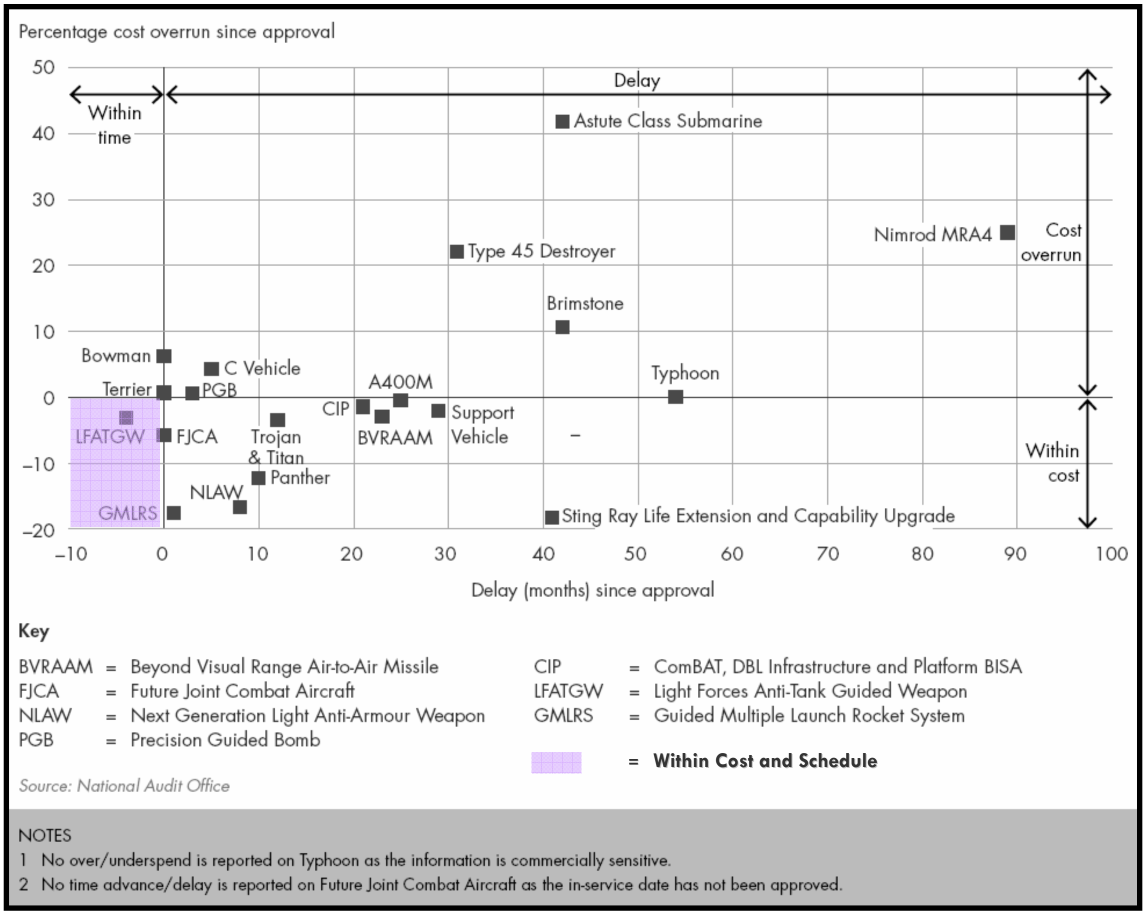

Figure 1: Forecast time and cost positions in MOD projects at 31 March 2006

There are many possible explanations for such poor performance in delivering complex projects. Some of these explanations are rooted in human behaviour; others are systemic, owing to the structure of the systems in which organisations operate.

Human Behaviour

There are clearly situations where greater performance is promised than is really possible within the time and cost budgets specified. This will sometimes be due to a poor understanding of the complexities of the system required. It may be due to analytical errors by engineers working on the proposal, who invariably will be able to allocate less time to the process of preparing a bid than they would like. It may even be attributable to vanity on the part of bid teams, who believe their individual and organisational capabilities are more advanced than they really are. There are countless traps to effective decision making [Russo and Schoemaker, 1990] that can distort project estimates. These traps include, for example, wanting to justify past decisions that are no longer relevant (the sunk cost trap), being overly influenced in our estimates by the first data we see on a subject (the anchoring trap), and actively seeking evidence to support our theories and downplaying contradictory evidence (the confirming evidence trap). The result of these traps may be a multiplicity of poorly bounded 'known unknowns' facing a project, and worse still a number of 'unknown unknowns' that had not even been anticipated, but that might have been foreseen with a better approach.

Once a project has started, human factors may influence the project team's ability to manage the project's requirements. It is difficult to say no to a powerful customer who requests design changes mid-project. The customer would clearly prefer, however, an operational product that doesn't exactly meet its new requirements, to a faulty product that would match the requirements if only it worked at all.

Systemic factors

The discussion above might suggest that if we were more careful about the personnel we selected to prepare bids and manage projects then many of the problems would go away. This ignores the fact that there may be features built into the system that could lead even a perfectly rational decision maker along an unhelpful path.

There is uncertainty in any engineering project. As the project progresses, new information will become available about the capabilities of the organisation tasked with delivering the system, about the precise requirements of the system, and about the technological possibilities. At the bid phase of a project, much is unknown and the bid will be made subject to a number of key assumptions. If, as is often the case, these assumptions turn out to be too optimistic, then the project will generally underestimate the cost and time to deliver the working system. In a simple world where there is only one buyer and one supplier, this does not matter too much. When the supplier's assumptions underestimate costs, they make less money on a project, and when they overestimate costs they make more money. In a competitive situation, however, in which many companies bid for a similar project, the lowest bid will generally be successful. There is therefore a strong incentive to be optimistic about costs down to the point where the amount of profit the project is expected to deliver is small. What is particularly worrying is that, when suppliers compete primarily on price to deliver a well defined product, there need be only two organisations in an industry for it to exhibit the behaviour of a highly competitive industry of many organisations. This is illustrated in the decision matrix of Figure 2, where each organisation prefers to set price low, regardless of the choice of the other organisation. The stark implications of this are that in any competitive bidding process (i.e. with more than one supplier bidding), the organisation that is most optimistic about its costs will generally win the contract. In many cases, this optimism will be ill-founded, as "neophyte and expert project managers alike seem to assume that Murphy's Law has been repealed in the case of their personal project" [Meredith and Mantel, 1995: 311]. The more organisations that are bidding, the more likely it is that the lowest cost bidder has significantly under-estimated cost or system complexity. Winning a bid for a major project may therefore not be such a cause for celebration after all. This is especially true if the prospective supplier hasn't paid sufficient attention to the details of the contract it has signed up to.

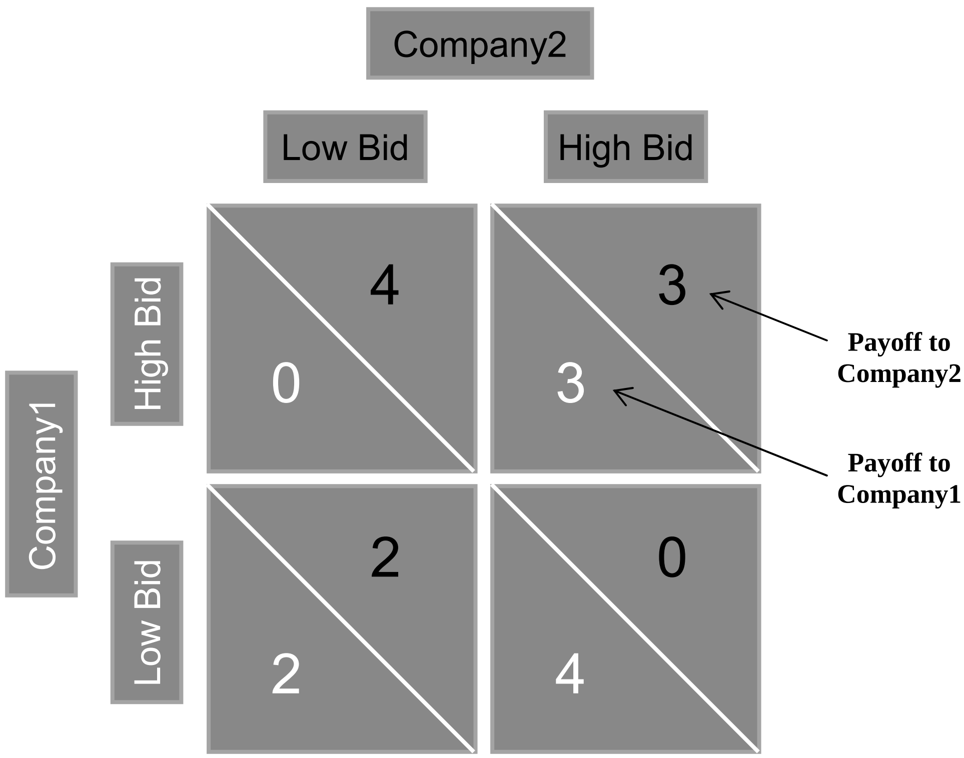

Figure 2: Bid pricing game for 2-company competition

A further systemic barrier to effective project management is the way in which projects are generally judged – i.e. on measurable progress. Definition activities at the start of a project, whilst possibly preventing costs from being incurred, often deliver little visible output. This can put pressure on managers to start delivering visible output of little value to the project at the expense of performing value adding planning or strategic tasks. Any benefits coming from giving 'momentum' to the project (including boosting morale when 'real' work actually starts) needs to be weighed against the benefits of these definition activities, since many of the resources required to give the project impetus could also support the early definition activities. A better solution would be to have measurable outputs associated with the early definitions that can be mapped against the value they add to the system development. Many managers make the mistake of not involving team members in early planning meetings, perhaps assuming that team members should only concern themselves with their specific jobs. In fact, it is very important that at an early stage both the manager and the team members buy in to the goals of the project and the means to achieve those goals [Meredith and Mantel, 1995].

Measuring Project Success

The degree of success of a finished project can be measured in many ways. One measure is the extent to which the quality of the delivered system delights the customer. Another measure is how quickly the system is delivered and at what cost. Ultimately we are interested in the value that the project creates for the organisation that delivers it, though. Ideally, a project that creates high value for the supplier should also be one that satisfies the customer's requirements of quality, cost and time. Since quality measures are difficult to quantify, we will assume that quality is adequate once a project is complete. We can then focus on the cost and time required to complete the project.

The most common measure of a project's value is net present value (NPV). NPV calculates the expected cash flow (C) each year for a number of years (N) into the future (typically five, ten or fifteen years). A discount rate (r) is applied cumulatively to future profits or losses to reflect the fact that money received in the future is worth less than money received now. This is because money received now could be invested in other cash generating projects (or put in the bank if all else fails), and will therefore create extra money each year. The principle that a pound received today is worth more than a pound received tomorrow is called the time value of money [Brealey, Myers and Allen, 2005]. The NPV is then the sum over the chosen number of years of the annual discounted cash flow (DCF) scores. An N-year NPV is therefore given by:

$$NPV = C_0 + \sum_{i=1}^{i=N} \frac{C_i}{(1+r)^i}$$

Implications of the Time Value of Money

The key implication of the time value of money for project management is that we would rather receive money now than next year, and we would rather spend money next year than now. This has some interesting implications for how we would ideally distribute effort in a project, depending on the rules for when payment is received.

For projects where no income is received until the project is complete and where project completion cannot occur before a fixed date in the future (due to dependence on an external supplier, for example), we would like to delay all expenditure as much as possible, subject to completing the project on time. The value of delaying will depend on the discount rate, representing the importance of the time value of money (and a measure of project risk). Of course, if the project's NPV is less than the NPV associated with abandoning the project, we would rather not complete it at all.

For projects where income is received as soon as progress is made on the project, on the other hand, there is a strong financial incentive to make progress as soon as possible (or, more importantly, to be *seen* to be making progress).

Defining ‘left shift’

Typical project resource use profiles

The lifecycle of any development project tends to follow a similar pattern when looked at in terms of the resources used. There is a slow start following project initiation where the project team is assembled and development plans started. During the design stages and early production stages momentum builds until effort reaches a peak. A decline in effort starts towards the end of production and during the integration phase and continues to fall during the final testing commissioning. Depending on how aggressively the close out procedure is followed, the resource is quickly re-allocated or can tail off slowly. This profile at the end of the project will be determined by the structure of the organisation and the portfolio of work it undertakes. If we plot resource used per unit time against time the profile tends to look like a skewed binomial distribution as shown on the left hand side of Figure 3.

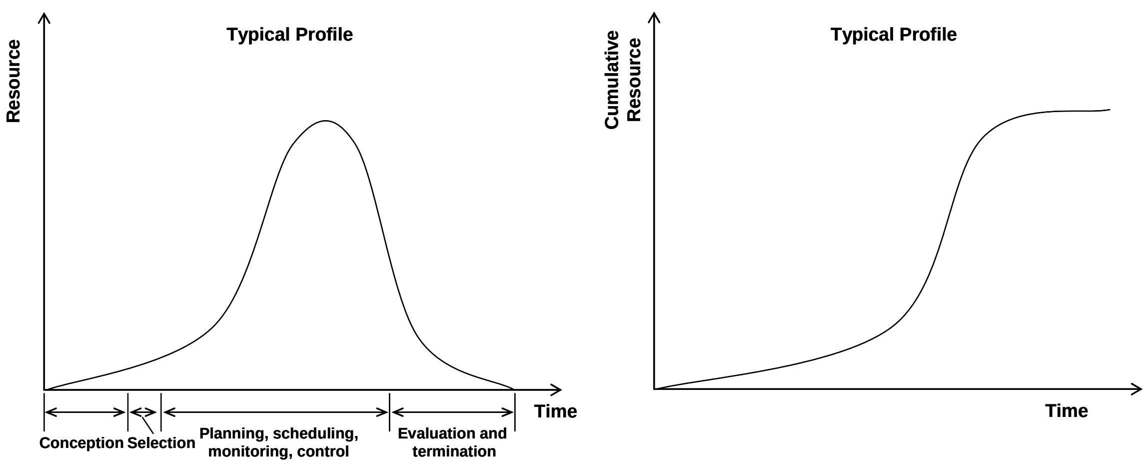

Figure 3: Typical profiles of Resource use per period and Cumulative Resource Use

The right hand side of Figure 3 plots cumulative effort versus time revealing a characteristic s-curve. Conventional wisdom about how projects progress suggests that the focus between cost, schedule and performance changes during this typical lifecycle [Meredith and Mantel, 1995]. Early in the project, where the progress is still slow, the focus is often on solving the problem at hand, defining the technology or performance that will eventually be used to provide the solution. During the ‘rapid’ part of the project during system production, the project manager is more focused on control of costs and finally, as delivery approaches, the focus moves towards schedule.

Some research challenges this conventional wisdom, though, finding that, except during initial planning, the performance of the project takes precedent as the project manager asserts ownership rights on delivering performance to the customer [Kloppenborg and Mantel, 1990]. This can lead managers to make trade-off decisions that are biased toward the project and which may be at odds with the needs of the organisation undertaking the project or are not objectively justifiable. Using rules such as NPV to justify project decisions can help to avoid such behaviour.

Origins of 'left shift'

The term 'left shift' is not a technical term, and is rarely referred to in Systems Engineering literature. Its first formal use seems to have been in Operational Research literature [Giffler and Thompson, 1960] in relation to scheduling algorithms, referring simply to left shift as being permissible only when there is an idle machine upon which an operation could be performed earlier. It has since come into colloquial use in the Systems Engineering community (see, for example [Farncombe, 2001]) seeming to refer to the concept of shifting the effort profile in a project so that the peak occurs earlier than would otherwise have been the case (see Figure 4).

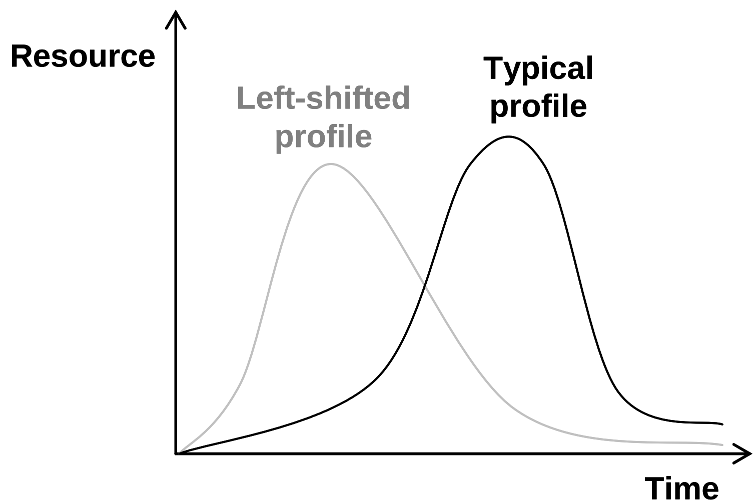

Figure 4: Typical and left-shifted effort profiles

Absolute Left Shift

It is debatable whether or not an effort profile on its own can be judged to exhibit a particular level of left shift. If one argues that left shift is characterised by a particular shape of profile, then left shift can be defined in *absolute* terms by defining the extent of the left shift by the movement of the mean of the distribution relative to the project's midpoint.

Figure 5 shows two examples of effort profiles with peaks left-shifted relative to the project's midpoint. Profile A on the left also has a mean to the left of the midpoint. Profile B, on the other hand, has a mean to the right of the midpoint. The definition we have adopted for a left-shifted profile in absolute terms defines Profile A as having a positive left shift and Profile B as having a negative left shift (or a right shift).

The extent of an absolute left shift can be defined as the ratio *a* : *b* in Figure 5, i.e. as the distance that the mean has moved to the left of the midpoint as a proportion of the distance from the midpoint to the start point. A left shift of 100% would therefore represent a project that finished in the first period. Note that the effort shown on the *y*-axis is the *effective resource*, i.e. the resource that is usefully employed in delivering the project (including performing definition or systems engineering activities). Allocating a large amount of resource to the early phases of a project but not employing this resource is not considered an example of left shift.

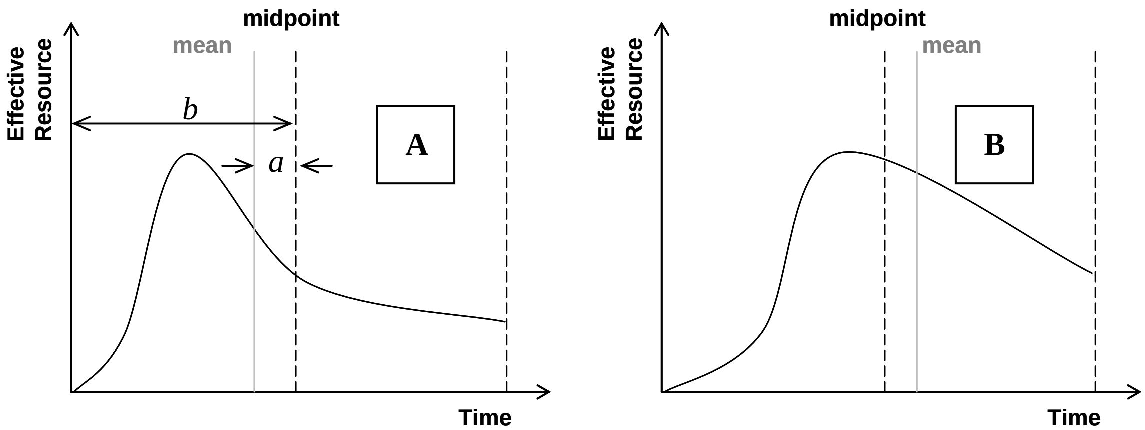

Figure 5: Two profiles with left-shifted peaks

Relative Left Shift

It may be more meaningful to classify projects as 'left-shifted' based not just on the current resource profile, but as relative to some expected or ideal profile. This ideal profile might assume, for example, that tasks are completed with no unforeseen problems, that no rework of previously completed tasks is required and that no additional tasks must be performed that hadn't been anticipated. The ideal profile takes no account of financial costs or benefits of different profiles, but merely reflects the expected effort as a function of time to complete the project using the resources readily available.

In addition to this ideal profile, we can define a fastest possible profile as being one which relaxes resource constraints to allow, for example, hiring of additional staff, but still recognises that there is a practical limit to the amount of progress that can be made each period. There may be practical limits to the amount that resource levels can increase within the time of the project (workers, machinery, etc.). There may also be dependencies on external suppliers, or physical limitations (including minimum durations for tasks such as transportation), etc.

A relative left shift is then defined as the movement of the actual mean from the ideal mean as a proportion of the movement of the fastest mean from the ideal mean (ratio *c* : *d* in Figure 6). In Figure 6, the relative left shift is therefore approximately 50%.

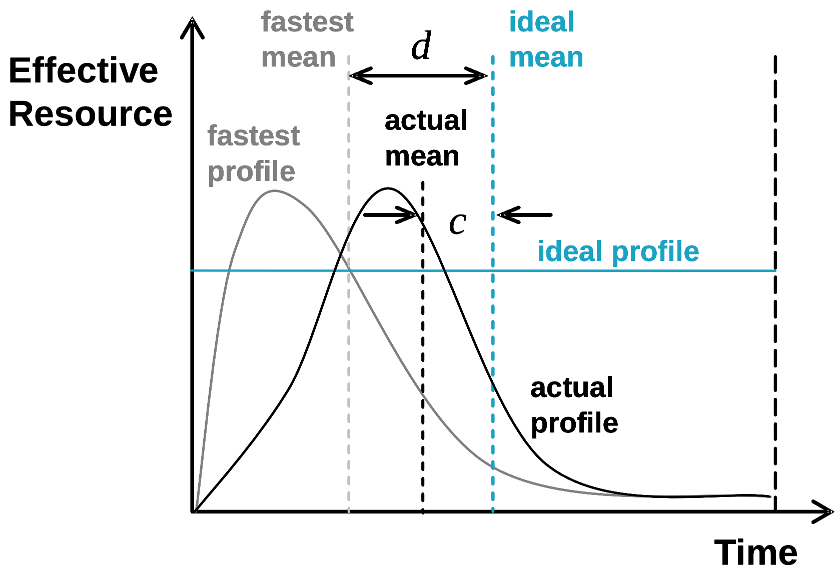

Figure 6: Defining relative left shift

Relevance of Left Shift to Systems Engineering

There is evidence to suggest that projects that spend a greater amount of resource on the early definition activities are less prone to finish late and exceed budget than projects that spend little or no resource on these activities.

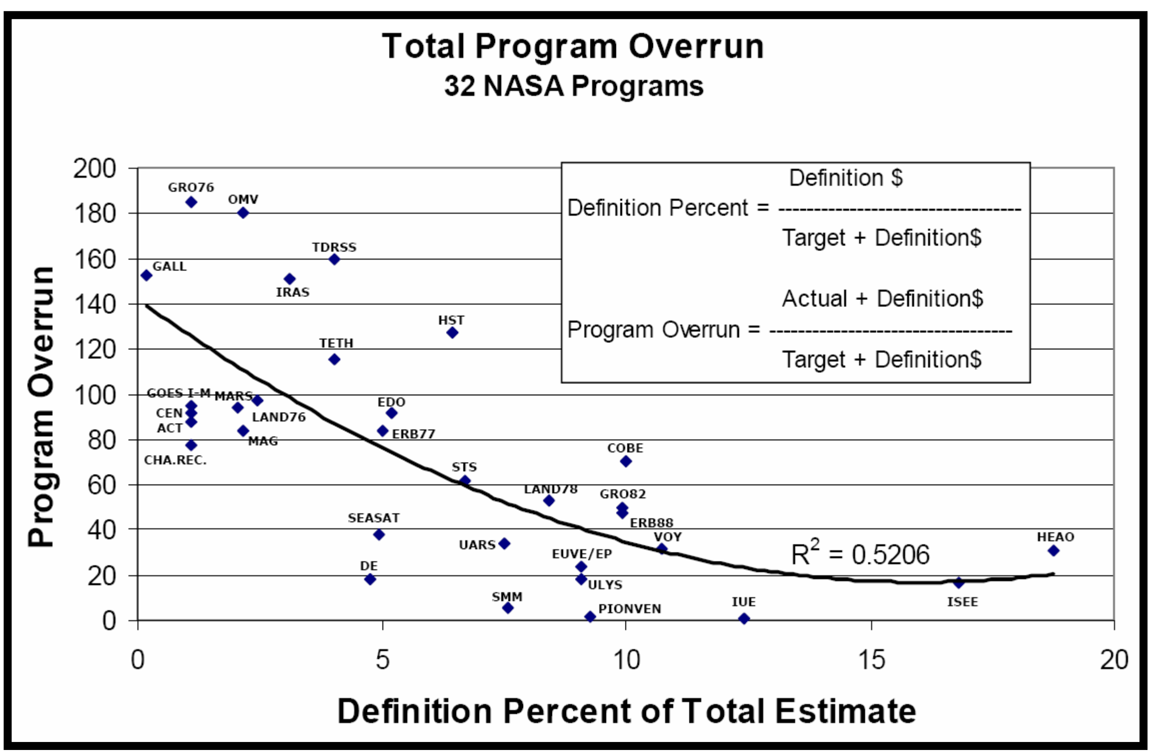

Figure 7: NASA project performance as a function of definition effort [Gruhl, 1992]

Figure 7 shows that for NASA, the optimum proportion of total project effort spent on the definition phase of a project is around 15% [Gruhl, 1992]. Honour [2004] argues that the amount spent on the definition phases of a project is strongly correlated with the level of systems engineering effort in a project. This suggests that successful projects should employ a positive relative left shift so that the number of unexpected problems encountered late in a project is limited.

Research Methodology

In order to investigate the implications of the time value of money and left-shift principles, we have developed a scheduling model that calculates the resource distribution that maximises NPV for a given situation.

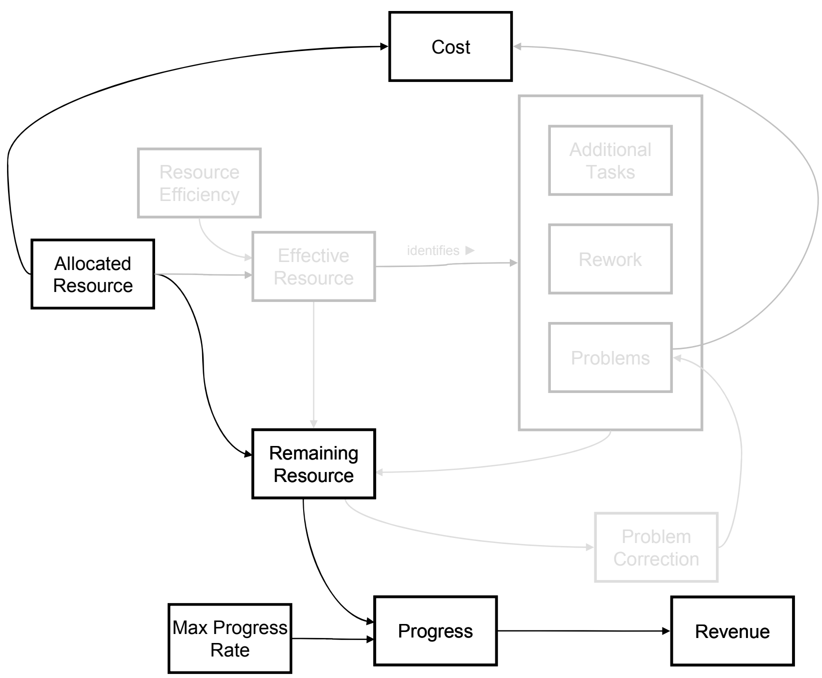

Figure 8: Ideal Project Flow

Figure 8 shows the flows for an ideal project in which everything progresses as anticipated. A certain resource is allocated each period, which leads to progress and thereby generates revenue. Figure 9 shows the flows for a more realistic situation in which each period new additional tasks are identified, previous tasks need to be repeated and problems arise which cannot be immediately solved, slowing progress and increasing costs.

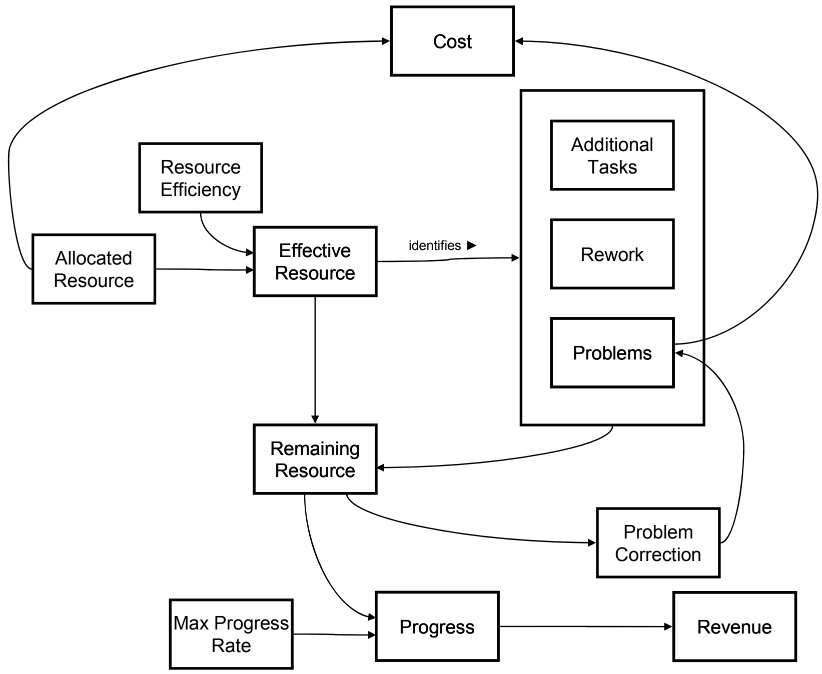

Figure 9: Real Project Flow

Hypothetical Situation

The model makes a number of assumptions as listed in the appendix, and is applied to the following hypothetical situation:

A customer wants a new stadium to be built within 8 years, and will pay £1000m for the project. The average inflation rate is expected to be 3%. There will be a £100m penalty for every year the project is late.

Results

Various combinations of other parameters were tested, and the optimum resource profile was established for each, assuming integer values for allocated resource or 'effort'. Parameter values and the optimum level of left shift are shown in Table 1.

Situation	Discount Rate (*r*)	% Payment on completion (*x*)	Earliest allowed finish (*n*)	Cost factor for unplanned resources (*F*)	Probability of problems or rework (*p*)	Optimum left shift
A	5%	100%	8	3	20%	12%
B	25%	100%	8	3	20%	12%
C	5%	10%	8	3	20%	12%
D	25%	10%	8	3	20%	93%
E	5%	100%	4	3	20%	84%
F	25%	100%	4	3	20%	84%
G	25%	100%	4	3	5%	65%
H	5%	100%	4	10	20%	13%

Table 1: Parameters for Schedule Optimisation

Actual and ideal/expected values for effort, progress, problems, cost, revenue and discounted cash flow are shown for Situation E in Figure 10. The actual profile is the optimised schedule which returns the greatest NPV given the parameter values chosen.

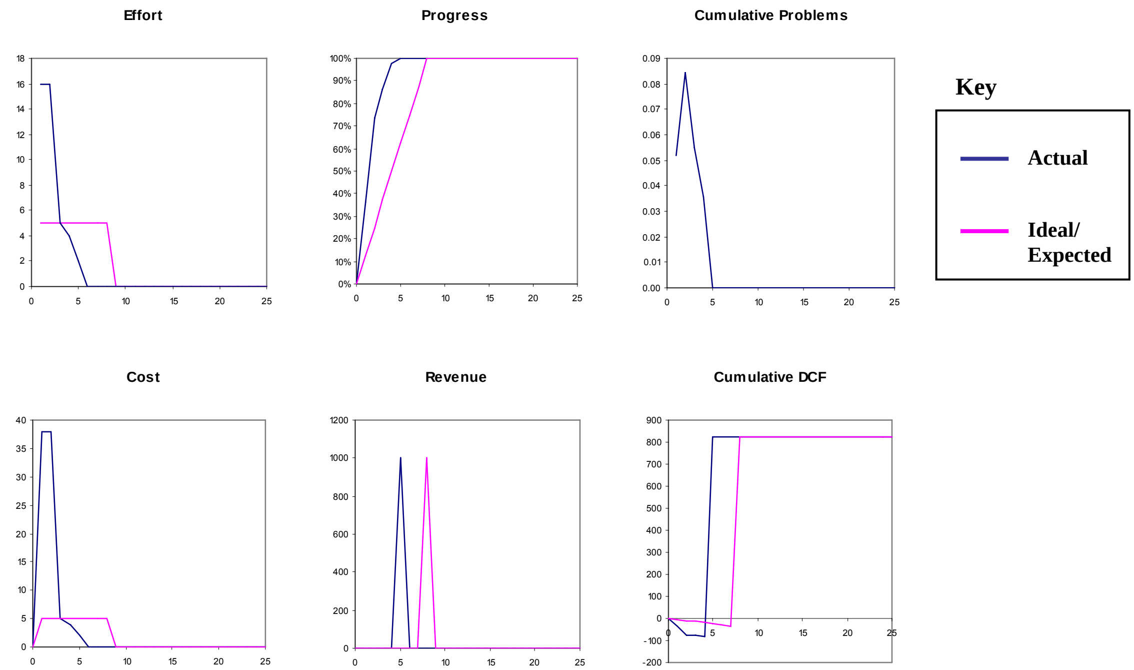

Figure 10: Results for Situation E (optimised)

If instead of assuming a mean occurrence of problems, additional tasks and rework, we assume a random distribution with the same mean, and allow the productivity of the workforce also to vary randomly, we can investigate the sensitivity of the project NPV. Figure 11 shows that if resourced in such as way as to optimise NPV (as in the top left chart of Figure 10), the project is over 50% likely to actually end up making a loss, and only around 45% likely to make a profit above £500m.

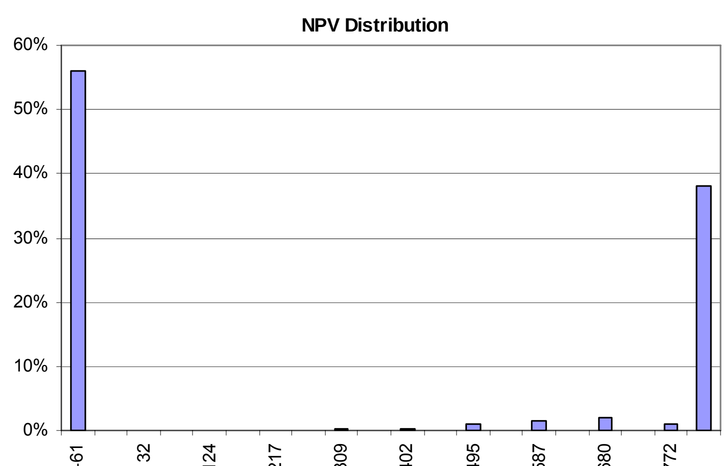

Figure 11: NPV frequency distribution for Situation E (optimised)

A lower risk approach to managing the project would be to allocate an effort profile as in Figure 12. Here, a flat effort profile is assumed for 10 periods (representing 21% left shift, since for the average case the resource produces no visible output after period 6). This has the result that unanticipated additional work will be more easily accommodated within the schedule.

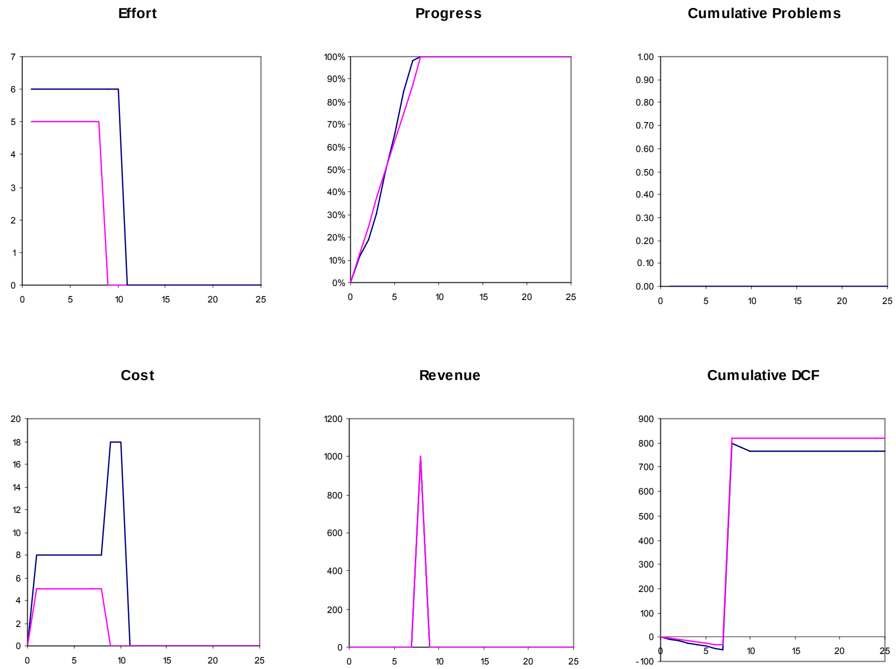

Figure 12: Results for Situation E (low risk)

The expected (average) NPV in this case falls from £824m to £769m (6.7% reduction). The sensitivity of the NPV to random variations is much reduced, though, with 82% of 1000 random trials returning an NPV in excess of £500m. Interestingly, adopting the same approach in Situation F – identical but for the discount rate – the expected NPV drops by 44%.

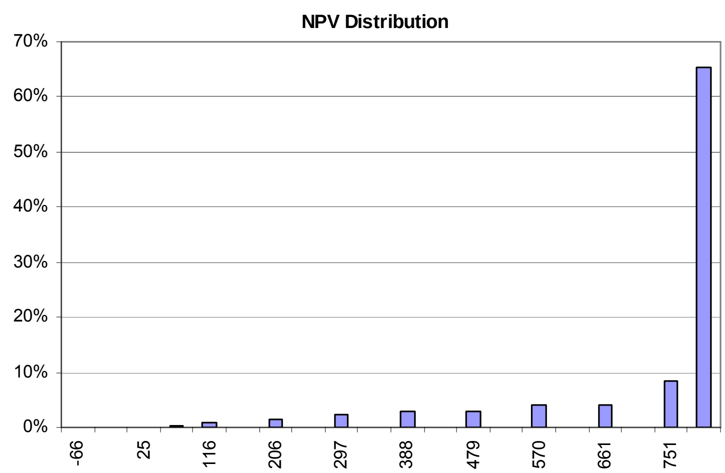

Figure 13: NPV frequency distribution for Situation E (low risk)

Discussion of Results

Predictably, the more likely it is that problems occur during the project, the more valuable left-shifting the resource profile becomes.

When payment for a project is largely staged based on progress, a high discount rate leads to a high preference for left-shifting the project effort in an attempt to progress faster (Situations C and D in Table 1). When payment is upon completion, the effect of the discount rate is smaller, and is much less important than the earliest date at which the project may be deemed complete and paid for (which may depend on third party suppliers).

Figure 11 and Figure 13 demonstrate that, in this model at least, optimised left-shifted profiles are more susceptible to random variations than longer, smoother, development profiles. When the discount rate is low, the time value of money is reduced so there is less to gain from aggressively left-shifting profiles, and risk can be reduced by adopting a flatter or longer profile.

Conclusions

Table 1 shows that the optimal effort profile in terms of the amount of left shift applied is strongly dependent on the conditions facing the project. To assume that 15% of a project's expenditure is the optimal amount to allocate to systems engineering or definition activities ignores the variability between projects of factors such as the payment schedule, the discount rate and the cost of increasing resource levels above a standard baseline.

It has been suggested that it costs 100 times more to find and fix a problem after software delivery than it does to find and fix a problem in the early design phases [Boehm, 1987]. This 'right first time' recommendation may seem at odds, however, with more recent iterative design philosophies such as concurrent engineering, agile methods, and IDEO's 'fail often to succeed sooner' mantra [Kelley, 2001].

In fact, all of these approaches recognise the importance of setting a project off in the right direction before committing significant resources to manufacturing. The principle of left-shifting the overall effort profile in a project is undoubtedly useful, whether it be to give more time towards the end of a project for correcting unforeseen problems, or to allow the project to finish earlier (or less late!) and hence start generating sales income sooner.

It is, however, clear that the principle of left shift should be considered together with the financial principle of the time value of money when deciding exactly how much left shift can be justified on a given project.

Further work

It is proposed to develop the model used here and to incorporate it in a research project investigating the value of systems engineering in different industries, the optimal amount of systems engineering in different projects, and how the barriers to the wider use of systems engineering techniques can be overcome.

In addition, further analysis will be performed to investigate the value of left shift under different circumstances.

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Appendix: Model Assumptions

A1. A customer wants delivery of a new stadium within 8 years.

A2. The customer will pay £1000m for the project.

A3. Payment will be made x% upon completion and 100 – x % based on progress each year.

A4. The nominal discount rate is r % and the average inflation rate is expected to be 3%.

A5. There will be a £100m penalty for every year the project is late.

A6. The earliest the customer will pay for completion of the project is after n years.

A7. There is a p % probability each period of rework being required, and a p % probability of a problem developing.

A8. Each period each unit of resource allocated to the project identifies an average of 0.1 units of additional work that is required.

A9. Additional resources allocated to the project over and above the ideal/expected level cost F times as much as each unit of expected resource.

A10. Each period the productivity of each unit of resource increases by 10% due to learning effects and technological progress.

A11. Rework and additional tasks add to the expected tasks to be completed the following period.

A12. Problems are cleared up at a rate defined by an s-curve with minimum 20% and maximum 50% per period. The position on this s-curve depends on how much spare resource is available. Problems disappear below a certain threshold (0.02).

A13. The project is considered finished when tasks are 100% complete and any outstanding problems are resolved.